ICTTRE 2012

International Conference on Technology Transfer and Renewable Energy • Mauritius

ICTTRE 2012 – International Conference on Technology Transfer and Renewable Energy

21–22 June 2012 · Mauritius

Book of Papers

DIREKT
Small Developing Island Renewable Energy Knowledge and Technology Transfer Network

University of Mauritius

Project is funded by the European Union.

ACP S&T PROGRAMME

Table of Content

Session - Other Renewable Technologies

Session - Energy Efficiency & Management

Session - Energy Policy and Financing

PREFACE

This book of papers contains a collection of the papers to be presented at the International Conference on Technology Transfer and Renewable Energy 2012 (ICTTRE 2012), being held in Mauritius on 21-22 June 2012.

The event is part of the project DIREKT, a cooperation scheme involving universities from Germany, Fiji, Mauritius, Barbados and Trinidad & Tobago with the aim of strengthening their science and technology capacity in the field of renewable energy. The project is funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region (Africa, Caribbean, Pacific).

The use of renewable energy is one of the tools which can be used towards climate change mitigation. This is especially so in developing countries, where current usage of fossil fuel poses a serious burden to their economies, despite the fact that they possess a wide range of resources, and a sound basis upon which the use of renewable energy can be built. Bearing in mind that small island developing States (SIDS) have much potential in the use of renewable energy, it seems sensible to find ways to realise it. The project DIREKT and the conference ICTTRE 2012, are meant to be contributions to this process.

Whether dealing with the performance characteristics of a downdraft biomass gasifier, or the viability of using cassava as feedstock for bioethanol production in Fiji, this book of abstracts per se and the papers to be presented at the conference, serve the purpose of fostering the cause of renewable energy use in small island States.

Finally, a note of thanks. The Conference itself could not have been realised without the contributiion from some key people. First are foremost, I thank the team of University of Mauritius, especially Professor Romeela Mohee and Dr Dinesh Surroop, for their tireless efforts (please include their names here of anyone else from UoM or elsewhere which deserve to be mentioned). Thanks are also due to Veronika Schulte, Isabel Ribeiro and Agnieszka Czachórfor the valuable assistance they provided. Our sincere thanks also go to the Authors on the one hand, and the Reviewers on the other, who have spent a considerable amount of time in the assessment of the manuscripts. They have all contribute to the success of the conference.

Prof Walter Leal

DIREKT Coordinator

Conference Co-Chair

Dear Partners and Participants,

Welcome to all participants to this first International Conference on Technology Transfer and Renewable Energy (ICTTRE 2012) held in Mauritius.

We have been awaiting this event since long. The goal behind this International conference is to assemble experts in the field of Renewable energy and technology transfer from various part of the world to exchange their experience and knowledge to tackle energy related problems. However, the true success of this International conference will be realized through the active participation of all of us and I hope that everyone will leave feeling personally enriched. During this Conference, the latest advances in Renewable energy and technology transfer will be presented. Great care has been taken to elaborate a program with a selection of high standard oral and poster presentations.

I would like to express my gratitude to Professor Walter Leal, the Conference co-chair, the DIREKT partners from Germany, Fiji, Barbados and Trinidad and Tobago without whose help this conference would not have been possible today. I would also like to thank all the ICTTRE local organizing committee members, who have put in enormous efforts and their personal time in the planning and organization of this event. ICTTRE today is only possible due to the combined effort of the local and foreign DIREKT coordinators in synchronizing and executing the various tasks necessary to make this symposium a resounding success.

I wish that all of you present here find ICTTRE 2012 informative and enriching, and for our overseas guests, I wish that your stay in Mauritius will be an enjoyable and memorable one.

Prof Romeela Mohee
Local DIREKT Coordinator

ICTTRE 2012

Dear Participants,

On behalf of the Organizing Committee, I would like to extend a warm welcome to all the participants to the International Conference on Technology Transfer and Renewable Energy (ICTTRE 2012) held on 21-22 June 2012 in Mauritius.

ICTTRE 2012 is sponsored and funded by the European Union under the Small Developing Island Renewable Energy Knowledge and Technology Transfer Network (DIREKT) project. The objective of the ICTTRE is the enable reserachers around the world to report and present the results of their findings in the field of renewable energy and to transfer the renewable energy technologies. ICTTRE 2012 is organized to gather experts/researchers from different part of the world to present their leading-egde work, expanding our community's knowledge and insight onto the significant challenges currently being addressed in their research. The conference Scientific Committee is itself quite diverse and truly international with members from America, Europe, Asia, Africa, Caribbean and Pacific.

The conference has solicited and gathered technical research submissions related to all aspects of renewable energy. All submitted abstracts have been peer reviewed by reviewers drawn from the scientific committee and external reviewers depending on the subject matter. The high quality of the program can be assessed when reading the contents of the program.

I would like to thank the session chairs, organization staffs and members of different committees for their support. I am grateful to all those who have contributed to the success of the ICTTRE 2012. I hope that all participants and other interested readers benefit scientifically from this book of abstracts. Finally, I would like to wish you success in your technical presentations and social networking.

With our warmest regards,

Dr Dinesh Surroop
Chairman of Organizing Committee
ICTTRE 2012
21 -22 June 2012
Mauritius

Conference Information

The papers invited for this conference cover a wide range of issue related to renewable energy. The different themes are:

- Biofuels
- Bio-energy
- Solar Energy
- Wind Energy
- Other Renewable Energy Technologies
- Energy Policy and Financing
- Technology Transfer and International Cooperation
- Energy Efficiency & Management

Program

Thursday 21 June 2012

Registration, Opening Ceremony, Keynote speech, Plenary session and Gala dinner

Friday 22 June 2012

Keynote speech and Plenary session

Instruction to Authors

Oral Presentation

Total time allocated for presentation is 10 minutes with 2-3 minutes for questions. Presentations running over-time will be stopped to keep the conference on schedule. Kindly introduce yourself to your session chair 10 minutes before the start of your session.

Poster Presentation

Posters shall be fixed on board outside the presentation rooms. All poster shall be fixed on the board on Thursday 21 June 2012 from 08.30 – 09.15. Posters will be hung up for the duration of the conference.

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Modern technologies of biomass combustion andpre-treatment for more efficient electricity production-review and case analysis

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Abstract

Biomasscombustion and biomass-coal cofiring represents a near-term, low-risk, low-cost, sustainable, renewable energy option that offers reduction in effective CO_2 emissions, reduction in SOx and NOx emissions. However, untreated woody biomass has a relatively low energy density, low bulk density, high moisture content and is difficult to comminute into small particles.As a matter of fact, these properties make biomass preparation and conversion to electricity expensive. Moreover, biomass can absorb moisture during storage and may rot as well. These properties have negative impacts during energy conversion such as lower combustion and electricity generation efficiencies. Therefore, enhancement of biomass properties is advisable not only is to improve its inferior characteristics as well as make it as suitable alternative for fossil fuels. In order to address those problems, biomass is required to be pretreated to improve its quality.

Keywords: Volumetric Combustion, ROFA, Biomass, Biomass Pre-treatment

1. INTRODUCTION

At present there are very well known and established combustion technologies used to burn fossil fuels. For example combustion technology to burn coal was a subject of more than hundred years of development. Coal depending on its properties and quality can be burned efficiently using well known technologies: grate combustion technology, fluidized bed combustion technology and pulverized fuels combustion technology. Using already well known in-furnace techniques of combustion it is possible to make combustion complete (low CO, low LOI) and clean (low NOx combustion, in-furnace SOx reduction) keeping at the same time very high efficiency of the boiler. Using end of tubes reduction methods it is possible to obtain even lower emissions of NOx, emission of SOx as well as keep very low emissions of dusts.These technologiesdeveloped for coal are now used to burn biomass. Because biomass has very different properties from coal there are many differences in physics and chemistry of coal and biomass combustion. Main differences between biomass and coal influencing combustion process and boiler performance are higher:

- calorific value of coal comparing to biomass,
- content of volatiles in biomass comparing to coal,
- content of alkali metals and chlor in biomass resulting in higher risk of slagging and corrosion when burning biomass.

Consequently there are followingtechnical problemsto be solved when boilers designed to burn coal are to be used to burn biomass:

- combustion process modernization,
- anti-slagging, anti-fouling and anti-corrosion measures ,
- fuel preparation and fuel pre-treatment.

Depending on combustion technology different solutions are applied. This work focuses technology of pulverized and dried biomass combustion. Fluidised bed combustion of wet biomassis not discussedin this work. Main reason for such decision is the fact that cobustion of dry pulverized biomass has higher efficiency and in case of conversion from coal to biomass gives much higher chances to achieve the same capacity of the boiler.

2. COMBUSTION PROCESS MODERNIZATION

Although there are many ways to modify a combustion process, there are only a few which modify the combustion process and can still guarantee minimum emissions, complete combustion, maximum boiler efficiency, and low operational and maintenance costs. Modern power plants must now use different coals, biomass or even waste fuel. Thus, modern combustion processes must be fuel flexible and must be able to accommodate changing fuel supplies. It has to also be able to utilize difficult fuels and reduce negative effects of fuel blends by enabling direct large percentage co-firing and 100 % fuel switch. Traditional air staging systems are not uncommon in utility and district heating boilers independent of firing configuration or combustion technology. However, ability to accommodate different fuels and NOx reduction for traditional systems is limited. Typical organization of staged combustion is shown in Figure 1. In order to prevent formation of nitrogen oxides from fuel-bound nitrogen, the primary combustion zone is operated under sub-stoichiometric conditions with excess air number (□) less than one. To complete combustion a secondary air is introduced into the upper furnace by means of air supply system called Over-Fire Air

(OFA). The secondary combustion zone is operated with excess air number (□) above one. Interaction between the two separated combustion zones is difficult to control in large scale combustion chambers particularly when boiler's load and operational parameters change. Negative effects of such staged combustion are well seen when large percentage co-firing (above 40 % of coal replaced by renewable fuels) or 100 % fuel switch are introduced. Common negative effects of biomass combustion are:

-incomplete combustion (CO, unburned volatiles, carbon in fly and bottom ash),

- wrong temperature distribution along the height of boiler's combustion chamber (thus too high use of spray water),

- slagging, corrosion and wastage of water walls inside the boiler combustion chamber as well as steam preheater,

- drop of steam temperature and steam production rate resulting in reduction of boiler capacity up to 20 %.

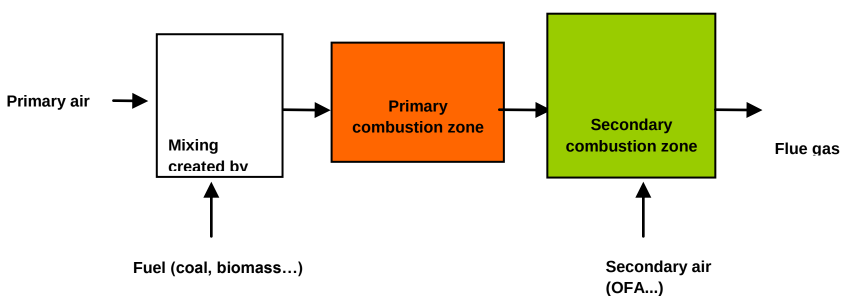


Figure 1. Conventional staged combustion concept

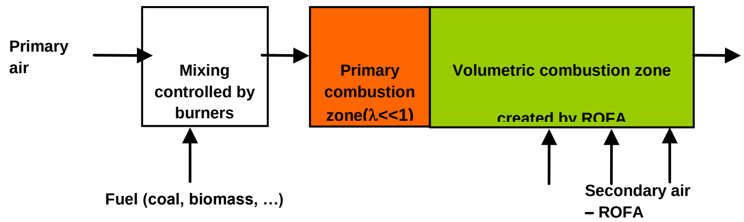


Figure 2. ROFA influence on staged combustion process creating Volumetric Combustion System

ROFA (Rotating Opposed Fired Air) [1,2,6] is a boosted over-fire air system that includes a patented rotation process. With ROFA, the gas volume in the furnace is set in rotation via special asymmetrically placed high velocity air nozzles. ROFA promotes intensive internal recirculation of flue gases from the level of secondary air injection down to primary combustion zone. It is particularly important when burning biomass with high content of volatiles. Combination of air staging and internal flue gas recirculation changes not only in-furnace flow but also affects the combustion.

Due to intensive recirculation and good mixing between secondary air and flue gas the combustion volume is larger than with conventional staged combustion. Such combustion is termed Volumetric Combustion System (Figure 2). With ROFA, volumetric combustion is created by very intensive mixing and recirculation of hot, reacting flue gases. Volumetric combustion is stabilized by uniform temperature of circulating flow field. Main advantage of applying such type of combustion is a very deep air staging and consequently nitrogen oxides (NOx) formation reduction, [6]. With ROFA the flue gas is well mixed with the available air in the entire upper furnace. This improves particle burnout and volatiles burnout. ROFA also increases particle residence time by changing their trajectories to utilize more of the furnace volume, thus reducing carbon content in the fly ash (LOI). The highly turbulent mixing and rotation prevent the formation of stratified flow, which enables the entire furnace volume to be used more effectively for the combustion process. Existence of the stratified flow, called also a "chimney" flow is a common phenomenon in case of the conventional air staging. It is often accompanied by non-uniform and too high temperature and CO concentration at the upper furnace outlet. Application of volumetric combustion changes the flow pattern of flue gases and eliminates these negative effects. More efficient mixing of the combustion air can also reduce the need for surplus excess air and also reduces CO emissions.

3. SLAGGING, FOULING AND COROSION

There are already reported in literature negative consequences when co-firing coal with biomass. Present in biomass are ash-forming elements like potassium, sodium, calcium, magnesium, silica or alumina can cause slagging, fouling, and high temperature corrosion. Mixing of ash from two fuels during direct co-firing enhances the negative effects because of the typically lower ash melting temperature for biomass ash.

Figure 3. Photo of superheater with deposition accumulated as a result of biomass combustion.

Mixing of biomass ash with coal ash can negatively influence the performance of the electrostatic precipitator and can cause de-activation of SCR (Selective Catalytic Reduction) catalysts, used for nitrogen oxide reduction.

Mixing of ash can create problems with ash utilization by cement or building industry. High alkali and/or chlorine content can lead to excessive ash deposition and can cause corrosion of heat transfer surfaces as well as flue gas cleaning equipment. At lower percentages of co-firing there is no major problems related to slagging, fouling, and corrosion. However, there are problems at a high percentage of co-firing or when 100% biomass is fired.

Substantial deposition of fly ash on heat transfer furnaces is often observed and example is shown in Figure 3. Deposition in the lower part of furnace (around burners) and in the upper part of the furnacearealso the often problem. Ash distributed uniformly is quite easy to remove but requires more frequent use of so called soot blowers. Thickness of deposition on walls can be between 5 – 30 mm. At the superheater the thickness of ash deposition can be between 15 – 50 mm (Figure 3).

Remove of chlorides is a way to avoid these negative effects and to protect heat transfer surfaces. After volumetric combustion zone installation application of chemicals injection system allows for efficient and cost effective reduction of this problem. Ammonium sulfate, $(NH4)2SO4$ reduces the KCl levels in the flue gas and consequently reduces the deposition and corrosion rates of heat transfer surfaces firing biomass. Potassium chloride, KCl is converted into much less corrosive potassium sulfate, $K2SO4$ by about 80%.

4. CONVENTIONAL COFIRING AND BIOMASS PREPARATION SYSTEMS

Forced by new European Community legislation to reduce emissions many power plants planed now to burn biomass instead of coal to produce electricity. There are few big boilers in the order of 200 MWel capacity where 100 % fuel switch from coal to biomass is going to be introduced. Some smaller boilers (in the order of 50-70 MWel capacity) are already fully converted from coal to biomass. However, still the most common way of burning biomass is co-firing of coal with biomass. There are following concepts of cofiring;

- Low percentage cofiring when maximum up to 10 % of coal (by energy fraction) is replaced by biomass,
- Intermediate percentage co-firing when up to 40 % of coal is replaced by biomass,
- Large percentage cofiring when more than 40 % of coal is replaced by biomass.

In case of a low percentage cofiring only a few percent of dry biomass (max 10 %) is burned together with coal. Raw biomass is mixed with coal before it is fed to the existing coal mills. Existing coal mills dry and pulverize biomass together with coal producing pulverized coal-biomass mixture. Such mixture is burned in existing boilers without any substantial modernization of combustion system or boiler itself. Low percentage cofiring is used mainly because of very low investment cost and high profit when burning biomass. Existing boilers are able to accommodate such coal-biomass mixture without any serious modernization of the combustion system. There were some safety problems with milling biomass together with coal. However, after a few years adaptation of coal mills to low percentage cofiring was done. At present rather safe, reliable operation is possible with satisfactory size distribution of the coal-biomass mixture.

Intermediate percentage cofiring (up to 40%) requires feeding of pulverized and dry biomass directly into boiler's combustion chamber. Biomass is injected via separate nozzles or via burners. Number of nozzles as well as their location depends on amount of biomass, its properties but mainly on applied combustion system. Biomass can be injected also via new biomass burners or via existing modified coal burners (dual fuel burners).Intermediate percentage cofiring requires much wider modification of air combustion system and some modifications of heat transfer surfaces.

Large percentage cofiring as well as complete fuel switch [3,4,5] requires also feeding of pulverized and dry biomass through modified burners. Coal burners must be modified to handle higher mass flow rates of fuel and to guarantee complete stable combustion in the whole range of operation. Full modernization of combustion system for example application of the volumetric combustion as well as substantial modernization of the boiler heat transfer surfaces is necessary if the same capacity and steam parameters are to be kept.

Biomass has a higher volatile content than coal, creating a potential for a combustible environment. Therefore, the handling and processing of dry biomass must be performed safely. To ensure plant safety and operational reliability, the biomass handling system has to be designed to avoid and eliminate possible combustion within the biomass storage, transport, and milling systems. The standard dry biomass feeding system [*Wroclaw paper*] is comprised of the following main components:

- biomass conveyance line from the fuel yard,
- biomass (pellet, wood chips…) storage silo,
- hammer mills,
- dust separation cyclone filters,
- powder silo,
- biomass injection system (nozzles or burners).

Dimensions of the feeding system, (size and number of biomass storage silos, number of hammer mills, size of filters, size of powder silo, size and number of burners) thus also investment costs depends on capacity of boiler and amount of biomass replacing coal.

Conventional biomass feeding systems are commonly used although there are well known problems and disadvantages. Main problem is that even dried biomass has a relatively low energy density, low bulk density and is difficult to comminute into small particles. Moreover, it can absorb moisture during storage and may rot as well. These makes biomass transportation not sustainable and very expensive as well as can have negative impacts during energy conversion lowering for example combustion efficiency. Therefore, enhancement of these properties is advisable toachieve the following benefits:

- reduce fuel transportation costs,
- reduce operational costs of fuel preparation and milling
- improve combustion process and boiler efficiency,
- reduce risk of slagging, fouling and corrosion thus improve boiler’s availability
- reduce investment costs in fuel feeding system.

4. BIOMASS PRE-TREATMENT TECHNOLOGIES

To achieve the above listed benefits biomass must be pretreated to have higher calorific value, grindibility and resistivity to moisture. In recent time, wood pellet industry has experienced rapid expansion in energy market. The global wood pellet production in year 2009 was 13 million ton/year and 8 million ton/year of it was consumed by European countries. It is predicted by European Biomass Association that the consumption of 50 million ton will be reached in European countries by 2020. However, conventional wood pellet holds some problems such as lower hardness, lower specific weight, high sensitivity to moisture and low heat content. Moreover, transport cost is considered to play an important role in wood pellet industry. Improved densified biomass can save transport and handling cost to larger extent.Therefore, improvement of wood pellet quality both in terms of fuel quality and densification seems indispensable. Currently, different approaches have been considered to improve the quality of the wood pellet, for example, torrefaction and fast pyrolysis. Another promising technology is steam explosion pretreatment process. Previously, application of biomass steam explosion process was devoted to ethanol, and bindles panel production. Both concepts are applied together with pelletisation of pre-treated biomass to reduce transportation costs and explosion risk.

Recently this concept has been brought into attention for improvement of wood pellets to produce so high quality and high density pellets called “black pellets” as a biomass fuel replacing fossil fuels like coal or oil.

4.1 Steam explosion

Woody biomass is constructed of cell wall with polysaccharides (cellulose and hemicelluloses) and an aromatic polymer named lignin. Cellulose and hemicelluloses are considered to be strongly bonded with lignin in wood. In steam explosion process, saturated steam of temperature ranging from 453 K to 513 K is used to disrupt different components of biomass. Steam explosion process involves separation of main components of woody biomass (lignin, cellulose and hemicelluloses) by both chemical degradation and mechanical deformation. The process involves adiabatic expansion of water inside the pore of wood tissue and auto hydrolysis of cell components.Steam explosion pretreatment process can be divided into three different sub steps. Initially, biomass is fed into the reactor and pressurized the vessel with steam up to desirable pressure and temperature. Afterwards, sudden decompression is created by releasing pressure of the reactor. Later on, produced slurry is passed through filtration unit to separate solid from liquid part.

Steam explosion pretreatment is striking in context of alteration in elementary composition of fuel. Greater degree of carbonization and removal oxygenated compounds leads to increase in heat content of the fuel. Moreover, total amount of ash is also reduced in pretreated residue. Removal of ash content can be attributed to combination of water leaching and disrupted cell structure. Although steam pretreatment shows promising in terms of reducing alkali and heavy metal components of biomass, degradation in ash fusibility was observed in steam treated residue.

Pellet produced from steam treated residue showed increment in physical properties of pellet such as higher density, impact resistance, and abrasive resistance. Higher density of pellet can be attributed to greater degree of fines produced during the process. On the other hand, higher impact and abrasive can be attributed to melting of low molecular weight lignin on the surface of the pellet during pelletization, [9].

4.2 Biomass torrefaction

Torrefaction [10,11] is, a thermal pretreatment process, applied to enhance fuel quality of biomass. In torrefaction process, numerous products are formed such as solid, liquids and gases. The solid is rich in carbon in comparison with oxygen. As a result, significant improvement of heat content of biomass (solid) can be achieved (20-23 MJ/kg). The heating value of torrefaction gas can vary from 5.3 to 16.2 MJ/Nm3. Therefore, torrefaction gas is applicable to combustion to generate process heat. Although torrefaction process is validated in laboratory and pilot scale, there are many issues that need to be addressed before realizing in commercial scale. It includes safety issues, fouling and corrosion when using it in co-firing. In addition, choice of appropriate reactor for torrefaction is considered decisive in plant performance.

Several reactor technologies are available now-a-days. With choice of appropriate technology, torrefaction can be proved beneficial for biomass chain supply. It is expected that torrefaction process will provide important contribution to biomass chain supply in a near future. The concept for torrefaction process is shown in Figure 5, [12]. Initially, wet biomass is dried in a dryer with flue gas to desired moisture content to 10% from 20 %. The drying temperature is considered as 135°C to provide sufficient energy for drying and avoiding saturation of the gases and volatilization of biomass. Dried biomass is torrefied at certain process condition by using majority of torrefaction gas. The reason of using torrefied gas is to ensure inert atmosphere for torrefaction process. Torrefaction gas is used as main source of energy for the process. If the process required additional energy, due to higher moisture content, part of the torrefied biomass is used as the energy source.

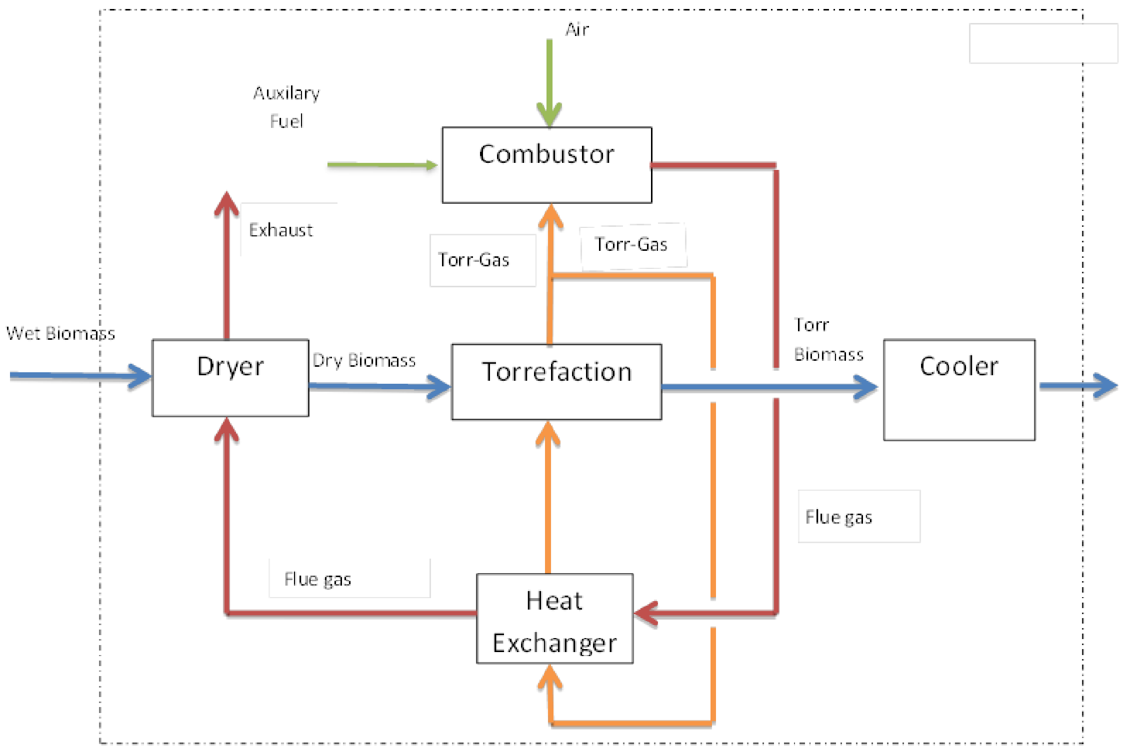


Figure 5. Process Flow Diagram for torrefaction process

Biomass type has significant effect on both product yield, energy retained in product (Figure 6) and torrefaction process efficiency (Figure 7). Softwood tends to provide higher process efficiency in comparison with hardwood and agricultural residue. On the other hand, choice of process condition has great importance when considering process efficiency. Extreme process condition may lead to excessive mass loss, hence, reduction in process efficiency. Therefore, it is advisable to operate process under less severe condition, hence, below auto-thermal point to maximize process efficiency. Although process efficiency is observed to be around 80-90%, it can be significantly improved by recovering heat from cooling water of the solid which can be used as preheated water for district heating system. Therefore, desirable process performance can be achieved by choice of biomass, process condition and effective way of using low quality heat of the system

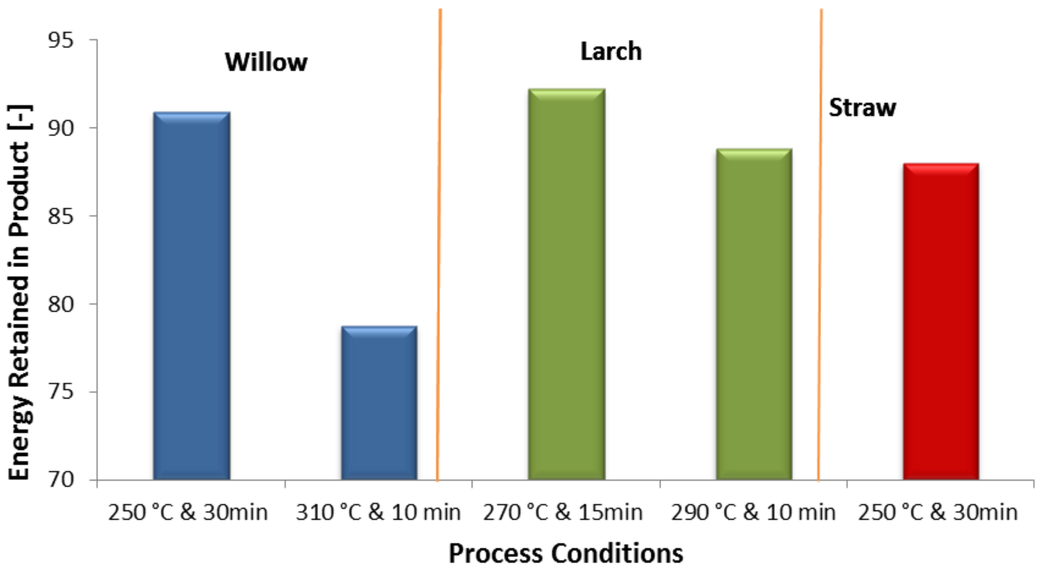


Figure 6. Energy retained in product (torrefied biomass) after the torrefaction process versus the process conditions.

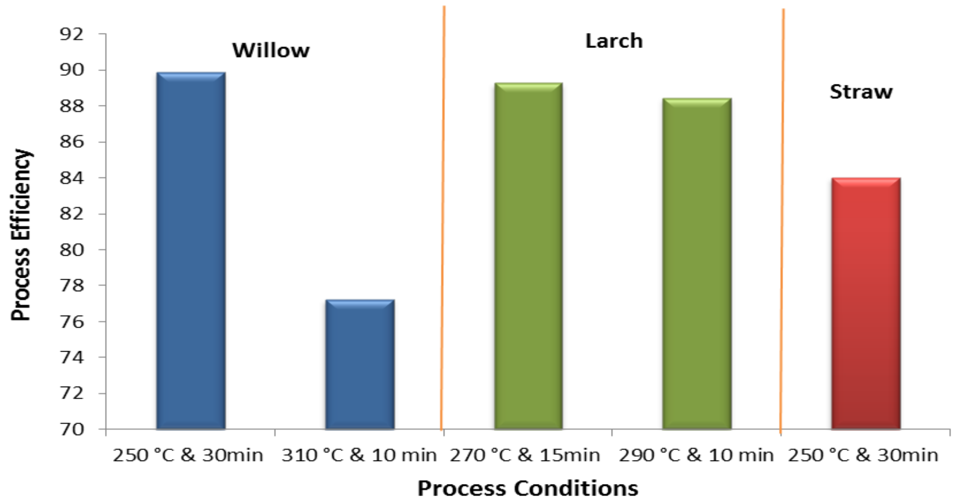


Figure 7. Overall torrefaction process efficiency versus the process conditions.

5. INFLUNCE OF BIOMASS PRE-TREATMENT ON BOILER MODERNIZATION

It is known common practice that even moderate percentage co-firing of pulverized dried biomass requires modification of air supply system in order to secure better mixing inside of a combustion chamber. Combustion of pulverized torrefied biomass requires also modernization of combustion process and combustion air supply system. It is particutraly necessary when large-percentage co-firing of torrefied biomass and coal or complete fuel switch is to be performed. Applying conventional combustion technologies in such case will encounter such difficulties as a fall in boiler efficiency, reduced steam production, drops in steam parameters, increased fouling and corrosion of heat transfer surfaces inside the boiler.

Biomass as well as torrefied biomass has much higher content of volatiles. Large fraction of torrefied biomass is released as volatiles (up to 65-75 % of mass) therefore gas phase temperature distribution will be different comparing to pulverized coal combustion or standard biomass. Modified combustion system must be flexible and secure complete and clean combustion of volatiles as well as particulates but also must secure performance of a boiler; that is the same stem flow rate and steam parameters.

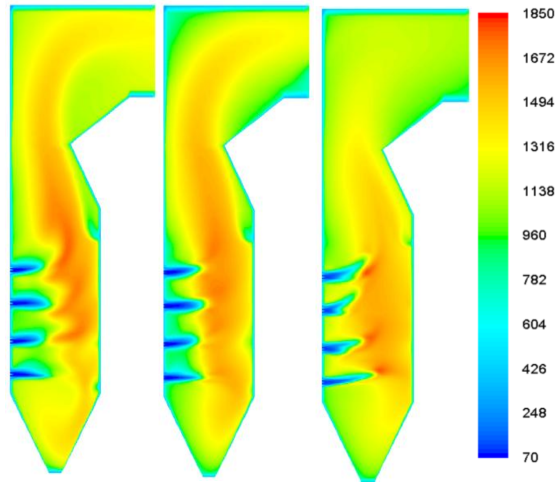
It is known that change from coal to co-firing significantly influences the temperature distribution along the boiler height. When firing coal, the highest temperature area is located just above the burner zone. When co-firing, there are two zones of higher temperature: one zone just above the burners and a second zone much higher in the upper furnace. The reason for this bi-modal temperature distribution is a lack of good mixing. In order to improve and control the temperature in the upper furnace and at the inlet to the superheater, the much better mixing must be introduced.

The highly turbulent mixing and rotation prevent the formation of stratified flow, which enables the entire furnace volume to be used more effectively for the combustion process. Existence of the stratified flow, called also a "chimney" flow is a common phenomenon in conventional boilers. It is often accompanied by non-uniform and too high temperature and CO concentration at the upper furnace outlet.

Figure 8 shows temperature distribution in a vertical cross-section of steam utility boiler fired with different pulverized fuels. In all three cases the firing capacity is the same as well as similar size distribution. Applied combustion system is the same as it is traditionaly used in case of pulverized coal combustion. It can be easily noticed that torrefied biomass with the same calorific value as bituminous coal creates much higher temperature at superheater level. In case of such combustion process and fuel switch from coal to torrefied biomass the boiler will not work properly. Therefore, above mentioned modernization of air supply system as well as introduction of much intensive mixing seems necessary.

Application of proper air supply and mixing system will result in much more uniform temperature distribution, complete combustion, good operation, boiler load flexibility and good steam parameters. Because of better mixing, modification of burners is often not required and existing burners can be used to burn pulverized coal or pulverized torrefied biomass with good flame stability.

Because of differences in the chemical composition of biomass and coal firing system, boiler modifications and equipment additions are also required. Extra heat transfer surface at convective part of the boiler must be analyzed and most probably additionally installed when 100% of torrefied biomass is fired. Decision of course must be based on thermal calculations of the boiler.



a) b) c)

Figure 8. Temperature distribution in a vertical cross-section of steam boiler fired with pulverized a) torrefied biomass no1, b) torrefied biomass no 2, c) bituminous coal.

Slagging, fouling and corrosion when firing torrefied biomass

There are already reported in literature negative consequences when co-firing coal with biomass. Present in torrefied biomass are ash-forming elements like potassium, sodium, calcium, magnesium, silica or alumina can cause slagging, fouling, and high temperature corrosion. Mixing of ash from two fuels during direct co-firing enhances the negative effects because of the typically lower ash melting temperature for biomass ash. Mixing of biomass ash with coal ash can negatively influence the performance of the electrostatic precipitator and can cause de-activation of SCR catalysts, used for nitrogen oxide reduction. Mixing of ash can create problems with ash utilization by cement or building industry. High alkali or chlorine content can lead to excessive ash deposition and can cause corrosion of heat transfer surfaces as well as flue gas cleaning equipment. In order to avoid all these negative effects anti-slaging chemicals injection system must be installed.

SUMMATION

Volumetric combustion created by Rotating Opposed Fired Air (ROFA) is a very effective method to perform large percentage direct co-firing of pre-treated biomass and coal what offers possibility to utilize a large quantity of biomass at low investment cost.

Biomass pre-treatment combined with modern combustion technology offers new effective way of biomass utilization for efficient, clean and low cost electricity production.

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The DIREKT project: an example of a technology transfer project on renewable energy

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Abstract

This paper presents an example of a technology transfer project on renewable energy which is undertaken by the Hamburg University of Applied Sciences, namely the Small Developing Island Renewable Energy Knowledge and Technology Transfer Network (DIREKT), a cooperation scheme involving universities from Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. The overall aim of this project is to strengthen the science and technology capacity in the field of renewable energy of a sample of African, Caribbean and Pacific (ACP) small island developing states, by means of technology transfer, information exchange and networking. The project is funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region.

This paper introduces the DIREKT project, its aims and the partnership. It presents the methodology and results of a survey that was conducted in the work package 2 of the project, namely the Assessment of Needs for Market-Oriented Research and Technology Transfer, along with a comparison of the results obtained in Fiji, Mauritius and selected Caribbean countries. A comparative analysis of the political and institutional frameworks in the field of renewable energy in the ACP regions and in Germany is presented, along with an assessment of research and innovation needs in science and technology. Finally, the paper summarises the similarities and differences between the surveyed regions regarding renewable use and promotion, also characterising the role of the DIREKT project as a technology transfer project for renewable energy.

Keywords: Small Developing Island States, Renewable Energy, Technology Transfer

1. Introduction

1.1. The DIREKT project

Small island developing states (SIDS) are island nations characterised by low to medium GDP levels, which justify their rankings as developing nations. There are several dozen SIDS distributed across the Caribbean, African and Asia-Pacific regions. Figure 1, which illustrates the wide range of SIDS in the Latin American and Caribbean regions, serves the purpose of describing the diversity of shapes and sizes of SIDS in any given region.

Figure 1 Schematic map with an overview of Latin American and Caribbean small island developing states (© Climate Click 2012)

Most SIDS are heavily dependent on increasingly expensive imported fossil fuels to supply their basic energy needs, and are thus exposed to unpredictable price fluctuations. Oil prices have virtually doubled in many countries since the year 2000, hence putting additional pressures on the economies of SIDS countries. This has led to diversions of funds, which could be better used in health care or education, towards meeting the costs of imported fuel, a situation which is rather unsustainable.

Despite the current dependency on important oil, SIDS have a visible potential for renewable energy generation, especially in respect of solar and wind power and marine renewable energy technologies. Indeed, as stated by Boyle (2004) renewable energy offers very interesting prospects to developing countries. Global trends in renewable energy as a whole and in sustainable energy investment in particular are on the increase in developing countries (Hohler, Greenwood and Hunt 2007).

A number of international gatherings have been organised and attempted to discuss the problem. The Outcomes Pacific Energy Ministers' Meeting held in Noumea, New Caledonia, in 2011 for example outlined the potential in the field of renewable energy seen in the Pacific region – according to Singh (2009), provided the adequate infrastructure is in place. In doing so, vulnerable SIDS such as Fiji or Tonga – which has a renewable energy road map (TERM 2010) – may be able to take better advantage of the opportunities renewable energy offers them.

The predominant situation is that these countries suffer a lack of awareness about the role they can play by using renewable energy, have very few experts working in this field and have limited availability of academic programmes on renewable energy, all of which has hindered progress in this field.

In an attempt to address the problems outlined here, the Small Developing Island Renewable Energy Knowledge and Technology Transfer Network (DIREKT) project has been initiated. DIREKT is a university-based project with an emphasis on communication, education and training, aimed at promoting the implementation of renewable energy technologies in selected African, Caribbean and Pacific (ACP) regions. The overall objective of DIREKT is to enable the partners to better exploit their renewable energy resources by means of technology and knowledge transfer, information exchange, capacity building and networking. The partners involved are universities in Germany, Fiji, Mauritius, Barbados and Trinidad and Tobago. The project is funded by the ACP Science and Technology Programme, an EU programme for cooperation between the European Union and the ACP region.

1.2. The work package 2 of the DIREKT project

The DIREKT project is structured along a set of work packages (WPs), one of which is concerned with the Assessment of Needs for Market-Oriented Research and Technology Transfer (WP2), the subject of this paper.

In order to achieve good and sustainable results through technology and knowledge transfer in the field of renewable energy between the DIREKT partners, it is first essential to investigate the current situation and to explore existing structures. Therefore, a number of studies which have analysed the status of policy making and the use of renewable energy in small developing island states and which have been conducted at different times in the past, have been analysed. Some examples of international studies that are thematically similar to the one presented in this paper are provided here.

In 1999, the Caribbean Council for Science and Technology published a paper assessing the status of energy sources in the Caribbean and the potential of renewable energy in particular. It provides outlooks on possible future scenarios involving renewable energy and suggestions on policy making in this field. An aspect that the paper highlights is the broad spectrum of advantages that are inherent to the use of renewable energy. Accordingly, the implementation of renewable energy technologies is not only good for meeting energy demands, but also improving resource management, environmental preservation and sustainable development. The paper emphasises the major potential for creating employment opportunities that the development of renewable energy holds. Examples given in the report are the emergence of small and medium-sized businesses in the renewable energy sector in Barbados, St Lucia and Costa Rica. Furthermore the paper stresses that these developments are, if not duly supported, in danger of going under in the competition between renewable and fossil energy sources (Caribbean Council for Science and Technology 1999).

The German Cooperation Agency (GIZ) published a paper in 2004 presenting the current status of renewable energy in Latin America and the Caribbean region with regard to policy making and baseline conditions. After presenting a background review of past efforts to promote renewable energy in the region, it divides the area into six subregions comprising several neighbouring countries. The subregions are analysed with regard to the current state of renewables in the region. Moreover, obstacles and opportunities for penetrating renewable energy and policy making in this field are described. The paper points out the importance of the sustainability of renewable energy production. This remark relates to the fact that the intensive use of hydroelectric power and power from biomass in some countries is practised without respect to the negative environmental and social effects it generates. Finally, the need for improved cooperation between important governmental, non-governmental and private organisations and institutions is expressed (GIZ and ECLAC 2004).

In the Pacific region, the RECIPES project, a European project promoting renewable energy in developing countries, surveyed selected island states in the region in 2004. The countries chosen to represent the Pacific region were the republics of Fiji, Vanuatu and Kiribati. Among others the objectives were to provide data on the renewable energy situation and energy policies and the description of renewable energy projects. The survey is in the form of a data acquisition study. Gathered information is presented in the form of tables or lists of facts with little or no analytical text. It consists of four parts. Part A contains detailed information on the status and potential of all renewable energy technologies and renewable energy policies as well as conventional energy technologies for each of the three states. Part B presents the current policies concerning energy and renewable energy. It identifies the main energy issues of the different countries and describes the present renewable energy programmes and policies and institutional policies. Part C contains maps of the region and the single countries. In Part D the most successful renewable energy projects and their outcomes are described in depth. The overall objective of the survey was to provide all stakeholders involved in renewable energy with information and insights and in doing so contribute to the implementation of renewable energies in the Pacific (RECIPES Project 2004).

In 2007 the Australian government organisation AusAID conducted a study involving various Pacific island states, assessing the potential of renewable energy for rural electrification in the region. Initially it gives an overview of the situation of renewable energies in the Pacific in a global context. The study report elaborates on the issues of rural electrification and fossil fuel dependency in the region. With particular regard to the problems caused by the unique geographical situation, the study analyses four rural electrification projects "in order to assess the cost-effectiveness of a particular renewable energy technology option in a rural Pacific island setting". Using least-cost analysis and benefit-cost analysis, a solar home systems project, a micro-hydroelectricity project, a wind hybrid system and a biofuel pilot project using coconut oil were assessed and compared to conventional energy production with a diesel generator. Based on the study results the authors recommended that Pacific governments actively promote the implementation of renewable energies through renewable energy policy making and renewable energy projects (Woodruff, A. 2007).

In 1998 the Danish Forum for Energy and Development published a general report on renewable energies on small islands in developed and developing countries, sampling the ACP regions among others. In the South Indian Ocean, Mauritius and Réunion were sampled as well as seven countries in the South Pacific and six in the Caribbean. A second revised edition of the report was published in 2000. The report's two main objectives were to show the particularly good feasibility of renewable energy on small islands and to develop global renewable energy cooperation and networking among islands. The report points out the major renewable energy potential that is inherent to small islands and the fact that this potential remains mainly untapped. The examined islands are categorised according to their actions and ambitions for the use of renewable energies and an overview is given of how progress distributes globally. The report also shows a link between the sovereignty status of the islands and the level of renewable energy implementation, saying that more islands with a formal connection to a developed country use renewable energies than islands that are politically independent. Another important aspect that the report emphasises is the role that islands can play in fostering renewable energy use worldwide. Due to their limited size small islands could become the first countries or communities that rely solely on renewable energies for their power generation and thereby act as an example for the rest of the world (Jensen, T. L. 2000).

Within the framework of work package 2 (WP2) of the DIREKT project, a survey was undertaken in the partner counties. The objectives of the survey were a comparative analysis of political and institutional frameworks in the field of renewable energy in selected ACP regions and an assessment of research and innovation needs in renewable energy science and technology. The countries sampled were Fiji, Mauritius, Barbados, St Lucia and Trinidad and Tobago. For the survey, 75 businesses and public and private institutions involved in renewable energies were interviewed in the period from January to June 2010.

2. Comparative analysis of political and institutional frameworks in the field of renewable energy in selected ACP regions

2.2. Renewable energy policy and institutional framework

The survey conducted in the context of WP 2 shows that all countries perceive renewable energy as an inevitable part of their future energy supply. Efforts are made on national and international levels. Policies and frameworks in the different regions are numerous, however this paper only describes the outlines of all the efforts made.

Several international energy frameworks exist in the Caribbean region. Trinidad and Tobago, Barbados and the Organisation of Eastern Caribbean States (OECS) are engaged in the Caribbean Renewable Energy Development Programme (CREDP), which is an initiative of the Energy Ministers of the CARICOM (Caribbean Community) region. CREDP mainly strives to remove barriers to renewable energy utilisation in the Caribbean.

In the Pacific region, the Pacific Island Forum (PIF) was founded in 1971 as an umbrella company to attend to general development matters in the Pacific island countries and territories (PICTs). The PIF comprises 16 countries, including Fiji, and oversees the activities of many regional organisations. The first international energy policy was the Pacific Islands Energy Policy PIEP (2004), which was succeeded by the Framework for Action on Energy Security in the Pacific (FAESP). FAESP does not focus on the implementation of renewable energy, however it does incorporate it (40th Pacific Islands Forum in Cairns in August 2009).

In the EU, an energy and climate change policy was introduced in 2008. Among other things, the ambitious targets of this policy are the reduction of greenhouse gas emissions by 20%, increasing the share of renewables in the energy consumption to 20% and improving energy efficiency/reducing energy consumption by 20% – all to be accomplished by 2020. These targets are elements of the “EU climate and energy package”, which was adopted in June 2009. It is compulsory for EU member states to undertake efforts to achieve them.

On a national level, Trinidad and Tobago possesses a Ministry of Energy and Energy Industries, which pursues a national energy policy which includes the use of RE.

Furthermore it formed a renewable energy committee in 2009 to produce a green paper for renewable energy development.

Fiji has a national energy policy that provides support for the development, demonstration and application of renewable energy as well as rural electrification policies. It was formulated as part of the Pacific Island Energy Policy Strategic Action Plan (PIEPSAP) project like several national energy policies of other PIF member countries. Recent analysis conducted by the Asian and Pacific Centre for Transfer of Technology and the United Nations Economic and Social Commission for Asia and the Pacific, has shown the potential of Fiji in this field (APCTT-UNESCAP 2010).
In Mauritius, the Ministry of Renewable Energy has a long-term energy strategy (2009–2025) and action plan dated October 2009 to develop renewable energy, reduce dependence on imported fuel and promote energy efficiency in line with the vision of Maurice Ile Durable (MID) to promote sustainable development. Its Central Electricity Board enacted the Utility Regulatory Act in 2008 to ensure utilities run more efficiently.

In Germany, extensive measures are being taken to make renewable energy a main component of energy generation. Important measures worth mentioning are:

- The Renewable Energy Sources Act (EEG), which took effect in 2004 and was revised in 2009. The EEG contributes to increasing the percentage of renewable energy sources in the power supply to at least 20% by 2020.
- The Federal Market Incentive Programme designed to promote renewable energy.
- The Renewable Energies Heat Act (EEWärmeG), which obligates owners of new houses to meet a share of the house's heating demands with RE.
- The National Biomass Action Plan for Germany, which aims to significantly increase the percentage of bioenergy sources in the power supply.

Compared to the international/national efforts made in the ACP regions, the aspired EU/German goals are rather ambitious. However this has to be put into perspective relative to the availability of expertise and technology available in each region. Moreover this is an indication of the strong potential for beneficial knowledge and technology transfer within the DIREKT network.

3. Assessment of research and innovation needs in renewable energy science and technology

A questionnaire was created to analyse the research and innovation needs in renewable energy science and technology. It was submitted to 75 businesses and public and private institutions involved in renewable energies in the surveyed countries and comprised the following three main aspects:

1. General information about the organisation

2. The organisation's research and innovation needs

3. The organisation's staff and training needs

Table 1 shows the distribution of all businesses that participated according to country.

Table 1 Number of organisations surveyed in the different countries.

Country/Island	Mauritius	Fiji	Trinidad and Tobago	Barbados and St Lucia
Number	33	20	13	9

The ratio between the different countries does not directly reflect the ratio between the numbers of organisations involved in renewable energy in those countries because the survey was also dependent on the willingness to partake in the survey.

3.1. General information about the organisations

3.1.1. Size of the organisations

As can be seen in table 2, the sizes of the surveyed organisations differ widely.

Table 2 Number of employees in the organisations surveyed.

Fiji	16 of the 20 organisations had between 0 and 20 employees. One employer in Fiji had ~100 employees
Trinidad and Tobago	Business organisations varied considerably in size, ranging from six to about 700 persons. However, the number of persons in these organisations directly involved in renewable energy ranged from 0 to 80.
Barbados and St Lucia	Business organisations varied considerably in size, ranging from four to about 130 persons. However, the number of those persons directly involved in renewable energy only ranged from 0 to 20.
Mauritius	Business organisations varied considerably in size, ranging from two to 241. There are two parastatal bodies that employ between 1,500 and 1,800 persons.

However, it becomes apparent that ACP businesses and institutions in the renewable energy sector are typically small or medium-sized. Furthermore, it is important to differentiate between organisations that are active solely in the field of renewable

energies (e.g. renewable energy service, repair and maintenance businesses) and those that offer renewable energy services as only one of several business segments (e.g. utilities or NGOs for which renewable energy makes up only a small part of their activities).
Table 3 provides information about how many employees of the companies in the various locations worked directly with RE.

Table 3 Percentage ratios of employees engaged in renewable energy in the organisations surveyed in the different countries.

Country/Island	Percentage/Range
Fiji	0% to 100%[1]
Mauritius	Most had about 30%[2]
Trinidad and Tobago	0% to 53%
Barbados and St Lucia	0% to 71%

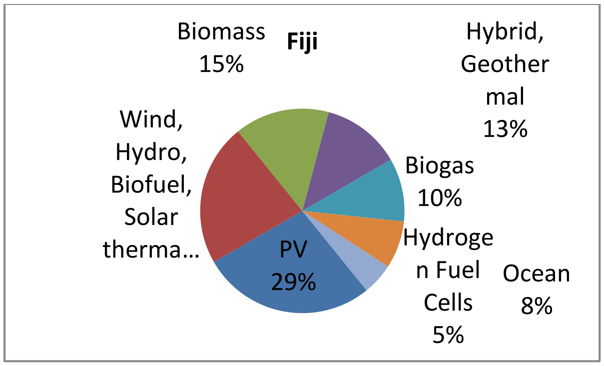
The results show that companies usually offer renewable energy as one part of their services. Organisations active solely in renewable energy are rather the exception. This demonstrates that renewable energy technology has not yet become profitable to the desirable extent and is not considered sufficiently profitable for specialisation in the ACP. However, it is also possible that only companies which have the knowledge required for working in the field of renewable energy are now gradually embracing the renewable energy market.
Generally, female staff entrusted with renewable energy tasks was relatively low, roughly amounting to 20%.
For Trinidad and Tobago, Barbados and St Lucia, enough data was available to make a statement about the distribution of employees within the renewable energy sector. Solar thermal technology, mainly solar water heating (70%), is the major renewable energy application in those regions, succeeded by electricity generation through photovoltaics (20%) and hydropower, wind, biomass, biofuels and fuel cells (10%).

3.1.2. Type of renewable energy of interest to the businesses and institutions

The graphs below show the percentage ratios of the different renewable energy technologies (RETs) in Fiji, Mauritius, Barbados, St Lucia and Trinidad and Tobago.

[1] Distribution was skewed towards both the low end (0% renewable energy staff) and high end (100% renewable energy staff).

[2] Two NGOs however had 100% renewable energy staff.



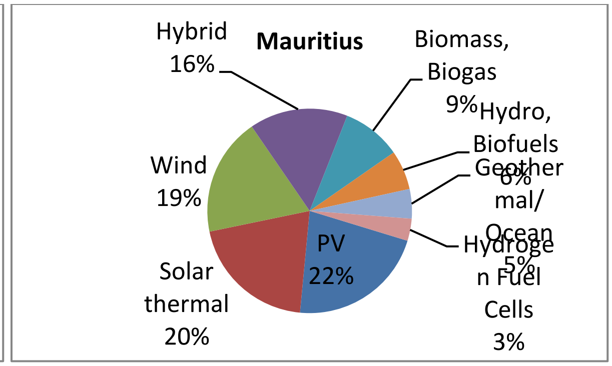
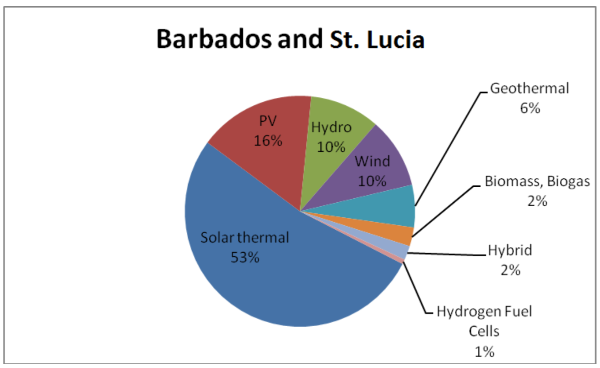


Figure 2 RET preferences in Fiji

Figure 3 RET preferences in Mauritius



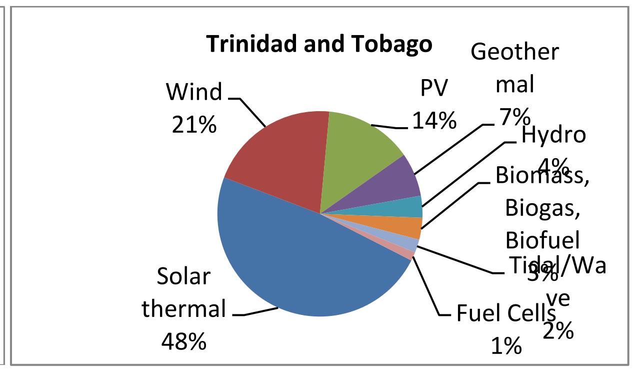


Figure 4 RET preferences in Barbados and Tobago

Figure 5 RET preferences in Trinidad and St Lucia

Photovoltaic, wind and solar thermal energy were the most utilised types of renewable energy in all regions. Subsequently, the trends in the regions differ: Fiji has hydro and biomass as the next two categories. Hydro is the 4th most important in Barbados and St Lucia, the 6th most important in Trinidad and Tobago, and the 6th most important in Mauritius. Also, biofuels are much more important in Fiji than in Mauritius, Trinidad and Tobago, Barbados and St Lucia.

Some of the aspects that might be responsible for this distribution pattern are:

- Electricity generation through photovoltaics and wind does not require much more than basic skills in electric installations because the sunlight and the wind are directly converted into electric potential (voltage) that is ready for consumption.
- Energy production through biomass is very simple (e.g. burning wood for heat), but is always limited to the biomass resources of the region. Fermenting biomass to create gas on the hand requires some education in that field.

Finally, hydro power generation is, in its complexity, comparable to power generation through photovoltaics or wind, but is always limited to the potential of that source of energy that is inherent to the region.

3.1.3. Types of organisations

The organisations with an interest in renewable energy cover all types of organisations that appeared in the questionnaire. Fig. 6 illustrates their distribution in the ACP regions included in the survey.

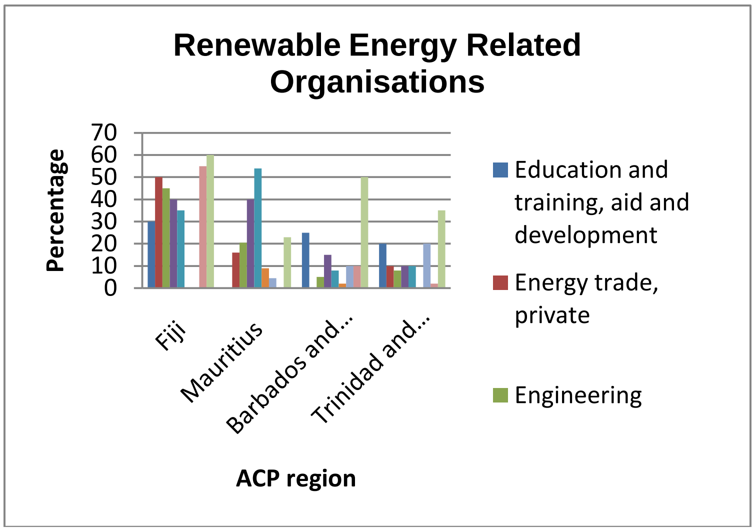


Figure 6 Types of renewable energy-related organisations surveyed in the different countries.

As can clearly be seen in Figure 6, business forms in the field of service, repair and maintenance for renewable energy technology play a key role in all ACP regions. Service, repair and maintenance is the most represented one in Fiji (60%), Barbados and St Lucia (50%) and Trinidad and Tobago (35%), but is less represented in Mauritius (23%).

These business forms are followed by education and training, aid and development facilities and governmental organisations in all regions except Fiji. The regional and international organisations come second in Fiji (55%), but are fourth in Barbados and St Lucia. In Trinidad and Tobago they are an absolute minority and in Mauritius they are not existent at all. Presumably, these differences partly reflect the geographical circumstances in the different regions. The South Pacific region consists of more than a dozen Pacific island states overseen by the Pacific Island Forum, of which Fiji is a member. Likewise, Barbados and St Lucia are members of a multi-island international area, as is Trinidad and Tobago. Mauritius on the other hand is a “stand-alone” country.

3.2. Research and innovation needs

3.2.1. Existing renewable energy abilities within organisations

The organisations were surveyed for their abilities in the following categories:

- Producing new renewable energy products
- Carrying out resource assessments
- Obtaining resource data from established sources
- Evaluating the economics of RETs
- Managing renewable energy projects
- Writing funding proposals

The majority listed their performance in these categories as excellent, good or satisfactory. Altogether the performance ratings for Mauritius were slightly lower.

3.2.2. Knowledge of government Incentive Schemes

The results of the survey indicate that government incentive schemes are well known in most organisations. Particularly in the Caribbean region, information about government incentive schemes was well distributed: 80% of the organisations surveyed in Barbados and St Lucia and 100% in Trinidad and Tobago are aware of them.

3.2.3. Information services provided by tertiary institutions of value to organisations

Tertiary institutions provide various services in the field of renewable energy such as research and development, renewable energy resource assessment, seminars and workshops, training in project management and design, and RET installation. The services tertiary institutions provide to businesses and organisations include joint research, consultancy, monitoring and evaluation of renewable energy projects, networking with businesses, and database services for RE.

Organisations in Fiji, Barbados, St Lucia and Trinidad and Tobago – but not Mauritius – listed these in the same order of importance. Research and development for instance was viewed as the most important service in Fiji, Barbados, St Lucia and Trinidad and Tobago, but not in Mauritius. Consultancy on the other hand was second in Mauritius but of lower priority in the other countries. These are shown in Table 4.

Furthermore, monitoring and evaluation of renewable energy projects was viewed as an important service (first in Mauritius and second in the other countries).

Table 4 shows the need for services offered by tertiary institutions in detail.

Preference	Fiji	Mauritius	Barbados and St Lucia	Trinidad and Tobago
1st	Joint research and development, consultancy and advisory services (45%)	Monitoring and evaluation of projects (36%)	Joint research and development (30%)	Joint research and development (25%)
2nd	Monitoring and evaluation of projects and database services (40%)	Consultancy (32%)	Monitoring and evaluation of projects (25%)	Monitoring and evaluation of projects (20%)
3rd	Networking with business or research partners (35%)	Joint research and development (28%)	Database services (25%)	Networking with businesses (15%)
4th		Networking, database services (20%)	Consultancy (25%)	Consultancy (12%)
5th		Database services (20%)	Networking with business (20%)	

The questionnaire distributed for this study also enquired about market-oriented services that tertiary institutions could provide in the organisations' opinion. Table 5 shows those services most frequently named by the institutions in the different regions.

Table 5 Market-oriented services that tertiary institutions could provide.

Fiji	Mauritius	Barbados and St Lucia	Trinidad and Tobago
Reports on suitability of renewable energy projects in areas of the Pacific	Training in construction and installation of renewable energy products	Training in different types of renewable energy technologies for staff	Training and capacity building for all categories of workers, especially technicians
R & D training	Funding information	R&D training	R&D training
Feasibility studies	Partnerships with private companies	Feasibility studies	Consultancy services
Energy audits	Energy audits	Energy audits	Energy audits
Monitoring and evaluation of renewable energy and energy efficiency projects		Funding information and consultancy services	Partnerships with private companies

3.2.4. Staff training needs in business organisations

3.2.4.1. Types of renewable energy knowledge staff already has

Based on the answers to this question, it can be deduced that the staff's degree of knowledge and the management's notion of what is needed vary. The major conclusions are as follows:

- Most said their managers had general awareness of renewable energy.
- Staff generally lacked academic training in renewable energy.
- Managers generally had adequate abilities in renewable energy management.
- In all countries surveyed, organisations said their finance staff lacked academic training in renewable energy finance.
- Staff had previous work experience in renewable energy.
- Staff had acquired knowledge and know-how through on-the-job training.

The high percentage of staff lacking academic knowledge in RE is surprising. Fig. 7 shows the deficit in academic knowledge for each country.

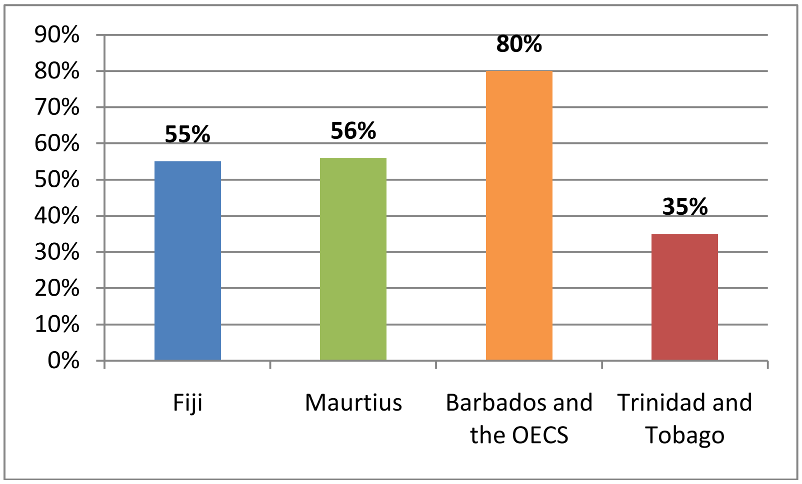


Figure 7 The percentage of staff lacking academic training in RE

3.2.4.2. Types of training required by staff in business organisations

- In Fiji, renewable energy awareness was mostly required by clerks/sales persons (50%), followed by finance and middle managers (45%). In Mauritius, 10% of all staff requires renewable energy awareness training. In Barbados and St Lucia and in Trinidad and Tobago, it was felt that most staff in all categories could benefit from further training in renewable energy awareness.
- In Fiji, academic training in management and finance was required by finance and middle managers (60%), managers (40%) and clerks/sales persons (25%). In Mauritius, it was most important for finance and middle managers (30%) and clerks (20%). Further academic training in management and finance was considered valuable by all organisations in Trinidad and Tobago and in Barbados and St Lucia.
- Essentially all categories in Fiji, Trinidad and Tobago, Barbados and St Lucia required academic training in renewable energy science and technology (all staff categories above 30%). In Mauritius, this was most important for the finance and middle managers (35%), managers (25%) and clerks/sales persons (25%).

3.2.4.2. What type of training is most appropriate for staff?

Generally, the most applicable training for staff was considered to be learning on the job or through in-house training. In Fiji 50% view learning on the job as important, whilst 60% viewed in-house training as also important. In Mauritius 56% said in-house training was important. In Barbados and St Lucia, the need for training in practical skills such as installation and sizing was emphasised. In Trinidad and Tobago the organisations expressed the need for training in design and in research and development abilities (about 70% of organisations), as well as for a better understanding of renewable energy policies (about 30% of organisations).

In all the tertiary institutions surveyed in Barbados, St Lucia and Trinidad and Tobago, the need for more staff in renewable energy across a wide range of renewable energy technologies and capabilities (such as wind, solar, ocean, geothermal, hydro, biofuels, and energy management and efficiency) was emphasised.

4. Conclusions

The survey showed the existence of similarities and differences between Fiji, Mauritius, Barbados, St Lucia and Trinidad and Tobago. As mentioned earlier in the paper, this is probably partly due to the level of complexity that is inherent to the different RETs. But a lack of appropriate technology transfer may also be a reason.

When comparing Fiji, Trinidad and Tobago, Barbados and St Lucia on the one hand and Mauritius on the other, one key difference lies in the geographical circumstances and their implications. Fiji is one of the island countries in the South Pacific region, and thus enjoys the presence of various international bodies and NGOs, many aid and development-related. The same applies to Barbados, St Lucia and Trinidad and Tobago in a Caribbean context. Mauritius on the other hand does not appear to belong to any such groups.

Even though Trinidad and Tobago is the most industrialised of all surveyed ACP countries, this fact doesn’t seem to make a big difference in terms of the utilisation and development of RE. This is presumably due to the acute awareness of Trinidad and Tobago that their oil resources are finite and the considerable emphasis they therefore place on the development of renewable energy technologies.

All in all the survey conducted in the WP 2 shows that all the DIREKT countries perceive renewable energy to be an inevitable part of their future energy supply. It is now crucial that these efforts are duly supported by means of appropriate knowledge and technology transfer. Best practices are shown so that the degree of preparedness to engage in further actions in this field may be increased.

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The Role of Renewable Energy in the Pacific Islands

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Abstract

The small island developing states of the Pacific suffer from both the high cost of fossil fuel imports and from numerous climate-related disasters. IPCC reports confirm that these vulnerabilities will worsen unless there is a substantial global shift away from fossil fuels towards renewable energy sources, coupled with significant improvements in energy efficiency. To effect such changes in the Pacific Islands themselves requires technology transfer, capital and education. This paper illustrates these points by reference to the teaching programs at the University of the South Pacific in RE and CC adaptation , and especially the technology/ knowledge transfer to and from them under Project DIREKT and the USP-Korea RE project. Apart from traditional wood-fueled cooking, the only substantial uses of RE in the Pacific currently are hydropower in some of the hillier island countries and household photovoltaic systems in some outer islands. The Fiji Electricity Authority has a reasonably realistic plan to have 90% of its supply from RE by 2015, drawing on hydropower (~50% now), biomass (including bagasse), and wind. Several other Pacific Island countries have ambitious RE targets but is much vaguer about how they are to be achieved. The paper concludes by examining the lessons learnt and not learnt from RE projects since the 1980s.

BIO-ENERGY

FAST PYROLYSIS AND KINETICS OF SUGARCANE BAGASSE IN ENERGY RECOVERY

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Abstract:

The trend for material and energy recovery from biomass-waste along with the need to reduce green house gases has led to an increased interest in the thermal processes applied to biomass. The thermal process applied to biomass produces either liquid fuel (bio-oil) or gaseous fuel. Liquid fuel is more preferred because it is easier to transport from one point to another and also it can be used for production of chemicals. One of the biomass obtained in Tanzania is sugarcane bagasse. The sugarcane bagasse is the fibrous materials that remain after sugarcane is crushed to extract juice. Currently, it is burnt directly in the boilers for production of steam, but it can be used for production of bio-oil. The bio – oil can be optimally obtained by fast pyrolysis, which is a fast thermal decomposition of biomass material at temperature range 523 – 800K in the absence of an oxidizing agent. In order to undertake a parametric study on the fast pyrolysis of sugarcane bagasse, it is imperative to establish its thermal characteristics. The paper reports the proximate and ultimate analysis, and thermal degradation of sugarcane bagasse in nitrogen as heating agent. The thermal degradation was conducted in a thermo-gravimetric analyzer from room temperature to 1000 K at different heating rates of 5, 10, 20 and 40 $Kmin^{-1}$. The thermo-gravimetric analyzer was used to study the effect of heating rate on the thermal degradation characteristics and to determine mass loss kinetics. The sugarcane bagasse was observed to be suitable for use in pyrolysis since it contains high volatile level of 80.5 % and fixed carbon of 8.2 %. The peak temperature was observed at 573 K at 10 $Kmin^{-1}$ and corresponding activation energy was 387.457 kJ/mol.

Keywords: Sugarcane bagasse, Bio-oil, Fast pyrolysis, Activation Energy, Thermo-gravimetric analyzer.

1. INTRODUCTION

Biomass is in fourth position in the ranks of energy resources on a global basis, providing 14% of the world energy need [1]. In developing countries like Tanzania 90% of the energy consumed is from biomass, in the form of wood and charcoal, while petroleum and electricity account for 8% and 1.2% respectively, the remaining source of energy is 0.8%, such as coal [2].

Sugarcane is one of the largest products that are obtained in Tanzania; there are about 17,000 hectares of sugarcane. All the sugarcane farms are owned by sugarcane companies; these are Kilombero Sugar Company, Mtibwa Sugar Estate, Tanganyika Planting Company (TPC) and Kagera Sugar. Each company produces about 450,000 tones of bagasse per year [3].

The produced sugarcane bagasse from Sugar Company has a moisture content of about 50%, with a calorific value of 10 MJ/kg. The mill bagasse has a low bulk density of 130 kg/m^3, which cause a storage problem, because it requires a large space and also equipment for handling [4]. In most of the sugar company the bagasse produced is directly burnt in the boiler for production of steam which can be used for production of electricity. This process generates residues that could lead to high disposal costs or pose environmental problem when disposed by means of open air burning [5].

An advanced thermal technology is required to harness energy with the intimacy of minimizing disposal cost and environmental pollution. The thermal technology requires knowledge of thermal behavior of sugarcane bagasse before application. Thermo-gravimetric analysis (TGA) is one of the techniques that are used to study the thermal behavior of solid fuels. The TGA assists to calculate mass loss rate per unit time, reaction constant (k) and the value of activation energy (Ea) of bagasse. The results are useful during application in process such as pyrolysis.

Pyrolysis is one of the thermal process which favoring the upgrading of energy content of biomass. Pyrolysis can produce both charcoal and bio-oil. The bio-oil produced from sugarcane bagasse has the gross calorific value of about 22.4 MJ/kg, which is twice the original bagasse. Also charcoal has heating value of 36 MJ/kg [6]. The transportation and storing is easier for bio-oil than charcoal, also synthesis gas and valuable chemicals can be produced from bio-oil.

The theme of this paper is to characterize the sugarcane bagasse in relation to the frequency factor and activation energy and also to determine the quality of bio-oil that can be obtained from sugarcane bagasse.

2. THE SUGARCANE BAGASSE REACTION KINETICS

Sugarcane bagasse mainly consists of cellulose, hemicellulose and lignin, the cellulose is in the range of 32 to 44 wt%, hemicellulose is between 27 and 32 wt%, and lignin is around 19 to 24 wt% [7]. Also bagasse has small amount of cane wax, organic acids and other materials, the composition of bagasse depends on the sugar beat content, age, nature of soil which the sugarcane plant was grown. The properties of each component are different, the cellulose fibers provide material strength and its degradation occurs at 240 - 350°C to produce anhydrocellulose and levoglucosan. The hemicelluloses decomposition occurs at a temperature of 200 - 260°C giving rise to more volatiles, but less tar and less char than cellulose. The third major component is lignin, which is more thermally stable and accounts for the production of residual char [8].

The variation of the components in biomass materials result to complexity of thermal decomposition, due to that reason several researches have been done to determine the behavior of each component. Broido-Shafizadeh studied the pyrolysis kinetics of cellulose, observed that the cellulose reacts at elevated temperature to form active cellulose and then decomposes into volatiles and, gas and solid materials as shown in Equation 1 [9].

$$Cellulose \rightarrow Active\ cellulose \begin{cases} \rightarrow volatiles \\ \rightarrow Char + Gases \end{cases} \quad (1)$$

In the Broido-Shafizadeh mechanism there is no change of mass in the transformation of cellulose to active cellulose, the transformation of the active cellulose to product is accompanied by a mass loss. In addition to that most of the pyrolysis mechanisms are based on cellulose since it is considered as a primary component of a lignocellulosic biomass. Finally, a mechanism which suggests the degradation of the biomass is the sum of the contribution of the individual degradation of the three components was applied, this is known as three-step mechanism, Equation 2, in this paper the degradation of the sugarcane bagasse is assumed to follow three step mechanism.

$$Biomass \rightarrow \begin{cases} \overset{k_1}{\rightarrow} gas \\ \overset{k_2}{\rightarrow} tar \\ \overset{k_3}{\rightarrow} char \end{cases} \quad (2)$$

There are different methods for determination of pyrolysis kinetics from Thermo-gravimetric analysis. These are Coats and Redfern [10], Agrawal sivasubramanian [11], Freeman and Carroll [12], Kissinger's method [13] among others. This study will consider Kissinger's method, since the process that used during thermo-gravimetric analysis of bagasse was non-isothermal.

The Kissinger's method does not depend on reaction mechanism for determination of activation energy, although the determination of the frequency factor assumes first order reaction mechanism [14]. The peak temperature (T_{max}) is used to determine the activation energy (E_a). Thermal decomposition rate are measured at different heating rate, through sequence of experiments. The pyrolysis rate is expressed by using Arrhenius Equation (3) and (4), k is the rate constant, which depends on temperature.

$$\boldsymbol{K = Aexp(-E/RT)} \quad (3)$$

$$\boldsymbol{dx/dt = Af(x)\exp(-\frac{Ea}{RT})} \quad (4)$$

$$\boldsymbol{x = (w_o - w)/(w_o - w_\infty)} \quad (5)$$

Where x is the reacted fraction as shown in Equation (5), T is the absolute temperature, Ea is the activation energy, A is the pre exponential factor, R is the gas constant and f(x) is the algebraic function depending on the reaction mechanism.

If temperature rises at a constant heating rate (β), which is expressed as Equation 6, the differentiation of equation 4 will result Equation 7.

$$\boldsymbol{\beta} = \frac{\boldsymbol{dT}}{\boldsymbol{dt}} \qquad (6)$$

$$\frac{\boldsymbol{d^2x}}{\boldsymbol{dt^2}} = \left\{\frac{\boldsymbol{Ea\beta}}{\boldsymbol{RT^2}} + \boldsymbol{Af^{'}(x)exp(-Ea/RT)}\right\}\frac{\boldsymbol{dx}}{\boldsymbol{dt}} \qquad (7)$$

The maximum rate occurs at a temperature T_{max}, defined by equating Equation 7 to zero. Approximations from the calculations give the equation 8.

$$\boldsymbol{ln}\left(\frac{\boldsymbol{\beta}}{\boldsymbol{T^2_{max}}}\right) = \boldsymbol{ln}\left(\frac{\boldsymbol{AR}}{\boldsymbol{Ea}}\right) - \left(\frac{\boldsymbol{Ea}}{\boldsymbol{RT_{max}}}\right) \qquad (8)$$

A straight line graph is obtained by plotting of $ln\left(\frac{\beta}{T^2_{max}}\right)$ v/s $1/T_{max}$, the slope is $^{Ea}/_{R}$ and the intercept on the vertical axis is an $ln\left(\frac{AR}{Ea}\right)$.

3. METHODOLOGY

3.1 Materials

The bagasse used in this study was collected from Tanganyika Planting Company, which is located in Moshi region, Tanzania. Pure nitrogen gas was used as heating agent. The Thermo-gravimetric analyser was used to study the thermo-degradation of the bagasse, fixed bed pyrolyzer was used for production of bio-oil, bomb calorimeter was used to determine heating value, furnace was used for determination of proximate analysis of the bagasse and atomic absorption spectrometer (AAS) was used for ultimate analysis.

3.2 Method

The experiments were divided into three parts; the first part was to study the characteristics of rice husk through proximate, ultimate analysis and high heating value (HHV). Secondly, the determination of pyrolysis kinetics of the bagasse and finally, the production and analysis of bio-oil obtained from bagasse.

The proximate analysis of the bagasse was carried out according to ASTMD 3172 method, ultimate analysis was done according to ASTMD 3176 and the HHV was obtained by ASTM D2015.

The experiments under non isothermal conditions were carried out in the TGA. The sample of a ground bagasse was at an average particle size of 100 μm and 30 mg of the sample was used for each experiment. The TGA experiments were conducted at heating rates 5, 10, 20 and 40, in nitrogen atmosphere. The weight change of sample was recoded by thermo-balance.

The fast pyrolysis process was applied to the 100gm of sugarcane bagasse by using fixed bed pyrolyzer. The operation of the fixed bed pyrolyzer is divided into, heating and experimental phase. The heating phase is done by heating the ceramic honeycomb to 600℃ by using methane burner. The flue gases that remain in the system are thereafter purged by nitrogen gas with the assistance of exhaust fan until the system is free of flue gases. The flue gases are monitored by using gas chromatography, at this stage the system temperature reduced to 500℃.

The sample is stored in the chamber just above the reactor and it is continually blown with nitrogen gas so as to remove air in the sample. After the temperature of the system stabilizes, the nitrogen gas which is blown to sample is stopped and the sample is introduced to the reactor. The temperature of the reactor and the sample temperature will be measured by using thermocouples.

The sampling line has bottles which are immersed in the ice bath, which act like a condenser, volatile matters that passes through the bottle will condense, gases will go to Gas chromatography for analysis, while char will remain in the basket.

The pyrolyzer is shown in Figure 1 and it consist of A is primary chamber, B is secondary chamber, C is ceramic honeycomb, D and E are Oxygen and methane line for the burner, F is sample, G is weighing machine, H is ice bath, I is sampling bottle and GC is Gas chromatography.

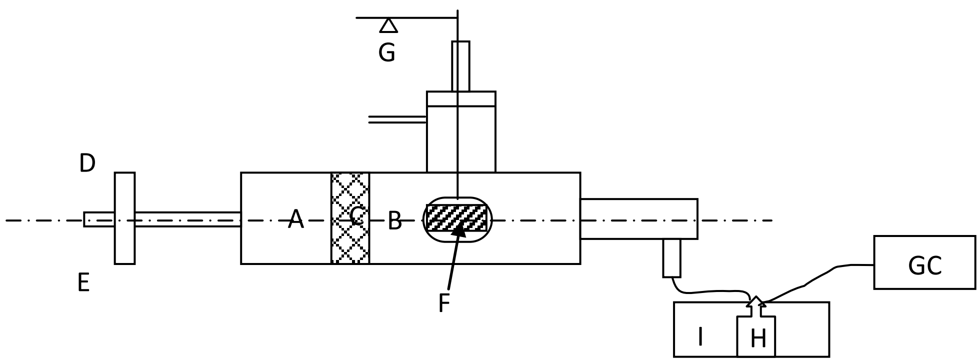

Figure 1: Pyrolyzer for bio-oil production process

4. RESULT AND DISCUSSION

The sample characteristics are shown in Table 1.

Table 1: The proximate, ultimate and Higher heating value of the bagasse

Proximate Analysis	wt%	Ultimate analysis	wt%
Moisture	9.00	C	48.10
Volatile	80.50	H	5.90
Fixed carbon	8.20	N	0.15
Ash	2.30	O	42.40
		Cl	0.07
		S	0.02
Higher heating value	17.33MJ/kg		

The carbon and hydrogen contents are the indicative of hydrocarbons that can be released during pyrolysis process. On the other hand the high oxygen content reduces the energy density of the fuel. The presence of chlorine and sulphur are not preferred since they contribute to the formation of corrosive compounds.

Thermo-gravimetric analysis of the sugar cane bagasse is shown in figure 2; it is the thermo-gravimetric (TG) against temperature. It is divided into three sections, the moisture content section which shows the mass change of the bagasse due to moisture released, secondly, the abrupt mass change due volatile matter and the last section is the constant section where there is no mass change or the mass change is significantly small.

There are differences between proximate analysis and thermo-gravimetric analysis, in thermo-gravimetric analysis the moisture content was 9.52%, volatile matters were 83.5%, while in proximate analysis the moisture and volatile matter are 9.00% and 80.5% respectively.

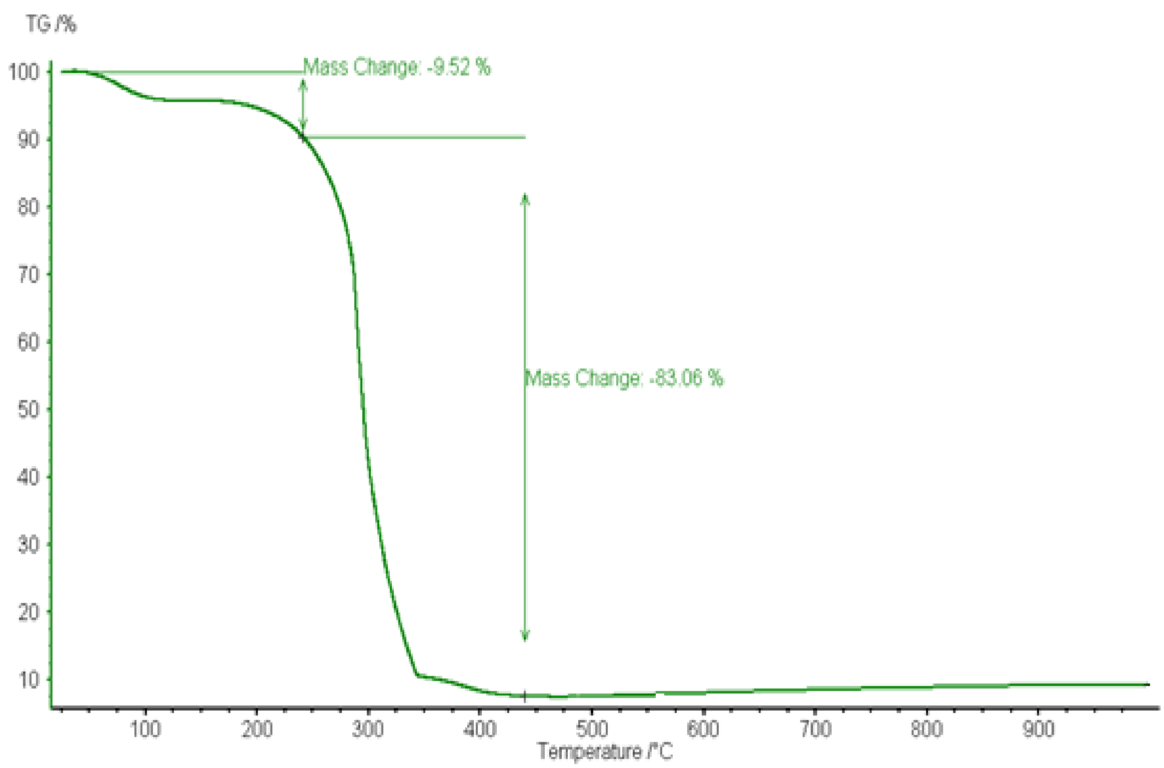

Figure 2: Thermo-gravimetric curve of sugarcane bagasse

The constant section in the thermo-gravimetric analysis is know as char, which consists of ash and fixed carbon, in Figure 2 the char was 7.40%, while in proximate analysis the fixed carbon and ash sum up to 10.5%.

The thermo-gravimetric analysis shows that the heating rate affects the thermo-degradation of sugarcane bagasse. Figure 3 describes that when 5 °C/min was applied to sugarcane bagasse the char collected was higher than when 10, 20 and 40 °C/min were applied. It also shows that the suitable heating rate that provides minimum char at low temperature (i.e., 405°C), this was 10°C/min, while in 20 and 40 °C/min, the small amount of char obtained were at 420 and 500°C respectively.

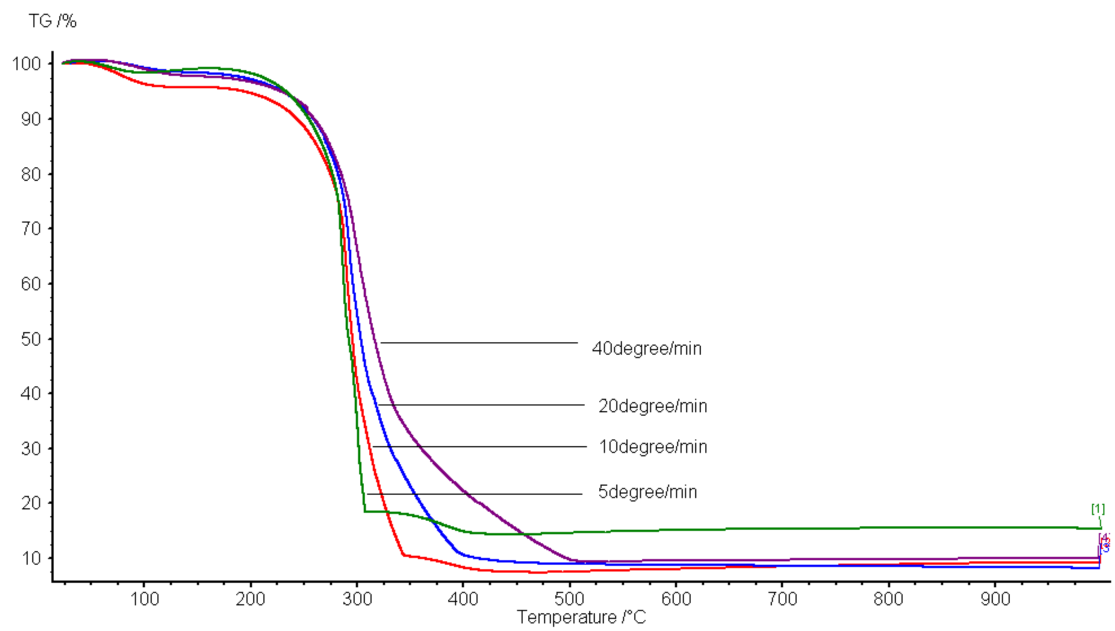

Figure 3: Thermo-gravimetric analysis of sugarcane bagasse at different heating rate

Figure 4 is the derivative of the Figure 3. It shows clearly that after 500°C there was no any weight change of the sample for all used heating rate, this described that the thermo-degradation of the sugarcane bagasse stopped. The remaining material was only char, which contains fixed carbon and ash.

The final temperature to degrade sugar bagasse increases as heating rate increases, The final temperature for weight change of sugar bagasse of 5, 10,20and 40°C/min were306, 340, 400 and 500°C respectively. This observation gives evidence that the degradation of sugarcane bagasse a slow reaction process, it requires a low heating rate.

Figure 5 was obtained by plotting the natural logarithm of the ratio of heating rate and maximum temperature against the reciprocal of maximum temperature. The heating rate and the maximum temperature were obtained from Figure 4. The determination of kinetic parameters was done by using Figure 5. The activation energy obtained was 387.457 kJ/mol and the pre-exponential factor is 0.74 s^{-1}.

The bio-oil obtained was dark brown liquid, with a density of 1200 kg/m^3 and viscosity of 23 cP at 40°C, the pH was 3, High Heating Value (HHV) was 23.2 MJ/kg and ash content was 0.02 wt%.

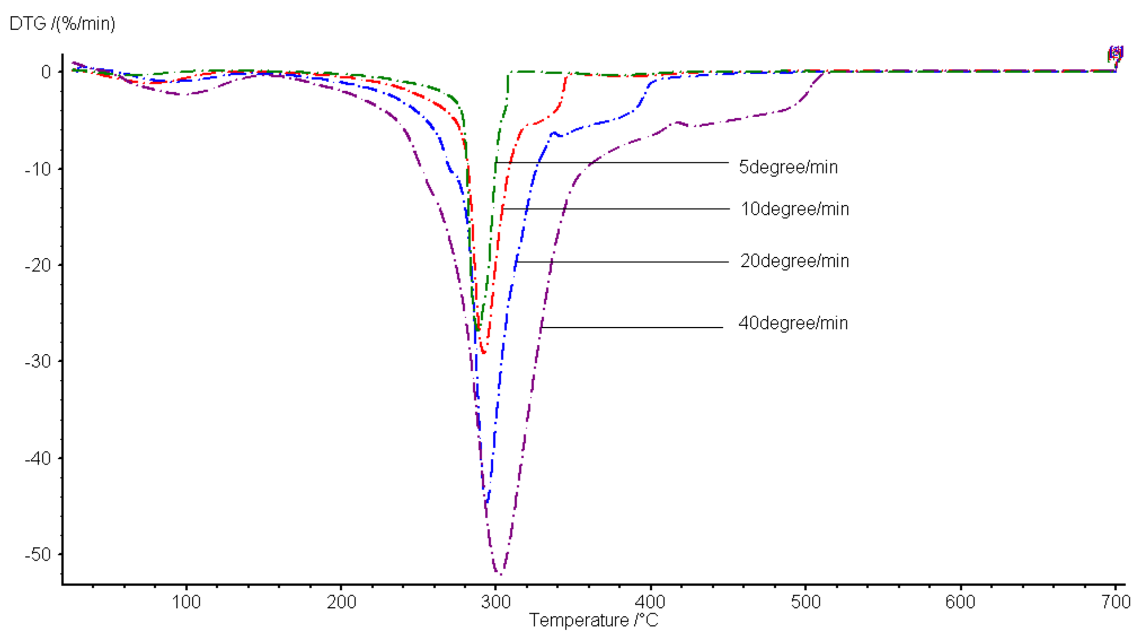

Figure 4: Derivative thermo-gravimetric analysis of sugarcane bagasse

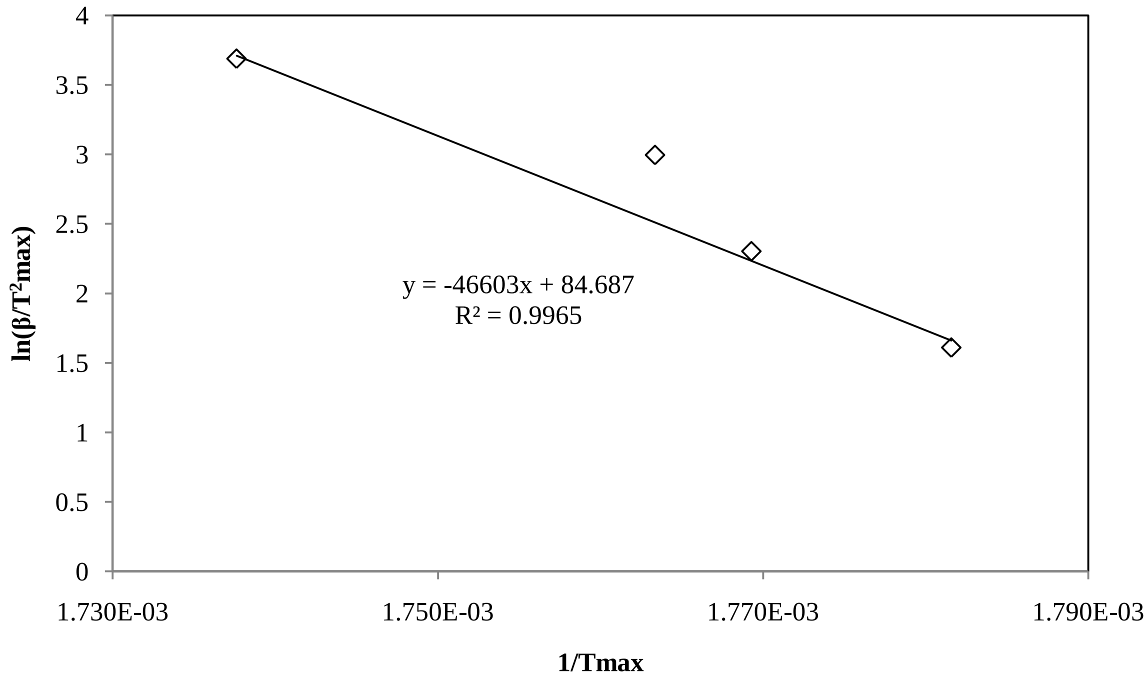

Figure 5: Graph for determination of kinetic parameters

5. CONCLUSION

The overall calculations of the thermochemical kinetics of sugarcane bagasse was done by using Kissinger's method, which assume that the reaction order was one, the activation energy and frequency factor obtained were 387.457 kJ/mol and 0.74 s^{-1}.

On the other hand the liquid fuel obtained during the pyrolysis process is more suitable since it has higher calorific value than the original sugarcane bagasse; this is an advantage because a little amount of bio-oil is able to produce enough energy.

6. SYMBOLS

Symbol	Description	Symbol	Description
A	Pre-exponential factor	R	Gas constant
AAS	Atomic Absorption Spectrometer	S	Sulphur
C	Carbon	T	Absolute temperature
Cl	Chlorine	TG	Thermo-gravimetric
Ea	Activation energy	TGA	Thermo-gravimetric

			analysis
H	Hydrogen	T_{max}	Maximum temperature
k	Reaction constant	w	Weight of a sample at time t
k1	Rate constant for gas	w_o	Initial weight
k2	Rate constant for tar	w_∞	Final weight
k3	Rate constant for char	x	Reacted fraction
N	Nitrogen	β	Heating rate
O	Oxygen		

7. ACKNOWLEDGEMENTS

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CHARACTERIZATION OF PYROLYSIS KINETICS FOR THE USE OF TROPICAL BIOMASS AS RENEWABLE ENERGY SOURCES

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Abstract:

Tropical biomass such as rice husks, sugar bagasse, coffee husks and sisal waste are among typical biomass wastes abundant in most of the tropical countries. However, despite their enormous potential as energy sources, they are hardly studied and their thermal characteristics are still not well known. The purpose of this work is to determine the thermochemical characteristics and pyrolysis behavior of these selected biomasses. Proximate, ultimate and heating value analyses were carried out on the samples. Results show that all biomass have a range of, volatile contents (50-80% w/w), fixed carbon (10-20% w/w), ash content (<3% w/w), carbon (50-56% dry basis) low nitrogen (0.7-1.3 % dry basis) and sulphur (<0.1 wt% dry basis) contents with heating value (HHV 14-18MJ/kg). The biomasses were thermally degraded through thermogravimetry analysis and their characteristics such as devolatilisation profiles and kinetics parameters (activation energy *E*, and frequency factor *A*) were determined, in an inert atmosphere. It is found that the kinetic parameters obtained can predict not only global devolatilization of biomass pyrolysis but also can predict the pyrolysis pathway of cellulose in the target biomass.

Keywords: Tropical biomass, Pyrolysis, Kinetics

1. INTRODUCTION

Tropical biomasses are among renewable energy resource available in tropical countries. These resources are from agricultural crop residues and forestry plantation or natural. The estimate form Tanzania harvest annually is 1.2 million m^3 of forests plantation (not waste) and 12.604 million tones of agricultural waste [1]. These resources can have high potential use as alternative source of fuel since are still not in use intensively for commercial form, regarding that the present source in the world fossil fuels are nearly exhausted, where is estimated to be able to sustain reserves availability for the next 40 years for petroleum and 60 years for natural gas [2]. The transport sector accounts high consumption, of around 97% of liquid fuel [3]. Also importation cost and environment emission of fossil fuel is a problem. From this respect, liquid fuel need to be generated from other resources, since currently it is from non renewable sources. Pyrolysis is the promising route to produce liquid fuels from biomass.

The technology of pyrolysis of biomass has been assessed as a promising route for liquid fuel production. However, uncertainties remain related to both production and utilization of technology [4]. Therefore, for the design of a conversion system that suits specific characteristics of the biomass, the material need be fully characterized. Pyrolysis kinetics is among the way that can lead to a dynamic and static condition of the process. During the dynamic condition, pyrolysis temperature is progressively increased with increasing heating time using a specified heating rate, while static condition maintains a selected constant temperature in a pyrolyzing reactor [5]

2. KINETICS OF BIOMASS PYROLYSIS

2.1 Materials

Characteristic properties of four selected tropical biomasses listed in Table 1 presents the proximate and ultimate analysis found of the biomass samples using ASTM as standards. The high hydrocarbons and less oxygen content are to be highlighted, together with high heating value of both tropical biomasses, compared to rice husks. The carbon and hydrogen contents are a good indicative of hydrocarbons content that are to be released during pyrolysis [6]. It was also found that, content of nitrogen, sulphur, and chlorine are very small for all biomass. On the basis of elemental composition, coffee husks exhibited high energy content due to their higher H:C ratio with relatively low O:C ratio.

Table 1 Biomass properties analysis for rice husks, sugar bagasse, coffee husks and sisal pole (source, [10])

	ASTM Standard	Rice Husks	Sugar Bagasse	Coffee Husks	Sisal Pole
Proximate Analysis (%)					
Moisture	ASTM E-949	8.80	9.00	6.70	10.10
Volatile matter	ASTM E-872	59.20	80.50	83.20	79.30
Fixed carbon	by difference	14.60	16.20	14.30	14.60
Ash	ASTM E-1755	26.20	3.30	2.50	6.10
Ultimate Analysis (%), dry basis					
C	ASTM E-777	45.60	48.10	49.40	47.00
H	ASTM E-777	4.50	5.90	6.10	6.00
N	ASTM E-778	0.1 9	0.15	0.81	1.66
O	by difference	33.40	42.40	41.20	39.10
Cl	ASTM D-6721	0.08	0.07	0.03	0.05
S	ASTM E-775	0.02	0.02	0.07	0.13
Higher heating value (MJ/kg)		13.24	17.33	18.34	17.35
"H:C" Ratio		0.13	0.12	0.12	0.13
"O:C" Ratio		0.94	0.88	0.83	0.83

2.2 Pyrolysis Kinetics

Pyrolysis kinetics provides important information for the engineering design of a pyrolyzer or a gasifier. It also shed light on the different processes in a pyrolyzer that affect product yields and composition. To optimize the process parameters and maximize desired yields, this knowledge is of key important [7].

Typical approach to the kinetics of thermal decomposition of a biomass is dividing the volatile evolution into a few fractions - lumps, each of which is represented by a single first-order reaction. These lumps are assumed to be non-interactizng and evolved by independent parallel reactions [8].

If pyrolysis is performed at a constant heating rate β (K/min), the first-order rate can be expressed in the following form.

Biomass $\rightarrow$ Volatile$_i$ $\quad\quad$ i = 1, 2, 3, ….. n

$$\frac{dV_i}{dT} = \frac{k_i}{\beta}\left(V_i^* - V_i\right) \quad (1)$$

Where V_i^* is the ultimate yield of the i-th volatile ($\tau \rightarrow \infty$), V_i is the accumulated amount of evolved volatiles from lump i up to time τ, k_i is the rate constant, which depends on temperature according to the Arrhenius equation.

$$k_i = A_i \exp\left(-E_i/(RT)\right) \quad (2)$$

Where E is the activation energy (kJ/mol), R is the common gas constant, T is the temperature (K), and A is the frequency factor (s^{-1}).

At the peak temperature at which volatile evolution reaches a maximum (T_{max}), the time derivative of the reaction rate should be equal to zero. The values of T_{max} of the volatile lumps at different heating rates will be determined from peak-resolution curves (DTG). Rearrangements the two equations, final form of equation will allows to determine kinetic parameters as follows;

$$\ln\left(\frac{\beta}{T_{max}^2}\right) = \ln\left(\frac{RA_i}{E_i}\right) - \frac{E_i}{RT_{max}} \quad (3)$$

The parameters E_i and A_i can be determined from the slope and intercept of a linear plot of $\ln(\beta/T^2_{max})$ vs. $1/T_{max}$ at various heating rates.

2.2.1 Thermogravimetric Analysis

Themogravimetric test were performed with thermogravimetric analyzer (TGA) type NETZSCH STA 409 PC Luxx. High purity nitrogen (99.95%) was used as the carrier gas and the flow rate was 60ml/min. About 30mg of sample with average particle size of less than 2mm was put in the crucible each time and heated from 35 to 1000°C with different heating rate ranging from 5 to 40K/min. Calculated thermogravimetric output from the TGA software was obtained.

3. RESULTS AND DISCUSSION

3.1 Biomass decomposition profiles

Fig. 1-2 presents the TG and derivative TG (DTG) profiles showing the thermal degradation characteristics of rice husks, sugar bagasse, coffee husks and sisal pole at a heating rate of 10°C/min. The TG profiles show the typical degradation profile for biomasses with well demarked regions for moisture release, devolatilization and char degradation. These differences play an important role in the pyrolysis of these materials and respective product yields.

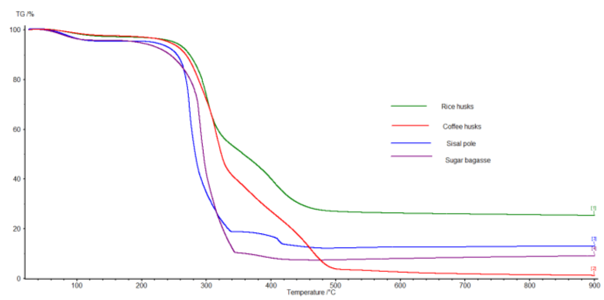

Fig. 1 Weight loss from the thermal decomposition of coffee husks, sugar bagasse, sisal pole and rice husks at 10K/min.

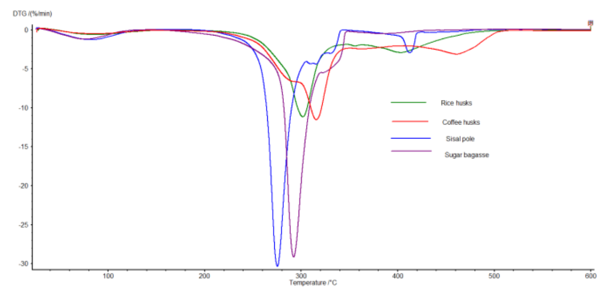

Fig. 2 Weight loss rate from the thermal decomposition coffee husks, sugar bagasse, sisal pole and rice husks at 10K/min

Fig. 1, show the weight loss observed for dried samples of rice husks, coffee husks, sisal pole and sugar bagasse, at a heating rate of 10 K/min (i,e. 5 to10 K/min for pyrolysis process). The temperature interval in which each biomass sample experiences the greater mass loss is different from one to another, these intervals are 250 – 510, 240 – 440, 240 - 450 and 230 – 480 °C, where a bout 88.7, 83.06, 79.45 and 68.74% of the total volatiles weight were released in coffee husks, sugar bagasse, sisal pole and rice husks, respectively. The volatiles yield is greater in coffee husks compared to both rice husks, sisal pole and sugar bagasse. Sugar bagasse have comparably much volatile matter content than sisal pole and rice husks but lower than coffee husks, the same for sisal pole than rice husks. The char yield is inversely proportional to the volatiles yield.

Fig. 2 show the DTG profiles where, sugar bagasse have similar decomposition to sisal pole but with slightly different maximum temperature of 292 and 275°C, and coffee husks have similar decomposition to rice husks with slightly different maximum temperature 315 and 302°C.

3.2 Kinetic analysis of biomass pyrolysis

For kinetics parameters determination, different values (as signed to the respect curve) of heating rate (β) were used (5 to 40K/min) and is observed that the DTG curves for all biomasses at these various heating rates, shifts the position of the peak extreme (T_{max}) to a higher temperature region as heating rate increasing. Effect of these heating rates is shown in Fig. 3. From this respect, it can be stated that the heating rate affects both location of the DTG curve and maximum decomposition rate.

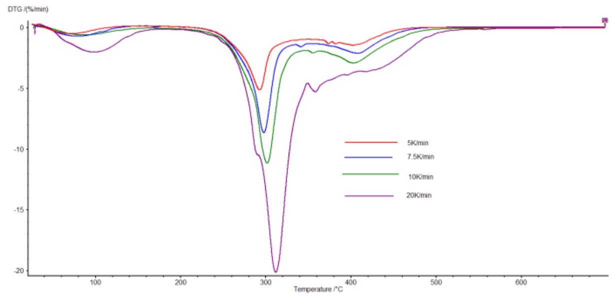

Fig. 3(a) DTG of rice husks at various heating rates

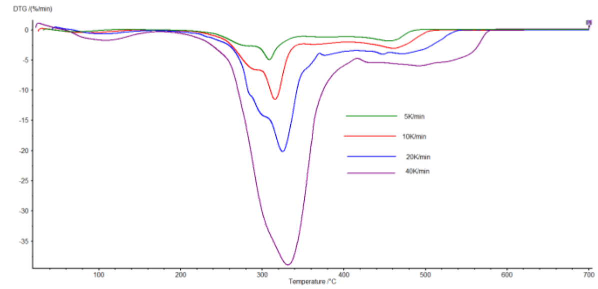

Fig. 3(d) DTG of coffee husks at various heating rate

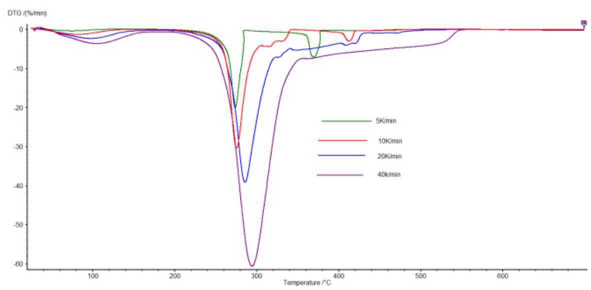

Fig. 3(b) DTG of sisal pole at various heating rates

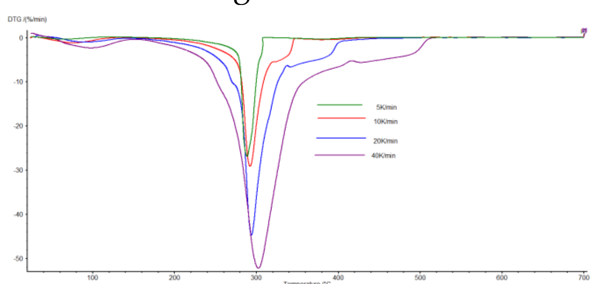

Fig. 3(c) DTG of Sugar bagasse at various heating rates

According to the above mentioned DTG curves, the experimental data obtained, were processed in order to obtain kinetic parameters like the activation energy *E*, and pre-exponential factor *A*, as expressed in Table 2. From the set of DTG curves at different heating rates of each biomass, the T_{max} were obtained for calculation into Eq. (3) and the linear plot for slop determination is presented in Fig. 4. Because at higher temperature no significant changes in conversion occur from the biomass [9].

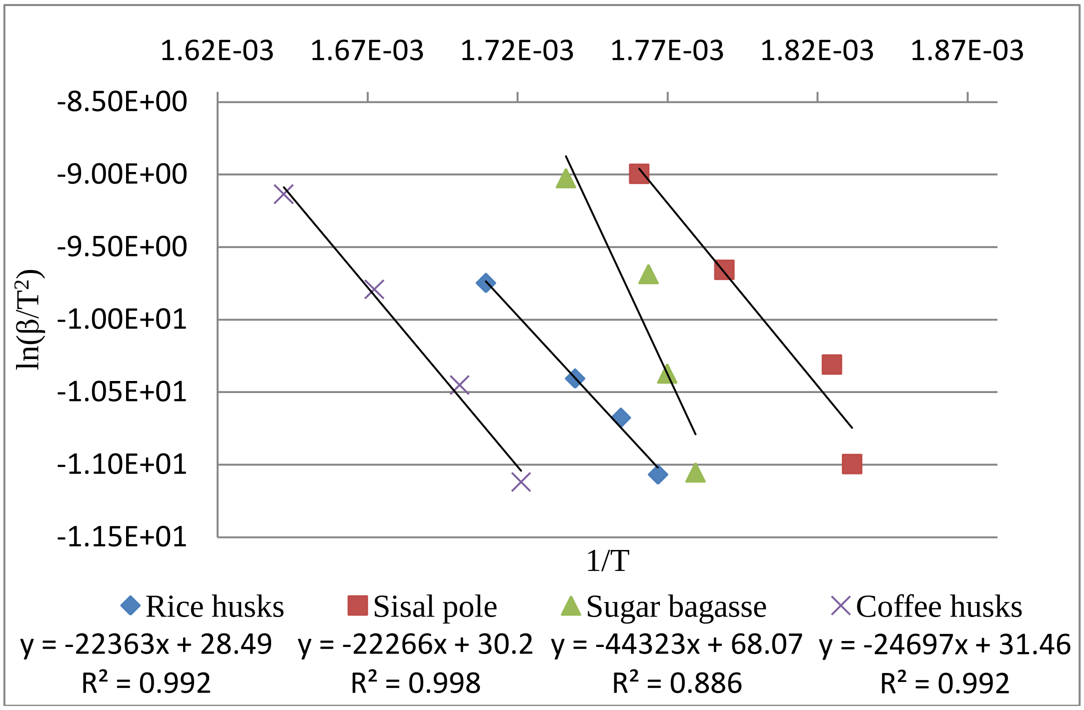

Fig.4 Linear plot of $\ln(\beta/T^2_{max})$ vs. $1/T_{max}$ at various heating rates for selected tropical biomasses.

Table 2 Kinetic Parameters of Thermal Decomposition of coffee husks, sugar bagasse, sisal pole and rice husks

	β (K/min)	E (kJ/mol)	A (/s)
Rice husks	5	268.98	5.28E+16
	7.5		
	10		
	20		
Sisal pole	5	267.81	2.91E+17
	10		
	20		
	40		
Sugar bagasse	5	533.11	1.62E+34
	10		
	20		
	40		
Coffee husks	5	297.05	1.14E+18
	10		
	20		
	40		

Finding from other literatures available on establishing kinetic parameters for the studied tropical biomass are; Kinetic data obtained for mill bagasse 460.6kJ/mol, coffee husks 370.8kJ/mol [10]. From this establish in respect of the method used by Ledakowicz and Stolarek [8], the kinetic parameters obtained are 297.05, 533.11, 267.81 and 268.98 kJ/mol for coffee husks, sugar bagasse, sisal pole and rice husks respectively, for heating rates ranging from 5 to 40 K/min. The variability of the kinetic parameters is accepted on the bases of method used, originality and specific nature of the biomass materials under the study.

4. CONCLUSION

Selected tropical biomasses were successfully characterized. The proximate and ultimate analysis findings show that these materials have acceptable heating value with enough content of volatiles to be used as renewable energy sources, coffee husks highlighted with high energy content as per discussion. The content of nitrogen, sulphur, and chlorine is marginal in all biomasses.

- As regard to TGA analysis, the thermal decomposition of volatiles is mainly observed in the temperature range 240 to 500^{o}C for biomasses, where coffee husk is characterized with highest volatiles than others 88.7%.

- From calculated kinetic parameters, is described that sugar bagasse has high values of activation energy 5.331kJ/mol. The highest value of activation energy denotes the high temperature sensitivity of the charcoal formation reaction.

Therefore through these analyses results it is conforming that these biomasses are suitable for renewable energy source.

5. ACKNOWLEDGMENTS

The authors wish to acknowledge Miss. E. Kasembe, Mr. W. Lugano, Mr. P. Mashingo, and Mr. S. Mahir, PhD students at the Department of Mechanical and Industrial Engineering, University of Dar es Salaam, for the assistance rendered.

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Prospects and limitations of Biomass Gasification for Industrial Thermal Applications in Sub-Saharan Africa

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Abstract

The paper presents an evaluation of the prospects and limitations of biomass gasification for small-scale industrial thermal applications in sub-Saharan Africa. The evaluation was done through a review of existing biomass conversion technologies that could be replaced by gasifiers and the availability of potential feedstock fuels, an economic analysis of potential gasification projects under different conditions with the use of RETScreen Clean Energy Project Analysis Software, and highlighting possible solutions to the challenges which the technology faces.

The findings show a continued heavy reliance on wood fuels for thermal energy together with a high use of inefficient conversion technologies in industries. Furthermore, significant quantities of agricultural residues remain un-utilized which could substitute about 40% of wood fuel use in industries. The economic analysis shows that the adoption of gasification technologies is economically viable, due to the high potential for revenues from fuel savings and the associated Green House Gas (GHG) emissions reductions when agricultural residues substitute or supplement the use of wood fuel. Some of the identified limitations of biomass gasification technology include liquidity constraints of the potential users, the lack of local knowledge in the design, manufacture and operation of gasifiers as well as the hazard and safety issues of gasifiers.

It can be said that biomass gasification can play a major role in energy efficiency and a shift from the wood fuel dependency in small-scale industries, which is important for the environment and beneficial to the users. However, there is need for incentives such as tax holidays, tax waivers on equipment as well as reduced debt payment rates to enable industries afford the required capital investments. Institutional mechanisms for easy access to carbon credit markets are also necessary as GHG emissions reduction

revenues contribute a significant portion of the annual revenues. Also investment in research and development of local skills in the design, manufacture and operation of gasifiers is vital to further reduce the capital investments and ensure proper management of the gasification-related hazard and safety issues.

Keywords: Biomass, Gasification, Thermal energy, Small-scale industries

1. INTRODUCTION

Sub-Saharan Africa faces many energy challenges, which have impacts on the social-economic aspects of the region. The key challenges include, high energy production-to-consumption ratio partly due to low level of industrialization; and inefficient energy conversion technologies, especially for biomass. Overcoming some of the challenges will require intensive and organized research and development activities to facilitate informed energy decision-making. Although energy research and development is still weak in sub-Saharan Africa [1] research effort and progress are being made in the various countries. One of the many technologies under research in the region is gasification technology. While this technology has been in existence for many years, its adoption and use in sub-Sahara Africa is still limited.

Gasification, by partial combustion, is a thermo-chemical process used for converting a solid fuel into a mixture of combustible gases known as producer gas [2]. The generated gas is mainly composed of hydrogen, carbonmonoxide, methane, carbondioxide, nitrogen and water vapor. Condensable hydrocarbons (tars) and ash are also produced. The heating value of producer gas varies from 4 - 6 MJ/Nm^3 for air-blown gasifiers to 13 – 15 MJ/Nm^3 for oxygen/steam-blown gasifiers [2]. The gas can be used for various uses, the ones more relevant to sub-Saharan Africa including provision of thermal energy, generation of electricity and as well as mechanical power through internal combustion engines.

The use of producer gas for provision of energy offers advantages over direct burning the solid fuel such as better combustion efficiency by achieving high temperatures as well as more clean combustion through the use of suitable gas burner technology. It should also be mentioned that gasification has more solid fuel conversion efficiency compared to the traditional open fire technologies that are largely employed in sub-Saharan Africa.

2. POTENTIAL OF BIOMASS GASIFICATION

While the population of the continent continues to grow annually, its energy supply remains low indicating a reduction in energy access on a per capita basis. The total energy consumption in Africa was estimated as 470Mtoe in 2008 with biomass, mainly wood, contributing the biggest share of 60% as shown in Fig. 1 [3]. It should also be mentioned that 90% of the coal in Africa is found in South Africa alone [1]. The biggest portion (61%) of the total energy is used for residential purposes such as cooking, lighting and heating followed by industrial purposes as show in Fig. 2. Considering the industrial sector, biomass's contribution was 32.4% (90.55Mtoe). The reliance on biomass is highest in Sub-Sahara Africa with over 90% of the total biomass consumption [4] which translates into 81.50Mtoe in industries in the region.

With the increasing deforestation levels, wood fuel continues to be scarce and expensive. Hence the use of agricultural residues as sources of energy in industries to substitute wood is an important possibility. The potential of agricultural residues in Sub-Sahara Africa was estimated to be 139.5 million tons from 36 out of 48 countries [5]. Using the average heating value of 16.7MJ/kg (dry fuel), the energy potential was calculated as 2,330PJ (55.7Mtoe). It is estimated that bagasse-based cogeneration from sugar industries could meet about 5% of the total electricity demand in the region [6]. Basing on the projected electricity demand of 680TWh by 2015 at a demand increase rate of 5% [7] the amount of bagasse estimate in 2011 was calculated as 2.44Mtoe. Assuming that 50% of the residues are used for other purposes – animal feed, cooking/heating, and soil fertility-, surplus agricultural residues can be used to substitute about 40% of wood fuel in industries.

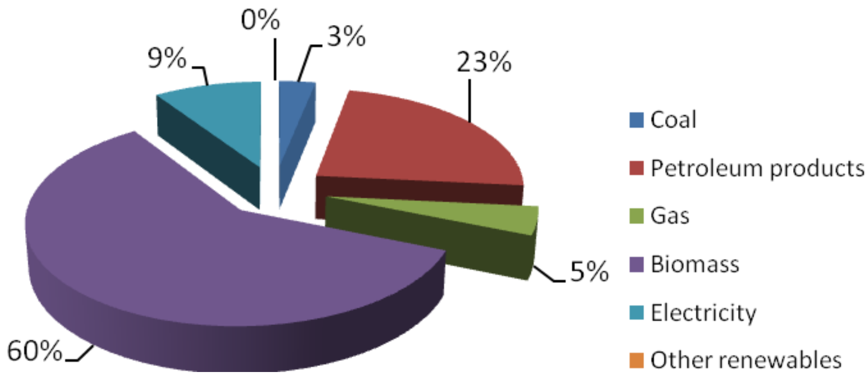

Fig 1 Energy sources in Africa, 2008

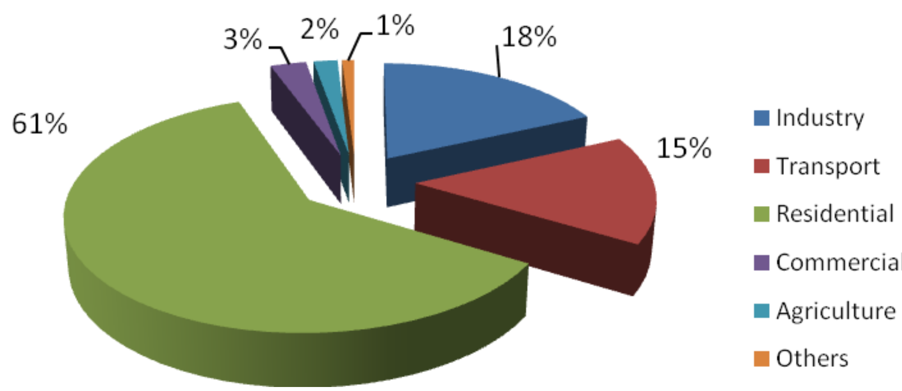

Fig. 2 Proportion of energy consumption in various sectors

It was also found out that large energy investments are mainly concentrated on the large-scale energy technologies whose application volume is small compared to small-scale energy technologies that are mainly used by the majority of the population as illustrated in Fig. 3 [8]. It is therefore important to that significant investment be made in small-scale technologies which comprise the majority of industries in the region.

Therefore the potential of gasification technologies utilizing surplus agricultural residues for industrial thermal applications is significant.

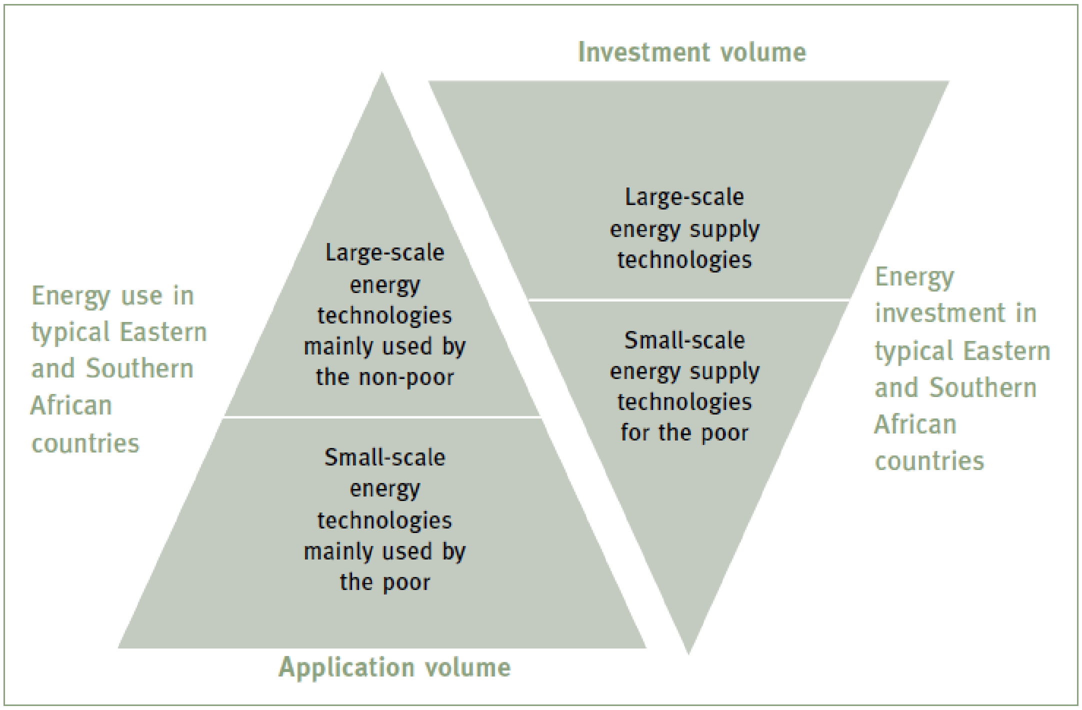

Fig. 3 Energy use vs. energy expenditure typical in Eastern and Southern Africa.

3. ECONOMIC EVALUATION OF BIOMASS GASIFIERS

3.1. The approach used

The study evaluated the economics of biomass gasification technology in the provision of thermal energy in small scale industries using the RETScreen Clean Energy Project Analysis Software (Version 4) that is freely available online [9]. This considered the project's fuel savings, revenues from emissions reductions trading against the capital investment and operation costs of the system.

A case study of MGM, a small-scale food processing industry in Uganda was used. MGM is engaged in agro-processing of grain to produce flour, bread and cakes. The factory produces a number of pre-cooked flour products made from maize, soy, silver fish, millet and rice. An oven of capacity of 180kg confectioneries per day is made from brick and cement-sand mortar with steel baking compartments. The oven is fed with large logs of firewood. The factory also employs two roasters made of steel drums driven by a small electric motor to provide rotary motion along the longitudinal axis. The drums are filled in batches with grains and heated directly with an open fire. The combined total production of the roasters was reported to be 2,000kg/day.

MGM operates 6 days a week and 8 hours per day throughout the year. The wood consumption was estimated to be 97.4ton/yr at the cost of US$56/ton of wood. These estimates were made based on the fuel wood records as well as the actual daily wood measurement. The wood moisture content was measured as 31.4% (wb). The wood combustion system used at MGM is similar to the inefficient 3-stone open fires, and hence its thermal efficiency was conservatively assumed to be 20% [10]. The installed thermal capacity of MGM factory was calculated from Eq (1) where E_{th}(kW) is the thermal output, η_{th} is the thermal efficiency(%), $\dot{m}_f$ is the fuel consumption rate (kg/s), MC_f is the wood moisture content (%wb) and LHV_f is the wood heating value(MJ/kg). The heating value for dry wood was taken as 19.5MJ/kg [11].

$$E_{th} = \eta_{th} \cdot \dot{m}_f \left(1 - MC_f\right) \cdot LHV_f \qquad (1)$$

Fixed bed gasifiers, because of their suitability for small-scale use, have been suggested. The gasifier system overall efficiency of 40% and its unit capital cost of US$200/kW [12] were used.

The key parameters used in the evaluation are average inflation rate of 6.2% over the past 15 years was applied [13], income tax rate of 25% and depreciation tax basis of 20% [14] with Straight-line method over 20 years. Other parameters assumed include fuel price escalation rate of 7% discount rate of 12.0% and project life of 25 years. The capital investment costs used are also summarized in Table 1.

Table 1: Capital investment costs

Initial costs		**USD**
Feasibility study	7.1%	2,000
Development	14.2%	4,000
Engineering	63.3%	17,860
Balance of system & misc.	15.4%	4,343
Total initial costs	100.0%	**28,203**

The study evaluated the financial viability of the project considering that the scenario where agricultural residues substitute 40% of the wood fuel. While the prices of agricultural residues range from US$3/ton to14/ton [15] depending on the source in Uganda, the evaluation considered a conservative price of US$15 per ton. Assuming the LHV of 16.5MJ/kg and the moisture content of 15% (wb) for air dry agricultural residues [16], the amount of residues required would be 18.6 tons/yr in addition to 29.0 tons/year of wood fuel. Without the use of agricultural residues, MGM would continue to use 48.3 tons/yr of wood.

The evaluation considered five cases to determine how they could affect the economic viability of the project.

- Case 1 assumes that MGM fully finances the project without getting a bank loan, incentive/grant or tax holiday.
- Case 2 assumes that MGM fully finances the capital investments but gets a tax holiday spread over 5 years.
- Case 3 assumes that MGM acquires a loan equivalent to 50% the total investment cost at debt interest rate of 23% [17] over a period of 5 years.
- Case 4 assumes that MGM acquires a loan as in Case 3 and receives an income tax holiday over 5 years.
- Case 5 assumes that MGM gets incentives/grants equivalent to 20% of the total investment cost

The results of the evaluation were compared with the scenario where MGM continues to use 100% wood fuel with the adoption of the gasification system.

The emission factors for CO_2, CH_4 and N_2O of 109.6kg/GJ, 0.03kg/GJ and 0.004kg/GJ respectively for biomass combustion [18] were used in the calculation of GHG emission reduction that would be achieved by switching to the use of a gasifier at MGM. Other parameters assumed in the emissions analysis are shown in Table 2.

Table 2 Emission analysis parameters

Parameter	Unit	Quantity
GHG credit transaction rate	%	2.5
GHG reduction credit rate	$/tCO2eq	20
GHG reduction credit escalation rate	%	3.0
GHG reduction credit duration	Yr	25

It should be noted that the calculation of GHG emissions reductions did not put into consideration leakages that come with the transportation and preparation of fuel, use of electricity to run the gasifier, and the possibility that the revenues from the emission reductions will be invested in activities which lead to generation of GHG emissions.

3.2 Results and Discussion

With the use of the gasifier, MGM's annual operating costs and savings/income are shown in Table 3 and 4 respectively. In effect, it means that the annual income of MGM –excluding interest on loans or depreciation - would be US$ 3,008- and US$1,427- when using a mix of wood and agricultural residues and using wood only respectively.

The results have also shown that the project with substitution of 40% wood fuel with agricultural residues is economically viable with significantly shorter equity payback periods and positive NPV values in comparison with the continued use of wood fuel only as shown in Table 5. The cumulative cash flows for both scenarios are also shown in Fig. 4 and Fig. 5. A tax holiday of 5 years has more impact on the case when MGM finances all the investments costs. Given the possibility of liquidity constraints in small-scale industries, it is most likely that loans have to be acquired in order to finance the implementation of the gasifier projects. A lower interest rate may help to reduce the payback period. The sensitivity analysis showed that variations in the fuel cost (proposed case) and the emission reduction credit rate can significantly affect the payback period and the NPV.

Table 3: MGM's annual operating costs

Annual costs	Amount (US$)	
	Using wood/agricultural residues	Using only wood
O&M	3,308	3,308
Fuel cost - proposed case	1,918	2,729
Total annual costs	**5,225**	**6,036**

Table 4 MGM's annual savings/income

Income source	Using wood/agricultural residues		Using wood only	
	Saving	**Income (US$)**	**Saving**	**Income (US$)**
Fuel cost – base case	97.4 tons/yr	5,503	97.4tons/yr	5,503
GHG reduction income	136t$CO2_{eq}$/yr	2,730	98t$CO2_{eq}$/yr	1,960
Total		**8,233**		**7,463**

Table 5 Pay back periods and NPVs for the two project scenarios

Scenario	Wood and agricultural residue		Wood only	
Case	Equity payback (yrs)	NPV (US$)	Equity payback (yrs)	NPV (US$)
1	8.1	3,421	15.4	-10,998
2	6.9	6,185	14.6	-9,864
3	10.5	1,498	19.4	-12.922
4	10.2	2,244	19.4	-12.862
5	6.8	7,652	13.1	-6,768

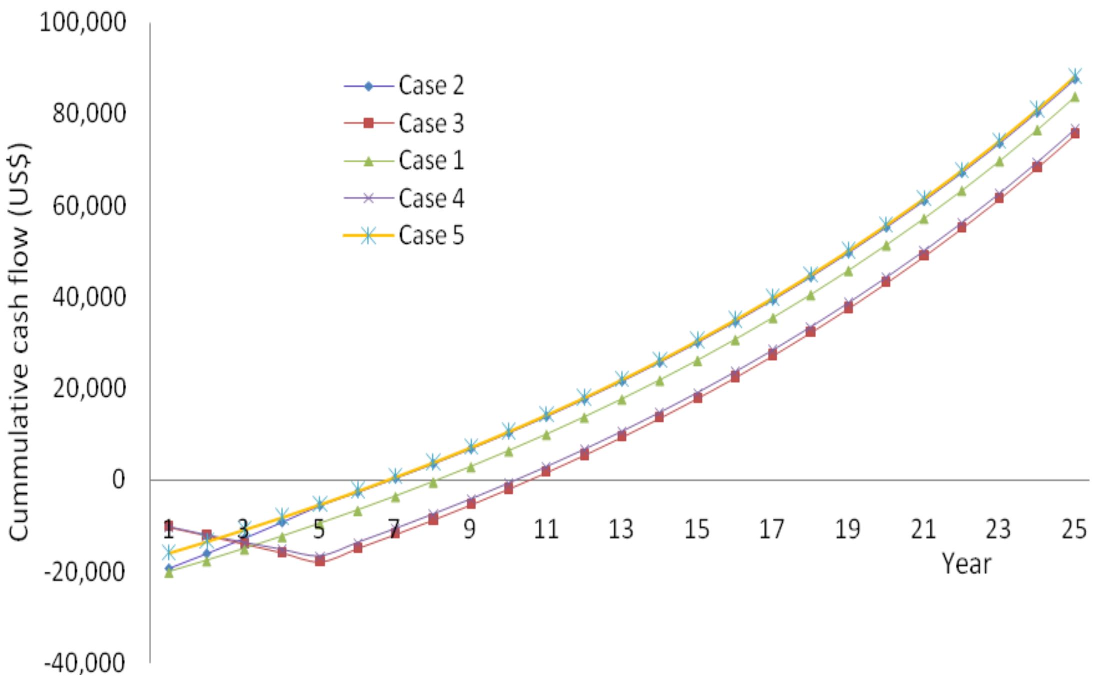

Fig. 4 Cumulative cash flows of with both wood and agricultural residues as fuels

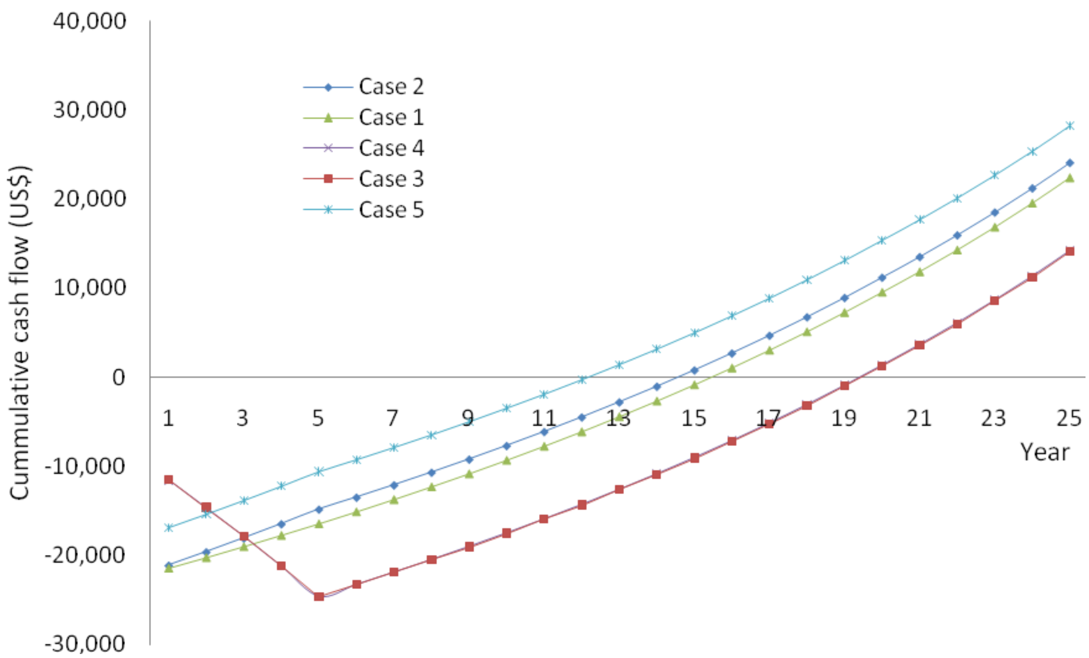

Figure 5 Cumulative cash flows with wood as the only fuel

The MGM gasifier project scenario presents opportunities for addressing the core challenges of sub Saharan African. Firstly, it addresses the issue of use of inefficient combustion technologies that are common in the region. This would help to reduce deforestation rate as well as reducing on emissions. Putting the project into perspective, the possible use of a gasifier by MGM would lead to annual GHG emissions reduction which is comparable to 31 acres of forest absorbing carbon every year. There would be great impact on the environment with the adoption of these technologies in many small-scale industries in the region. Specifically for thermal applications, the only modification that may be necessary to integrate with a gasifier is a properly designed gas burner/combustion chamber. The rest of the exiting system remains largely unmodified With tax holidays and reduced lending rates, small-scale industries should be able to acquire gasifiers for their thermal needs.

Secondly, the project is itself a source of income for the industries. Increasing the capital base of industries through fuel saving and GHG emission reduction trading directly leads to economic and industrial growth. This is achieved through diversification and increased employment opportunities.

Thirdly, for industries that can have access to agricultural residues in large quantities all year around, complete substitution of wood fuel would further reduce the annual operation costs and increase the annual income hence impacting greatly on the equity payback period. It should be mentioned that there may be additional investment costs that need to be met to accommodate the large quantities of the residues. They could include storage and handling facilities and pre-treatment systems where applicable.

4. LIMITATIONS OF BIOMASS GASIFICATION TECHNOLOGY

Due to the diverging capacities of different small-scale industries in sub-Saharan African, biomass gasification systems need to be designed in appropriate scales according to the user demands. This remains a key challenge because of the various factors that need to be considered such properties and types of feedstock materials, energy requirement etc. At the same time, biomass gasification systems need to be made economically affordable to small-scales industries. This however risks compromising the efficiency hence leading to operation difficulties and environmental problems.

Successful adoption of biomass gasification in sub-Sahara Africa requires additional support other than the fuel savings, GHG emissions trading and the way of energy utilization. Government or institutional policies on capital cost subsidies and tax cuts or tax holidays for are necessary. There is a challenge of high interest rates on bank loans which drive away the industries that may be interested in acquiring the systems. These all remain big challenges.

There still remain significant levels of lack of awareness of gasification technology in the region. Awareness campaigns by governments and institutions need to be put in place to educate potential users about the technology and its benefits. The development of skills in the design and operation of gasifiers in the region need to be emphasized.

5. CONCLUSIONS

The potential of biomass gasification for provision of thermal energy in small scale industrial applications exists with the availability of agricultural residues which could substitute about 40% of wood fuel use in industries. It has also been shown that the adoption of biomass gasifiers for provision of thermal energy in small-scale industries by replacing the traditional inefficient technologies currently in use is economically viable and has positive significant environmental and economic impacts when agricultural residues are used to supplement or substitute wood fuel.

In order to increase the rate of adoption of gasifiers, policies such as tax holidays, reduced debt payment rates, tax waivers on gasifier equipment supplies or any meaningful incentives should be put in place. With these, many small-scale industries that wouldn't ordinarily afford such high investments can be brought on board.

Given that the sources of revenue to help cover investment and operational costs are hinged around fuel savings and GHG emission reductions, governments and institutions in sub-Sahara Africa need to put in place mechanisms that can help industries access carbon credit markets relatively easily. Without the revenues from GHG emission reductions, most small-scale industries would need high incentives or subsidies and longer tax breaks in order to find adoption of gasification technology an economically sound venture.

It is also important that governments and institutions invest in research and skills development in the design and operation of gasification systems. This would go long away in reducing the high capital investments and ensuring high performance of the technologies.

6. ACKNOWLEDGEMENT

The authors thank the management of Maganjo Grain Millers for allowing us to collect useful data. Appreciation also goes to SIDA/Sarec for the financial support.

7. SYMBOLS AND UNITS

7.1 Abbreviations

[GHG]	Green House Gas
[ICSU]	International Council for Science
[IEA]	International Energy Agency
[LHV]	Lower Heating Value

[MGM]	Maganjo Grain Millers
[NPV]	Net Present Value
[REEEP]	Renewable Energy and Energy Efficiency Partnership

7.2 Symbols

[CH_4]	Methane
[CO_2]	Carbondioxide
[N_20]	Nitrous oxide
[$tCO2_{eq}$]	Ton of carbondioxide equivalent
[E_{th}]	Thermal Energy output
[$\dot{m}_f$]	Fuel consumption rate
[η_{th}]	Thermal efficiency
[MC_f]	Fuel Moisture content

7.3 Units

[yr]	year
[kg]	kilogram
[kW]	kilo watt
[Mtoe]	Mega tons of oil equivalent
[GJ]	Giga Joules
[MJ/Nm^3]	Mega Joules per normal cubic metre
[MJ/kg]	Mega Joules per kilogram
[PJ]	Penta Joules

7.4 Conversions

1Mtoe = 11.63 TWh

1 Mtoe = 41,868 TJ

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Assessing the potential of torrefaction for locally available biomass in Mauritius

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Abstract:
Mauritius is a small developing island without any natural fossil fuel reserves. It is highly dependent on fuel imports for its own energy provision. A small share of its energy requirement is fulfilled through the utilization of renewable energy. Hydropower and biomass namely bagasse are being exploited at an industrial scale for power generation while fuel wood is still being used in some households for cooking purposes. Mauritius has however got potentials to increase its renewable energy share through increased biomass use. The Maurice Ile Durable (MID) project is expecting a 35% share of biofuels in the energy contribution of the country by the year 2028. However, there are several problems associated with the use of biomass which include its storage and transportation problems, its relatively lower energy content, its high moisture content and low bulk density reducing its appeal as a fuel compared to conventional fossil fuels. This study was therefore initiated to assess the potential of torrefaction of biomass in Mauritius. For the purpose of this study, five locally available biomass sources have been chosen involving energy crops, agricultural residues and wastes. Torrefaction is known to be a mild pyrolysis process during which the lignocellulosicmaterial in the biomass are decomposed. Moisture and volatiles are eliminated from the biomass during the process. The benefit of torrefaction is that a fuel is produced commonly known as biocoal which has a uniform composition compared to unprocessed biomass. The biocoal has a relatively higher energy density; it is hydrophobic in nature and is not vulnerable to biological degradation thus reducing storage problems. The effect of torrefaction on the energy content and the chemical composition of the different biomass feedstocks namely: Elephant grass (Napier grass), paper, cane tops and leaves, wood wastes and palm trunks have been investigated. Samples of the biomass were treated at varying temperatures in the range of 200-300 ^{0}C in an inert atmosphere with a residence time of 1 to 3 hours. Using established methods, moisture content was determined for raw samples and energy analyses were performed on the raw and torrefied samples which were later compared. The optimum residence time and temperature for each of the different biomass feedstock was determined. The

amount of coal that can possibly be displaced and the greenhouse gases avoided by the use of torrefied biomass in Mauritius was subsequently evaluated.

Keywords: Maurice Ile Durable, lignocellulosic, Torrefaction, greenhouse gases

1.0 INTRODUCTION

The world is living with growing anxieties of an imminent energy crisis [7, 22]. Escalating energy demands in developed and developing countries whilst an almost stagnant energy supply is only aggravating the scenario. The globe's leaders are already insecure about the price and continued supply of fossil fuels in the forthcoming years. In January 2012, it was reported that the price of oil was around $103 per barrel [12]. An analysis of the Central Statistics Office (CSO) report leads to the conclusion that Mauritius is heavily dependent on imports to be able to meet its energy demands [11]. 82.5 % of the primary energy requirement in the island is fulfilled by fossil fuel imports with a 55 % share of petroleum products [11]. Hence, the country is highly susceptible to energy shocks such as rise in oil price in the world.

Moreover, growing fossil fuel use worldwide is also increasing the amount of greenhouse gas emissions in the world leading to a threatening climate change. Developing countries are considered to be more vulnerable to the climate change problem since they possess little resources to adjust and adapt to climate change in terms of social, technological and financial aspects [26]. Mauritius, though having little contribution to climate change compared to developed countries is already experiencing its negative effects. Rise in air temperature from 0.74 to 1.2 degrees Celsius in comparison to the 1990's, rise in sea level by 1.5 millimetres per year and an 8 % decrease in rainfall as well as warmer summers and milder winters [16] are some of the experienced consequences of climate change in the country. To combat the problems related to fossil fuels, alternative energy sources need to be sought. Biomass is a promising alternative to replace fossil fuels given its wide distribution globally compared to other sources of fuel [27]. Additionally, biomass is also a clean source of energy and will help in the reduction of emissions of greenhouse gases [29].

However, the contribution of biomass in energy generation in Mauritius is very minimal accounting for only 20.5 % of the electricity generation in the country which is sustained by the biomass bagasse, a by-product of the sugarcane milling process [11]. It can be clearly deduced that expansion of the biomass sector involves various challenges. Along with political, economic barriers and a lack of strategies and frameworks for promoting the biomass industry, the properties of the biomass itself as a fuel act as a significant hindrance for its own development [6].

A comparison of coal with biomass reveals that the latter is still regarded as a relatively inferior fuel not able to meet the same benchmarked characteristics as coal [6]. One of the main challenges encountered by biomass is that their low calorific value and low ash sintering temperature causes technical problems during its use in combustion and gasification [3]. Biomass also have high moisture content and low bulk density which further hinder its use due to high transportation costs associated for handling it [14]. A high level of moisture also poses storage difficulties and dangers of degradation or self-heating of the biomass along with reduction in the efficiency of biomass and it limits the gasifier construction design [6]. Moreover, the heterogeneous nature of biomass hinders its competitiveness in the energy market [10]. Efficient biomass conversion technologies can aid to improve of the problems related to biomass [23].

Torrefaction is a thermal pre-treatment process, which can be described as a mild pyrolysis, during which the biomass is subjected to a temperature range of 200 to 300 ^{0}C under atmospheric conditions with little or no oxygen [23]. The process helps to. Torrefaction is advantageous in many ways: biomass degradation is reduced since the water absorption capacity of the torrefied biomass is reduced and alongside, its energy value is also improved on a mass basis; the torrefied biomass can be easily ground to a powder and it can also be co-fired with coal [5, 2, 23]. The properties of the torrefied biomass are somewhat similar to low rank coal.

Various studies have been conducted on torrefaction [2, 6, 19, 23, 25] but none of them have focused on agricultural wastes: cane tops and leaves and palm trunks as well as the energy crop elephant grass. This paper investigates the relationship between the calorific value and the residence time and torrefaction temperature of four different biomass species available in Mauritius (sawdust, elephant grass, cane tops and leaves and palm trunks) and attempts to find the optimum temperature for each biomass.

2.0 METHODOLOGY

2.1 Moisture content and dry mass determination

To find the moisture content of the biomass, 100 g of each of the 5 different samples were weighed in different plates. The samples were then placed in the oven at a temperature of 105 ^{0}C and allowed to dry until constant weight was obtained.

2.2 Energy content of biomass

The energy content of the biomass samples was evaluated on a dry basis using a bomb calorimeter model 3188 series. The sample was first dried in an oven (Labcon) at a temperature of 105 ^{0}C for a period of 3 hours. It was then pelletised. The pellet should weigh less than 1 g. The sample was placed in a metal capsule which is then positioned on a ring which acted as an electrode to which a bent fuse wire is attached such that it touches the sample. The ring was placed on the bomb cylinder which is afterwards filled with oxygen at a pressure of 25 atm. The bomb cylinder was then connected to ignition wires and lowered in the bomb calorimeter bucket filled with 2 litres of water. After mounting the stirrer on the calorimeter bucket, mixing was allowed in the vessel. The initial temperature of the water was next recorded before switching on power to fire the fuse wire. The final temperature reached was noted and the higher heating value of the biomass was calculated taking into consideration the temperature difference and mass of the sample.

2.3 Torrefaction experiment

A batch cylindrical reactor with a length of 10 cm and a diameter of 10 was used. The reactor was enclosed in a heater whose temperature can be varied from 0 to 300 ^{0}C is used. The reactor had a gas inlet for supplying nitrogen to the reactor and a gas outlet to allow flue gas to leave the reactor. Nitrogen was supplied to the reactor at a rate of 2 litres per minute. For each run, 5 g of sample was placed in the reactor for a period of 1 hour at the required temperature. The heater was then switched off. The sample was allowed to cool in the reactor to room temperature before being removed after which the torrefied sample was weighed. Four different temperatures were chosen for the study: 230 ^{0}C, 250 ^{0}C, 270 ^{0}C, 290 ^{0}C. The torrefied samples were then analysed for their composition and heat value using a bomb calorimeter.

3.0 RESULTS AND DISCUSSION

3.1 Mass loss at different torrefaction temperatures and residence time

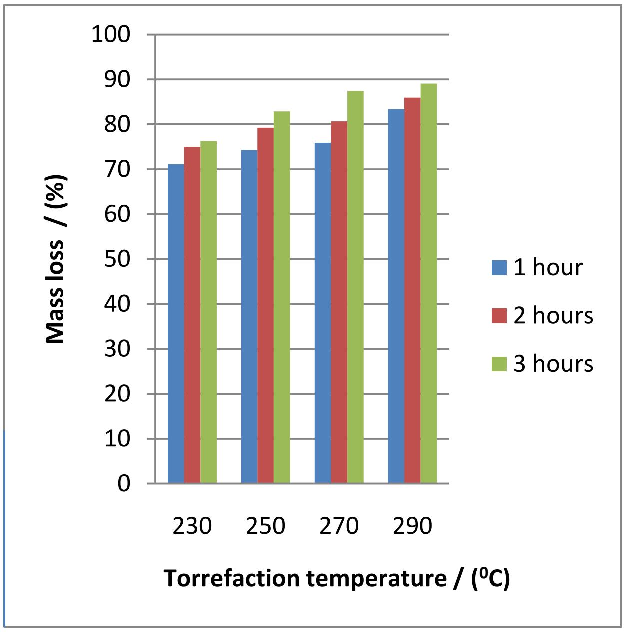


Fig. 1 Mass loss of CTL at different torrefaction temperature and residence time

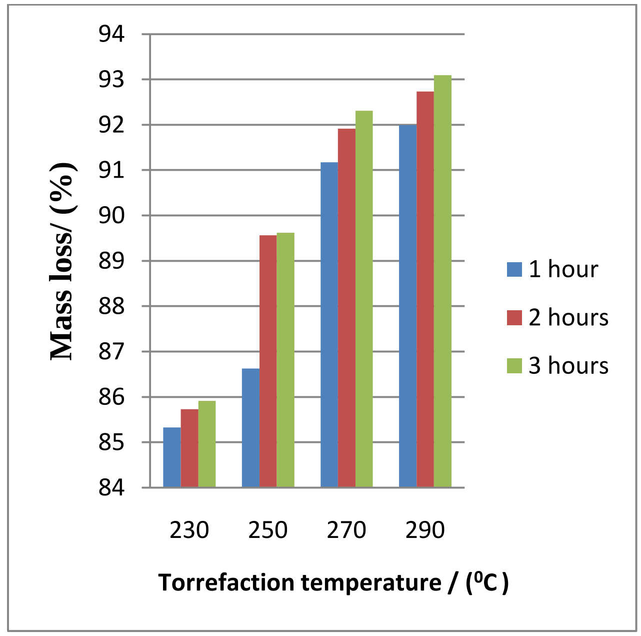


Fig.2 Mass loss of elephant grass at different torrefaction temperature and residence time

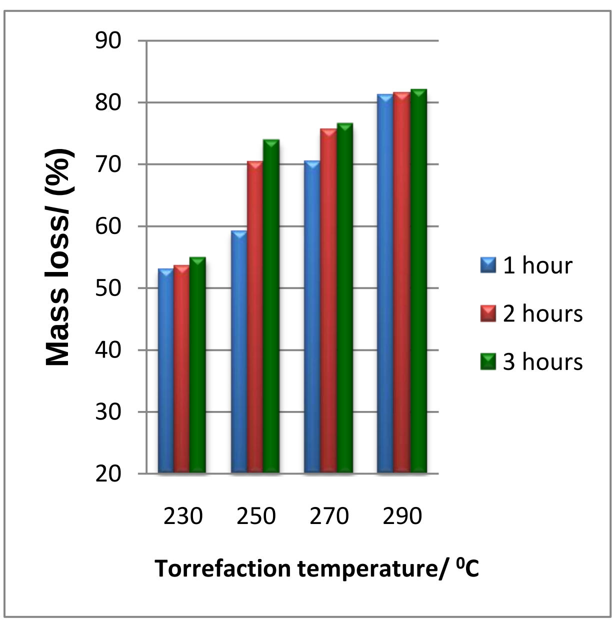


Fig. 3 Mass loss of palm wastes at different torrefaction temperature and residence time

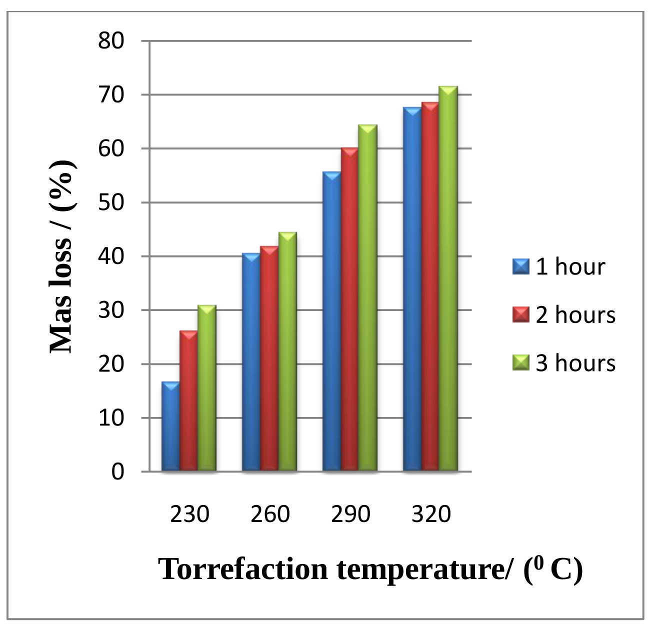


Fig.4 Mass loss of sawdust at different torrefaction temperature and residence time

One of the main benefits of the torrefaction process is that it eventually leads to the complete drying of the biomass and torrefied biomass is also known to be less prone to moisture absorption [19]. Hydrophobicity is conferred to the biomass due to the breaking of its OH bonds during the torrefaction process and its inability for hydrogen bonding [5]. Following torrefaction, char and volatiles are obtained as end-products. It has been reported that mass loss gives an indication of the impact of torrefaction on a particular biomass [1]. The mass loss occurring can be mainly attributed to the degradation of the hemicellulose structure producing volatiles [1, 19]. Chen and Kuo (2011) observed that at a temperature of 260 ^{0}C 37.98 wt% of hemicellulose were degraded while at 290 ^{0}C 58.33 wt% of hemicellulose were decomposed. Temperature and residence time significantly affects the torrefaction process [5].

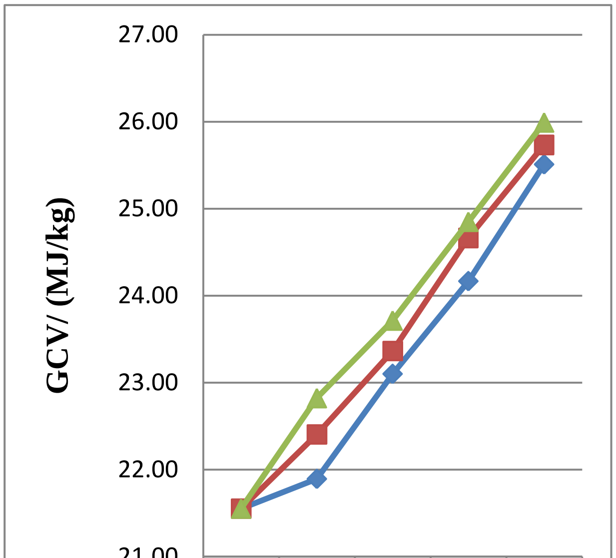
Figures 1, 2, 3 and 4 demonstrate the relationship between mass loss, torrefaction temperatures and residence times of CTL, Elephant grass, Palm wastes and sawdust respectively. As the temperature and residence time was increased, a rise in mass loss was experienced. From Figure 1, it was observed that for a residence time of 1 hour, as the temperature increased from 230 ^{0}C to 290 ^{0}C, the mass loss in CTL also increased from 71.1 to 83.4 %; at 2 hours residence time, the mass loss varied from 74.9 to 86.0 % while at 3 hours residence time, variations in mass loss from 76.2 to 89.1 % were observed. Similarly, in Figure 2, as the temperature rose from 230 ^{0}C to 290 ^{0}C for a residence time of 1 hour, noticeable mass losses were observed in the elephant grass species ranging from 85.3 % to 92.0 %. The rise in residence time from 1 to 3 hours at temperatures of 200 ^{0}C, 230 ^{0}C, 250 ^{0}C and 290 ^{0}C brought about increases in the mass loss from 85.3 % to 85.9 %, 86.6 % to 89.6 %, 91.2 to 92.3 % and 92.0 to 93.1 % respectively.Likewise, in Figure 3,a variation in temperature from 230 ^{0}C to 290 ^{0}C for 1 hour caused an increase in the mass loss of the palm wastes from 53.0 % to 81.2 %. At 230 ^{0}C, an elevation in residence time from 1 to 3 hours caused mass losses to increase from53.6 % to 54.8 %. From Figure 4, it was observed that at a residence time of 1 hour, as the temperature augmented from 230 ^{0}C to 290 ^{0}C, the mass loss in the sawdust increased from 16.5 to 37.6 %. For residence times of 1, 2 and 3 hours, the mass loss are as follows: at 230 ^{0}C, 16.5 %, 25.9 %, 30.7 %; at 250 ^{0}C ,40.4 %, 41.7 % and 44.2 %; at 270 ^{0}C, 55 %, 60% and 64.3 %; at 290 0C, 67.6%, 68.5 % and 71.4 %.

A rise in temperature and residence time brings about a decrease in the solid bio-coal yielddue to decomposition of the lignocellulosic structures in the biomass producing more volatiles [17]. Similar trends for mass loss at different torrefaction conditions for oven dried E.grandis, E.saligna, C.citrioda.samples were observed [1].

During the torrefaction process, drying of biomass occurs at temperatures of 100 to 150 ^{0}C [19]. From experiments, it was determined that when the different biomass CTL, palm wastes, elephant grass and sawdust were dried at a temperature of 105 ^{0}C, the mass loss due to moisture was 63.53 %, 52.89 %, 84.44 % and 14.80 % respectively. Further increase in temperature from 150 to 200 ^{0}C caused depolymerisation and degradration of the shortened polymer structure within the solid structure of the biomass [19]. At temperatures greater than 200 ^{0}C, the biomass started to decompose liberating volatiles and leaving behind a solid product known as char [5]. Thermal decomposition of the chemical compounds present in biomass such as hemicelluloses and celluloses cause mass losses and since hemicelluloses is less thermally, it is more easily degraded [1]. Rising temperatures lead to a decrease in solid bio-char yield [29]. The loss in mass was greater at temperatures higher than 250 ^{0}C. This may be attributed to the higher reactivity of hemicellulose at temperatures greater than 250 ^{0}C [17].

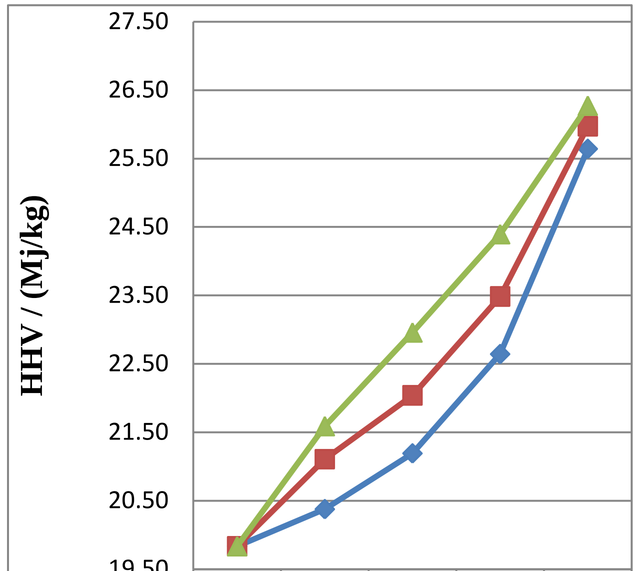
From Figures 1,2,3 and 4 it can be deduced that the mass losses for the different biomass are dissimilar. The mass loss was caused mainly by the moisture loss and devolatisation in the biomass. A rise in temperature gives rise to a decrease in the mass yield, oxygen content and volatiles but an increase in the carbon content [28]. At a temperature of 230 ^{0}C and residence time of 1 hour, elephant grass has the highest mass loss of 85.3 % followed by CTL with a mass loss of 71.03 % and palm wastes with a mass loss of 53.0 %. From Table 4.1, it can be deduced that elephant grass has higher moisture content than CTL whose moisture content is higher than that of palm wastes (52.89 %). Since the raw material used for the torrefaction experiments were on a wet basis, this explains that the moisture content of the samples influence the percentage mass. Another factor responsible for the difference in the mass of the 4 different biomass is the lignocellulosic content which varies for the different biomass.

3.2 Calorific value at different torrefaction temperature and residence time



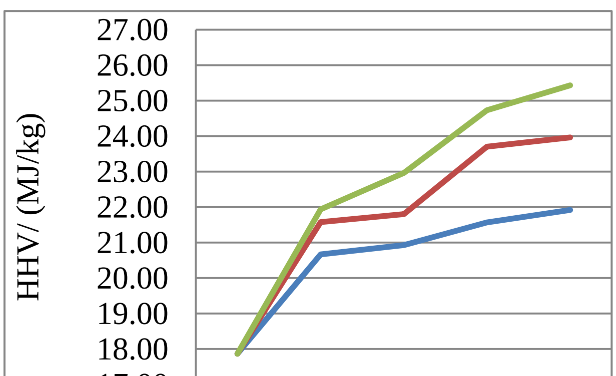
	raw	230	250	270	290
1 hour	21.55	21.89	23.10	24.17	25.51
2 hours	21.55	22.41	23.36	24.66	25.73
3 hours	21.55	22.82	23.71	24.85	25.99

Fig. 5GCV change in CTL at torrefaction temperature and residence time



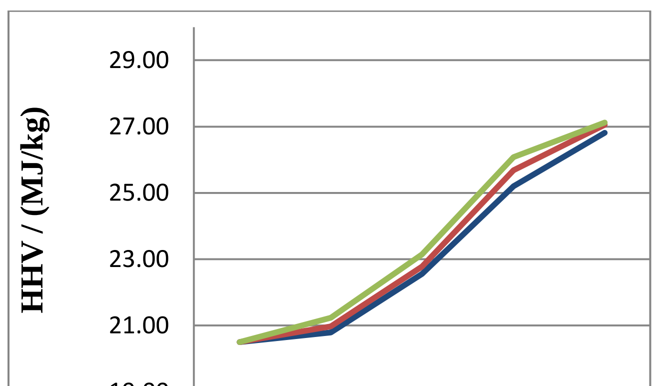
	raw	230	250	270	290
1 hour	19.84	20.38	21.19	22.64	25.64
2 hours	19.84	21.11	22.04	23.48	25.97
3 hours	19.84	21.59	22.96	24.39	26.27

Fig. 6 GCV variation in palm wastesat torrefaction temperature and residence time



	raw	230 0C	250 0C	270 0C	290 0C
1 hour	17.87	20.66	20.92	21.56	21.91
2 hours	17.87	21.57	21.80	23.70	23.96
3 hours	17.87	21.94	22.96	24.72	25.43

Fig. 5 Energy changes in elephant grass at different torrefaction temperature and residence time



	raw	230 0C	250 0C	270 0C	290 0C
1 hour	20.50	20.79	22.55	25.20	26.82
2 hours	20.50	20.98	22.78	25.68	27.06
3 hours	20.50	21.23	23.15	26.08	27.12

Fig. 6 Energy changes in sawdust at different torrefaction temperature and residence time

The calorific value relates to the energy released during the burning of fuel in the presence of air. The gross calorific value represents the maximum amount of energy recoverable from the biomass. A rise in the calorific value indicates an improvement in the energy content of the torrefied biomass compared to the raw biomass [1]. One of the major challenges faced by biomass for its potential use as a fuel is its low calorific value. The torrefaction process helps to enhance the energy content of the fuel.

The relationship between the calorific value, torrefaction temperature and residence time for CTL, palm wastes, elephant grass and sawdust.is depicted in Figures 6, 7, 8 and 9 respectively.Improvements in the energy content of:CTL from 21.89 MJ/kg to 25.51 MJ/kg; Palm wastes from 20.38 to 25.64 MJ/kg; elephant grass from20.66 to 21.91 MJ/kg; sawdust from 20.79 to 26.82 MJ/kg have been observed as torrefaction temperature was increased from 230^0C to 290^0C for a residence time of 1 hour.The heating value of the biomass was observed to increase with the torrefaction temperature. This can be explained by the decrease in the oxygen to carbon ratio which is caused by the degradation of the lignocellulosic material in the palm wastes [15]. Additionally, an increase in residence time also improved the calorific values of CTL, palm wastes, elephant grass and sawdust. Changes in the calorific value at a temperature of 270 ^{0}C and for an increase in residence time from 1 to 3 hours were noted as follows: CTL, 24.17 to 24.85 MJ/kg; palm wastes, 22.64 to 24.39 MJ/kg; Elephant grass, 21.56 to 24.72 MJ/kg; sawdust, 25.20 to 26.08 MJ/kg.

Similar trends have been obtained with different biomass such as *E.Saligna* and *E.grandis* and *C.citriodora*[1]. The increase in calorific value with rise in temperature at specific residence time can be explained by the fact that during torrefaction, carbon monoxide and carbon dioxide are formed due to carboxylation reactions and splitting of the acetyl group present in the xylan chain in the biomass [21, 24]. The carbon dioxide formed reacts with the char formed during the thermal degradation of the sawdusts producing more carbon monoxide [15]. The carbon dioxide and carbon monoxide thus liberated causes removal of oxygen from the solid char thus decreasing the oxygen to carbon ratio in the torrefied sawdust and leaving behind a higher calorific value solid char [15]. As the torrefaction temperature and residence time is increased, an increase in fixed carbon and a decrease in volatiles and oxygen contentwerenoted for different varieties of biomass thus increasing its suitability for energy production [1,13]. During fuel combustion, the carbon in the fuel is mainly responsible for the exothermic reaction occurring while the oxygen present has an endothermic role and a higher torrefaction temperature leadsto a higher Carbon and lower Oxygen content [9].

Experimentation performed on Wheat straw revealed that at torrefaction temperatures of 230, 250, 270 and 290 ^{0}C and residence time of 30 minutes, the heating value of the torrefied biomass were 19400, 19800 and 22600 kJ/kg [6]. Likewise, the calorific values of willow at 230, 250, 270 and 290 ^{0}C at a residence time of 30 minutes were determined to be 20200, 20600, 21400 and 21900 kJ/kg respectively [6]. Torrefying Reed canary grass at 250, 270 and 290 ^{0}C for a period of 30 minutes resulted in heating values of 20000 kJ/kg, 20800 kJ/kg and 21800 kJ/kg respectively [6]. Chen *et al*., (2011) reported values of: 23.62 MJ to 28.08 MJ/kg for bamboo torrefaction; 23.71 MJ/kg to 29.64 MJ/kg for willow torrefaction at a 1 hour residence time. Untreated pine and pine torrefied at 230 ^{0}C, 260 ^{0}C and 280 ^{0}C had the following energy values : 20.2, 20.37, 20.45 and 21.70 MJ/kg respectively [20]. However in another study, heating values of 18.46, 22.87, 25.77 and 28.00 MJ/kg for untreated Banyan and Banyan samples torrefied for 1 hour at temperatures of 230 ^{0}C, 260 ^{0}C and 290 ^{0}C were reported [9]. The difference in HHV can be explained by the difference in lignocellulosic content of the different biomass.

At temperatures of 220, 250 and 300 ^{0}C,calorific values of torrefied Mesocarp fibreswere reported as 19.03, 19.24 and 22.17 MJ/kg respectively [25] which are than lower those reported in Figure 6. This can be attributed to the difference in biomass species, physical properties of the biomass and its harvesting season. The palm species used in the current study is utilised for the production of palm hearts in Mauritius which is used for culinary purposes and exportation while that used in Uemera*et al*. (2010) is a species grown in Malaysia specifically for oil production. Furthermore, the palm wastes consisted of only trunks and fronds which had a higher woody content than the mesocarp fibre and kernel shell. Moreover,the heating value of the raw palm biomass had been determined on a dry basis and was found to be 19.84 MJ/kg. In contrast, in a study performed on palm wastes, heating values of 18.8 MJ/kg and 20.1 MJ/kg for mesocarp fibre and kernel shell were reported respectively [25].

Table 1: Enhancement in HHV of the different biomass at different conditions

Enhancement in HHV				
		Torrefaction residence time		
Biomass	**Torrefaction temperature**	**1 hours**	**2 hours**	**3 hours**
CTL	230 ^{0}C	1.02	1.04	1.06
	250 ^{0}C	1.07	1.08	1.10
	270 ^{0}C	1.12	1.14	1.15
	290 ^{0}C	1.18	1.19	1.21
Elephant	230 ^{0}C	1.16	1.21	1.23

grass				
	250 ^{0}C	1.17	1.22	1.29
	270 ^{0}C	1.21	1.33	1.38
	290 ^{0}C	1.23	1.34	1.42
Palm wastes	230 ^{0}C	1.03	1.06	1.09
	250 ^{0}C	1.07	1.11	1.16
	270 ^{0}C	1.14	1.18	1.23
	290 ^{0}C	1.29	1.31	1.32
Sawdust	230 ^{0}C	1.01	1.02	1.04
	250 ^{0}C	1.10	1.11	1.13
	270 ^{0}C	1.23	1.25	1.27
	290 ^{0}C	1.31	1.32	1.32

The enhancement in calorific value was calculated by taking the ratio of the gross calorific value at the specified temperature and time to that of the of the raw biomass sample. From the Table 1, enhancement ratios in the energy content of the torrefied biomass were found to vary from 1.02 to 1.34 depending on the torrefaction temperature and the residence time of the biomass. It was observed that as the torrefaction temperature was increased, the enhancement ratio increased accordingly due to an increase in the energy in the pre-treated biomass. Likewise, with increases in residence time, the energy enhancements were also observed. At a temperature of 290^{0}C and following 1 hour of torrefaction, the enhancement of HHV for CTL was determined to be 1.18. In the case of palm wastes, at a temperature of 230 ^{0}C, for residence times of 1, 2 and 3 hours, the GCV enhancement increased from 1.03 to 1.06 to 1.09 respectively. When the torrefaction temperature is increased from 230 ^{0}C to 290 ^{0}C for a residence time of 1 hour, the enhancement is however more significant. This is because at lower temperatures the hemicellulose content is degraded but temperatures higher than 250 ^{0}C initiates degradation of the cellulose and lignin content as well [9]. Enhancement ratios in the energy content of the torrefied elephant grass were found to vary from 1.16 to 1.42 depending on the torrefaction temperature and the residence time of the biomass.At a temperature 290^{0}C and following 1 hour of torrefaction, the enhancement of HHV was determined to be 1.23. However, Chen *et al*. (2011) reported values of 1.40, 1.32 and 1.46 respectively for the same conditions with the biomass bamboo, banyan and willow. The lower value recorded can be attributed to the lignocellulosic content of the biomass owing to the fact that the elephant grass was harvested after 10 months and was not a fully mature plant.

3.3 Energy to mass loss characteristics

The Energy gain/mass loss for the four different biomass under study (Sawdust, Elephant grass, CTL and palm wastes) were evaluated at different torrefaction temperatures and residence time. From Table 2,it was observed that the highest energy gain to mass loss ratio for sawdust was obtained at torrefaction conditions of: 230 ^{0}C, 3 hour followed by 230 ^{0}C, 2 hours; 250 ^{0}C, 2 hours; 250 ^{0}C, 3 hours and 270 ^{0}C, 3 hours. In the case of Elephant grass, the utmost energy gain/mass loss can be specified at the following condition: 290 ^{0}C, 1 hour; 270 ^{0}C, 1 hour and 290 ^{0}C 2 hours. For CTL, the greatest energy gain to mass loss are at 250 ^{0}C, 1 h; 230 ^{0}C 1 hour; and 230 ^{0}C, 2 hours. As for palm wastes, the highest mass loss to energy loss are obtained at the following conditions: 250 ^{0}C 1 hour, 230 ^{0}C, 3 hours; 250 ^{0}C 2 hours; 230 ^{0}C, 1 hour.

Table 2: Energy gain versus mass loss of different biomass at different torrefaction conditions

Energy gain / mass loss					
Residence time	**Torrefaction temperature/ ^{0}C**	**Sawdust**	**Elephant grass**	**CTL**	**Palm wastes**
1 HOUR	**230**	6.39	-26.40	27.73	22.72
	250	15.72	-0.49	32.35	26.88
	270	15.37	13.05	14.63	16.44
	290	17.42	13.60	17.91	18.24
2 HOURS	**230**	20.50	-21.94	19.97	21.55
	250	19.86	9.92	18.35	19.16
	270	18.68	11.58	17.35	18.04
	290	17.74	12.56	18.92	18.94
3 HOURS	**230**	20.50	-20.04	17.73	19.17
	250	19.59	7.73	19.37	19.63
	270	18.86	11.20	19.99	19.81
	290	17.88	11.86	19.93	19.65

In this study, the energy gain to mass loss ratio was used as an indicator for the determination of the optimum torrefaction conditions for the different biomass with the highest ratio representing the best condition. A high energy gain to mass loss ratio would mean that energy recovered in the char is higher than the mass loss in the volatiles which also contain energy. The optimal condition conditions are summarised in Table 3. In the case of palm wastes, both a temperature of 250 ^{0}C 2 h and 230 ^{0}C 3 hours gave the same mass to energy ratio. However the torrefaction condition with a lower residence time was chosen since a higher residence time would increase the energy requirement of the process. It is observed that optimum conditions obtained for each biomass is different.

Table 3: Optimum conditions for torrefaction of each of the different biomass

Biomass	Torrefaction temperature/ (^{0}C)	Residence time/ (hours)	GCV / (MJ/kg)
Saw dust	230	2	20.98
Elephant grass	290	1	21.91
CTL	250	1	23.10
Palm wastes	250	1	21.19

3.4 GHG avoided

The torrefied biomass can be potentially co-fired with coal in existing power plants thus displacing a significant quantity of coal. The amount of coal displaced and greenhouse gas avoided by the different biomass torrefied at their optimum torrefaction conditions are shown in Table 4.

Table 4: Amount of coal displaced per kg of torrefied biomass

Biomass	Torrefaction temperature/ (^{0}C)	Residence time/ (hours)	Amount of coal displaced per kg biomass/ kg	Electrical energy from coal displaced/ kWh_e	GHG avoided/ (g CO_2)
Saw dust	230	2	0.776	1.34	1956.4
Elephant grass	290	1	0.811	1.47	2146.2
CTL	250	1	0.855	1.63	2379.8
Palm wastes	250	1	0.785	1.37	2000.2

From Table 4, it can be observed that burning 1 kg of sawdust torrefied at 2 hours at a temperature of 230 ^{0}C will avoid 19.56.4 g CO_2 by displacing 0.776 kg of coal. Amongst the different biomass, the GHG emissions avoided by torrefied CTL is highest due to its higher energy content and hence ability to displace a relatively larger amount of carbon.

It can be inferred that burning torrefied biomass will help offset the use of coal and will considerably reduce greenhouse gas emissions.

4.0 CONCLUSION

Pre-treatment technologies can however help valorise biomass as a source of fuel. Torrefaction of four diverse biomass available in Mauritius involving elephant grass, cane tops and leaves, palm trunk wastes and sawdust have been considered in this study. The biomass were subjected to different temperatures (ranging from 230 to 290 ^{0}C) and residence times (1 to 3 hours). During the process, major changes in mass loss were reported as the torrefaction temperature and residence time was increased. The mass loss was however varied for the different biomass depending on their composition. Likewise, a rise in temperature and residence time also brought about improvements in the energy content of the fuel. However, mass loss can also be associated with a loss in energy since the volatiles given off contain significant amount of energy. Thus, in certain cases, energy changes due to mass loss overpowered the energy gain due to torrefaction. Hence a ratio of energy gain to mass loss was calculated and the conditions giving the highest ratio were considered as the optimum torrefaction conditions for the different biomass studied and were as follows: CTL, 250 ^{0}C, 1 hour; elephant grass, 290 ^{0}C, 1 hour; sawdust, 230 ^{0}C, 2h and palm wastes, 250 ^{0}C, 1 hour. An evaluation of the amount of coal displaced and subsequently the amount of greenhouse gas avoided by the use of torrefied biomass was conducted.

The result and discussion from this study will be helpful for those willing to use torrefied CTL, palm wastes, wood wastes and elephant grass as a source of solid fuel. The potential use of biocoal produced from biomass through the torrefaction process is very solicited in Europe and the technology is under research and development in various countries. Torrefaction products can be projected as being a clean source of energy capable of offsetting large amounts of coal and promoting the use of biomass as a fuel. Moreover, due to its reduced carbon dioxide emission, torrefaction projects can be considered for emission reductions via the Clean Development Mechanism.

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Biomass Gasification Parametric Study; Gibbs Equilibrium Model

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Abstract:

Biomass gasification is a complex thermochemical process whose performance in terms of syngas yield, composition, and quality is dependent not only on the gasifier type but also on operational and external factors. Some of these factors include: feedstock type and size, operating temperature, oxidizer type, equivalence ratio, bed additives, and materials' moisture content. The process is dependent further on the intricate properties of biomass. Although biomass plant materials have cellulose, hemicellulose and lignin as their main components, the average proportions of these constituents are varying between species and within the species themselves. This is among the challenges facing those engaged in equipment selection and design. However, the application of modern modelling tools is useful in undertaking parametric studies to the processes before engaging in fabricating the plants. The Gibbs free energy minimization approach has been widely utilized by researchers. This is because the equilibrium models are independent of design of the gasifier and can predict thermodynamic limits of gasifier performance under different conditions. In the present work, coffee husks were utilized to undertake a parametric study to a downdraft biomass gasifier. The study results showed a strong correlation of temperature to the high yield of carbon monoxide and hydrogen. When gasification air temperature was preheated from 25 to 340, 500, and 700°C, carbon monoxide concentration (vol. %) in the syngas increased from 23.80 to 24.70, 25.70, and 26.90% respectively. In the same range of preheating the respective hydrogen concentration increased from 27.80 to 28.80, 29.30, and 29.90%.

Keywords: Biomass Gasification; Coffee Husks; Gibbs Free Energy; Temperature

1. INTRODUCTION

1.1 Biomass Gasification

Gasification is a thermochemical process in which a combustible gas is produced by blowing a limited amount of air into a bed of coarse, particulate, carbonaceous fuel such as coal, biomass, charcoal, densified biomass or crop residue. The combustible gases are carbon monoxide, hydrogen and non-condensable hydrocarbons, which are mostly methane. A small percentage of the hot gas as it comes from the gasifier contains combustible tar vapours and other undesired products like particulates, water vapour, nitrogen and carbon dioxide. Biomass gasification can be compared to stoichiometric biomass combustion by using equivalence ratio (ER), which is expressed in Eq. 1. From the equation, the numerator is the air consumed per unit of dry biomass in gasification while the denominator is the air consumed per unit of dry biomass in complete combustion under stoichiometric conditions. The equivalence ratio expresses the variation of the ratio of air (oxidizer) to the biomass feedstock. The range of ER for ideal and theoretical gasification is 0.19 – 0.43 [1-3].

$$ER = \frac{(Weight\ \ of\ \ air)/(weight\ \ of\ \ biomass)}{(Stoichiometric\ \ air)/(biomass\ \ ratio)} \qquad (1)$$

A detailed classification of gasifiers with respect to reactor design and reaction media is accounted by [2, 4]. The gasifiers are commonly classified into fixed bed and fluidized. Other gasifier classifications are moving bed, rotary kiln and cyclonic reactor. The performance characteristics of the different gasifiers are shown in Table 1. It can be generalized that due to their higher level of gas quality and their scalability, fluidized bed gasifiers are usually applied for capacities higher than 5 MW_{th} compared to fixed bed gasifiers that are suitable for small scale ranges.

1.2 Biomass Materials

Biomasses are composed of cellulose, hemicelluloses, lignin, extractives (terpenes, tannins, fatty acids, and resins), water and mineral matter (inorganic materials). The concentration of each class of compound varies from specie to specie and within the same specie it varies with the habitat, age and along the trunk, branches, top and roots

[5-7]. Due to the carbohydrate structure, biomass is highly oxygenated compared to conventional fossil fuels that include liquids and coals. To illustrate this, Jenkins et al. [8] showed that the atomic oxygen-to-carbon (O:C) ratio for biomass materials ranges from 0.38 to 0.86 whereas the respective ratio for coals ranges between 0 and 0.36. A similar study by the Authors [9] as summarized in Fig. 1 revealed the O:C ratio for tropical biomasses to range between 0.48 and 0.94. The high O:C ratio for biomass is detrimental to their energy content since materials rich in oxygen are associated with irreversibility leading to their low heating value [10-11].

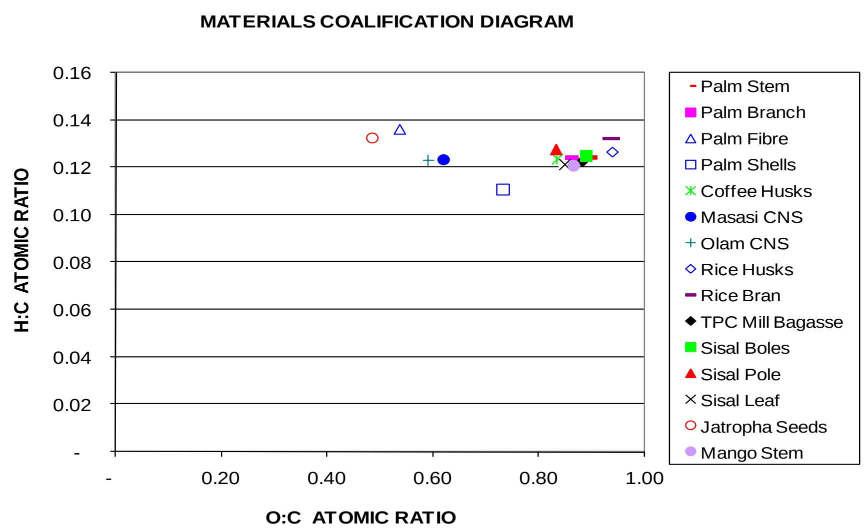


Fig. 1 Coalification diagram for selected tropical (Tanzania) biomasses

The exhibited variations in the characteristics and volume of the biomass components and differences in cellular structure make biomass heavy or light, stiff or flexible, and hard or soft. Further, the differences in the growing location and condition will influence the biomass properties, which include the inorganic materials content. Consequently, different biomasses behave differently when subjected to thermochemical processes like gasification. To illustrate the perceived differences, Figs 2 – 3, present thermogravimetry (TG) and derivative thermogravimetry (DTG) thermograms as obtained from a thermogravimetric type NETZSCH at a heating rate of 10 K/min in inert nitrogen atmosphere. It can be observed from Fig. 2 that the mass loss due to devolatilization for the sunflower stalks, jatropha husks, rice husks, and palm stem were 83.81, 72.60, 64.36, and 52.25% respectively whereas the respective residue mass were 7.91, 13.68, 27, and 44.20%. From these findings it can be inferred that the higher the volatiles release the less the residue mass.

Table 1 Comparizon of gasifiers' performance characteristics [4]

GASIFIER TYPE		TEMPERATURE, °C		TARS	PARTICULATES	TURN-DOWN	SCALE-UP ABILITY	CURRENT CAPACITY (T/H)	Mw_e	
		REACTION	EXIT						MIN.	MAX.
Fixed bed	Downdraft	1000	800	v. low	moderate	good	poor	0.5	0.1	1
	Updraft	1000	250	v. high	moderate	good	good	10	1	10
	Cross-current	900	900	v. high	high	fair	poor	1	0.1	2
Fluid bed	Single reactor	850	800	fair	high	good	good	10	1	20
	Fast fluid bed	850	850	low	v. high	good	v. good	20	2	50
	Circulating bed	850	850	low	v. high	good	v. good	20	2	100
	Entrained bed	1000	1000	low	v. high	poor	good	20	5	100
	Twin reactor	800	700	high	high	fair	good	10	2	50
Moving bed	Multiple hearth	700	600	high	low	poor	good	5	1	10
	Horizontal moving bed	700	600	low	low	fair	fair	5	1	10
	Sloping hearth	800	700	high	low	poor	fair	2	0.5	4
	Screw/auger kiln	800	700	high	low	fair	fair	2	0.5	4
Other	Rotary kiln	800	800	high	high	poor	fair	10	2	30
	Cyclone reactors	900	900	low	v. high	poor	fair	5	1	10

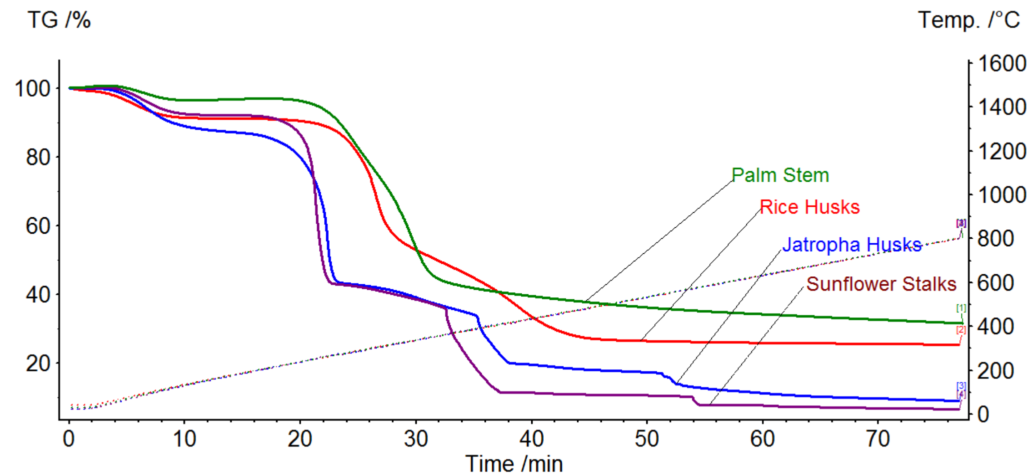


Fig. 2 TG thermograms for palm stem, rice husks, jatropha husks, and sunflower stalks

From the results of DTG thermograms, the biomass materials' characteristic peak rates of mass loss are spatial. The first peaks due to hemicellulose release for sunflower stalks, jatropha husks, and palm stem were -30.67, -23.82, and -4.77%/minute. The respective temperature where the hemicellulose peaks appeared was 253.11, 262.73, and 284.76 °C. On the other hand, the rice husks exhibited one peak only (hemicellulose and cellulose peaks merged) at 301.91 °C with a value of -11.09%/minute. By exhibiting higher peaks at relatively lower temperature the sunflower stalks and jatropha husks are more thermally reactive than rice husks and palm stem.

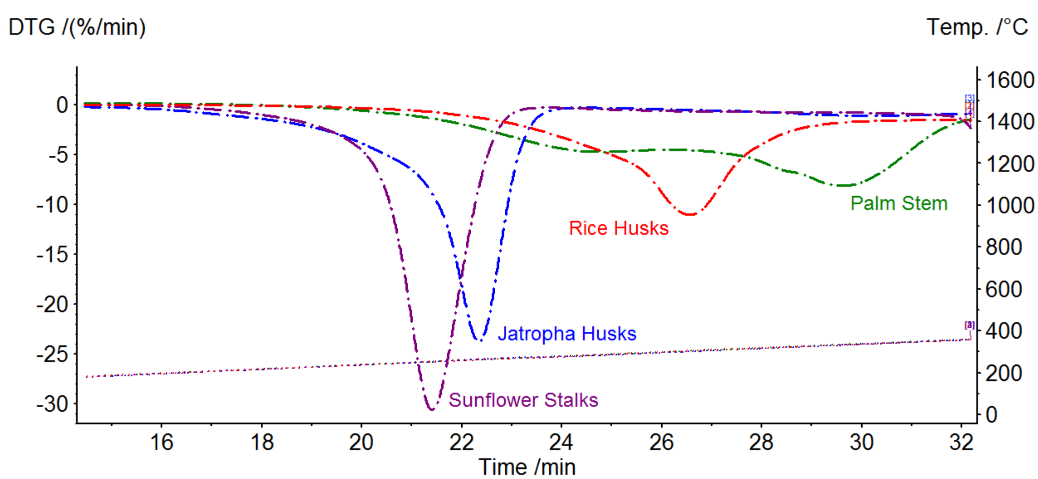


Fig. 3 DTG for palm stem, rice husks, jatropha husks, and sunflower stalks

2. GIBBS EQUILIBRIUM MODEL

The mass fractions of carbon (C), hydrogen (H), and oxygen (O) in the biomass material are obtained through its ultimate analysis and its simplified formula is shown in Equation 2. The global gasification reaction of biomass material is therefore presented in Equation 3.

$$C_x H_y O_z \tag{2}$$

$$C_x H_y O_z + j(0.21 O_2 + 0.79 N_2) + \alpha H_2O \rightarrow aCO + bCO_2 + cH_2 + dH_2O + eCH_4 + fC + gN_2 \tag{3}$$

Where *j* is the molar quantity of air used in the gasification process; α is the molar quantity of water per mole of biomass; and *a, b, c, d, e, f,* and *g* are the coefficients of the respective products (CO, CO_2, H_2, H_2O, CH_4, C, and N_2) of the gasification process. The coefficients are obtained from the mass balance of the global gasification reaction (3):

Carbon balance: $x = a + b + e + f$ (4)

Hydrogen balance: $y + 2\alpha = 2c + 2d + 4e$ (5)

Oxygen balance: $z + \alpha + 2 * 0.21 j = a + 2b + d$ (6)

Nitrogen balance: $2 * 0.79 j = 2g$ (7)

The concept of thermodynamic equilibrium of the gasifying process need be considered for developing the additional equations. This will involve main reactions under the gasification process. The enthalpy variation for a given reaction at a given temperature is calculated from Equation (8) as:

$$\Delta H_T^o = J + R(\Delta A.T + \Delta.B.\frac{T^2}{2} + \Delta C.\frac{T^3}{3} - \frac{\Delta D}{T}) \tag{8}$$

Where, *A, B, C*, and *D* are constant characteristic of particular species as tabulated in thermodynamics tables. Equation (8) offers a general method for calculating the heat capacity of a given reaction as a function of temperature. From the equation, the integration constant *J* can be established since the values of standard heat of formation at 298.15K are tabulated in thermodynamic tables.

Assuming that carbon remains in equilibrium, the three main reactions taking place during the gasification process are Boudouard, methanation, and primary water-gas reaction, represented respectively in Equations (9 – 11):

$$C + CO_2 \rightarrow 2CO \tag{9}$$

$$C + 2H_2 \rightarrow CH_4 \tag{10}$$

$$C + H_2O \rightarrow CO + H_2 \tag{11}$$

From the general gasification reaction (3) and utilizing the product gas coefficients (*a, b, c, d, e, f,* and *g*), the equilibrium constant for reactions (9 – 11), respectively k_1 – k_3, are established from the mixture partial pressures as:

$$k_1.n.b - a^2 p = 0 \tag{12}$$

$$k_2.c^2.p - e.n = 0 \tag{13}$$

$$k_3.d.n - a.p.c = 0 \tag{14}$$

Here, it is assumed that there are *n* moles of the gaseous products having total pressure *P* and that the partial pressure of carbon is zero. Consequently, the system of equations required to be solved for obtaining the equilibrium gas composition will constitute of mass balance equations (4 – 7) and equilibrium constant equations (12 – 14). In this work, a code written in Engineering Equation Solver (EES) environment was developed. EES provides built-in mathematical and thermophysical property (for example JANAF table and transport properties of gases) functions, which eases engineering calculations. The input variables of the code include thermodynamic properties of the chemical species considered in the model and biomass material's composition.

3. FINDINGS AND DISCUSSION

3.1 Biomass Material

The biomass material utilized under this study was the coffee husks, which was obtained from one of Tanzania's coffee processing plant located in Moshi – known as Tanganyika Coffee Curing Company (TCCCo). From the coffee husks ultimate analysis presented in Table 2, the simplified coffee husk formula is $CH_{1.47}O_{0.63}$.

Table 2 Coffee husks proximate and ultimate analysis (dry basis)

PROXIMATE ANALYSIS		ULTIMATE ANALYSIS	
Ash content (550 °C), %	2.50	Carbon (C), %	49.40
Volatiles content, %	83.20	Hydrogen (H), %	6.10
Fixed carbon, %	14.30	Oxygen (O), %	41.20
HHV, MJ/kg	18.34	Nitrogen (N), %	0.81
		Sulphur (S), %	0.07
		Chlorine (Cl), %	0.03

3.2 Syngas Evolution Characteristics with Temperature

The details presented in Fig. 4 show that as the gasification temperature increases, the concentration of carbon monoxide (CO) increases until it reaches a maximum value of 23.8% at 700 °C. On the other hand, the concentration of hydrogen (H_2) falls consistently whereas carbon dioxide falls to almost a stable value of 10%. The results on CO and CO_2 evolution characteristics can be explained by the Boudouard ($CO_2 + C \rightarrow 2CO$) reaction, which shows that the CO is produced to the detriment of CO_2.

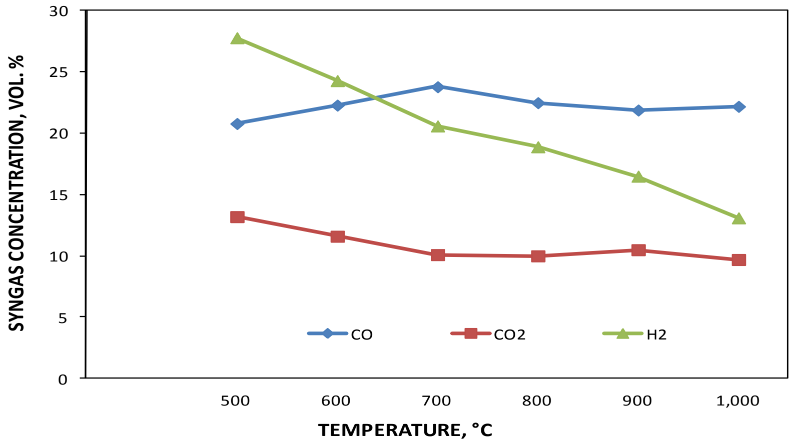


Fig. 4 Syngas evolution characteristics with temperature

3.3 Effects of Steam Injection

Generally, steam injection is more beneficial for H_2-rich syngas production (see Fig. 5). Carbon monoxide is relatively reduced when gasification is done with steam injection. The hydrogen evolution increases since the presence of steam allows the progression of water-gas shift reaction ($CO + H_2O \rightarrow H_2 + CO_2$) and steam reforming of methane ($CH_4 + H_2O \rightarrow CO + H_2$) both of which results in the production of H_2. The water-gas shift reaction consumes CO, whose concentration diminishes.

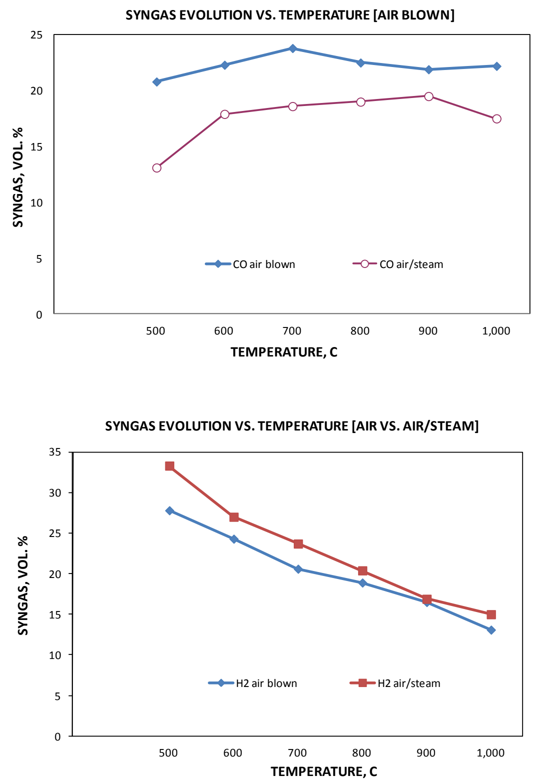


Fig. 5 Effects of steam injection on CO and H_2 evolution characteristics

3.4 Effects of Air Preheating

Air preheating improves the syngas quality since it increases the production of both CO and H_2. When gasification air temperature was preheated from 25 to 340, 500, and 700°C, carbon monoxide peak concentration (vol. %) in the syngas increased from 23.80 to 24.70, 25.70, and 26.90% respectively. The respective peak CO evolution under steam condition increased from 19.50 to 21.30, 22.30, and 23.40% (Fig. 6). In the same range of preheating the respective hydrogen concentration increased from 27.80 to 28.80, 29.30, and 29.90% whereas with steam injection the increments were from 33.30 to 34.50, 35.20, and 36% (Fig. 7). Preheating increases CO and H_2 evolution since it enhances endothermic reactions namely, Boudouard ($CO_2 + C \rightarrow 2CO$) and steam reforming of methane ($CH_4 + H_2O \rightarrow CO + H_2$) that progress well at higher temperature.

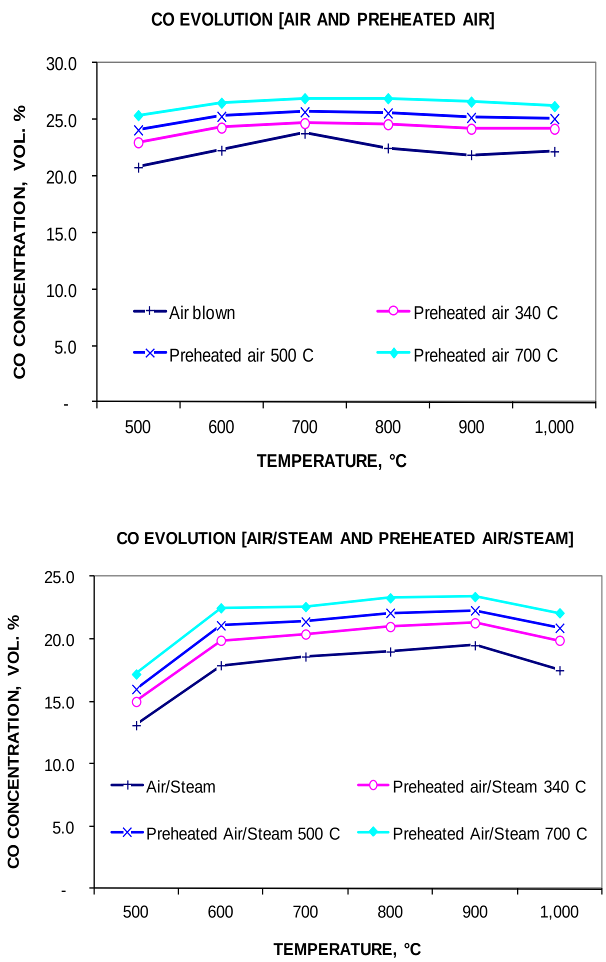
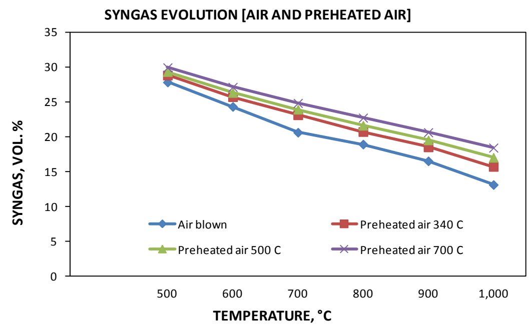


Fig. 6 Effects of air preheating on CO evolution characteristics



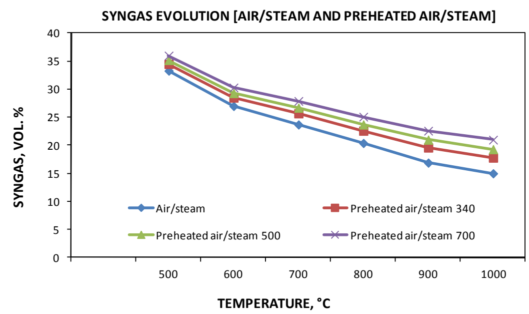


Fig. 7 Effects of air preheating on H_2 evolution characteristics

Since the low heating value (LHV) of a syngas is accounted by the individual syngas components as shown in Eq. 15 [12-14], it is expected that air preheating will also increase the LHV. Furthermore, the cold gasification efficiency of a gasifier (Eq. 16) will simultaneously increase. The variation of LHV and cold gasification efficiency, respectively, are shown in Fig. 8 and 9.

$$LHV = \frac{(30*CO+25.7*H_2+85.4*CH_4+151.3*C_mH_n)*4.2}{1000} MJ/nm^3 \qquad (15)$$

Where, [CO], [H_2], [CH_4] and [C_mH_n] are the molar fractions of carbon monoxide, hydrogen, methane and higher hydrocarbons.

$$Cold\ gas\ efficiency = \frac{LHV\ of\ gas(kJ/Nm^3 \times fuel\ gas\ production\ (Nm^3/kg)}{LHV\ of\ Biomass\ fed\ in\ the\ system\ (kJ/kg)} \qquad (16)$$

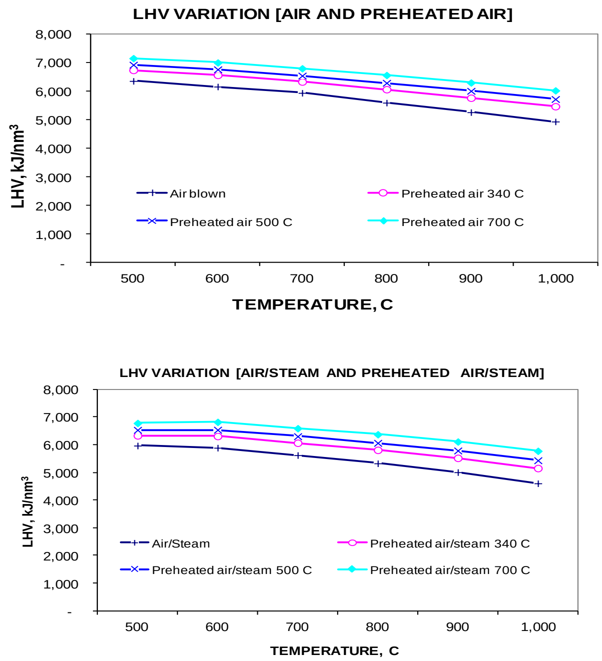


Fig. 8 Effects of air preheating on LHV variation

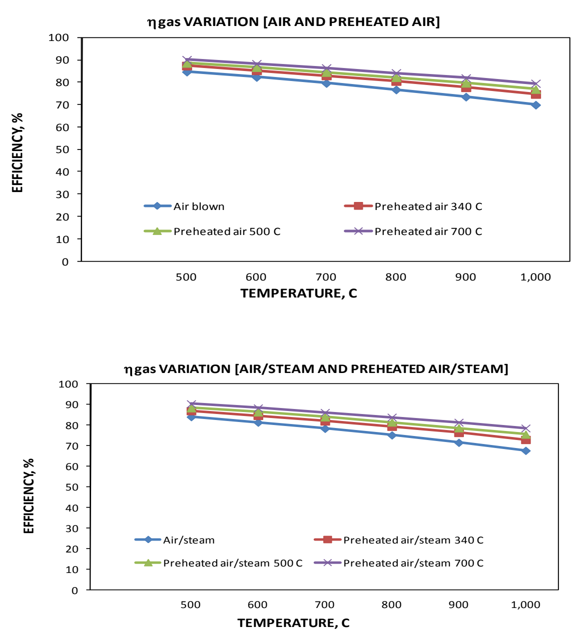


Fig. 9 Effects of air preheating on cold gas efficiency variation

4. CONCLUSION

Biomass gasification is a complex thermochemical process whose performance in terms of syngas yield, composition, and quality is dependent not only on the gasifier type but also on operational and external factors. The process is dependent further on the intricate properties of biomass. In order to contribute to the understanding of this process, the Gibbs free energy minimization model has been utilized under this study. Following are the key findings on the syngas quality and characteristics:

1. As the gasification temperature increases, the concentration of carbon monoxide (CO) in the syngas increases until it reaches a maximum value of 23.8% at 700 °C. On the other hand, the concentration of hydrogen (H_2) falls consistently whereas carbon dioxide falls to almost a stable value of 10%. The results on CO and CO_2 evolution characteristics can be explained by the Boudouard ($CO_2 + C \rightarrow 2CO$) reaction, which shows that the CO is produced to the detriment of CO_2.
2. Generally, steam injection is more beneficial for H_2-rich syngas. Carbon monoxide is relatively reduced when gasification is done with steam injection. The hydrogen evolution increases since the presence of steam allows the progression of water-gas shift reaction ($CO + H_2O \rightarrow H_2 + CO_2$) and steam reforming of methane ($CH_4 + H_2O \rightarrow CO + H_2$) both of which results in the production of H_2. The water-gas shift reaction consumes CO, whose concentration diminishes.
3. Air preheating improves the syngas quality since it increases the production of both CO and H_2. When gasification air temperature was preheated from 25 to 340, 500, and 700°C, carbon monoxide peak concentration (vol. %) in the syngas increased from 23.80 to 24.70, 25.70, and 26.90% respectively. The respective peak CO evolution under steam condition increased from 19.50 to 21.30, 22.30, and 23.40%. In the same range of preheating the respective hydrogen concentration increased from 27.80 to 28.80, 29.30, and 29.90% whereas with steam injection the increments were from 33.30 to 34.50, 35.20, and 36%. Preheating increases CO and H_2 evolution since it enhances endothermic reactions namely, Boudouard ($CO_2 + C \rightarrow 2CO$) and steam reforming of methane ($CH_4 + H_2O \rightarrow CO + H_2$) that progress well at higher temperature.
4. As a result of its enhancement in producing syngas combustible components, air preheating simultaneously increased both the syngas heating value and the gasifier's cold gasification efficiency.

5. ACKNOWLEDGMENTS

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Thermochemical Equilibrium Model and Exergy Analysis for High Temperature Biomass Gasification

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Abstract:

This paper presents the results of the thermochemical equilibrium modelling together with exergy analysis for a biomass gasification. Thermo-chemical equilibrium model was deployed to obtain the molar concentrations of the gaseous species resulting from the high temperature agent gasification (HTAG) process. The method of mass balances and chemical equilibrium was used to obtain the molar concentrations of syngas species of H_2, CO, CO_2, CH_4 and H_2O. To be able to obtain the optimal yields of these, exergy concept was deployed. Optimal efficiences obtained by way of exergy analysis in a thermochemical equilibrium modeling approach was realised. The present study is deploying coconut shells and sugar baggase gasification at different gasification conditions of temperature range from 800 to 1400K and the equivalence ratio from 0.2 to 0.4. The results show that the overall exergetic efficiency was in the range of about 65–85% while the syngas heating values were 3500kJ/kg to 7500kJ/kg.

Keywords: Gasification, Syngas species, High temperature, Equivalence ratio, Exergy

1.0 INTRODUCTION

The conservation of limited supply of fossil fuels and reduction in environmental pollution depends upon the utilization of other indigenous fuel energy sources. This has resulted in the use of biomass as an alternate energy source [1]. Most of biomass materials, especially the agro-wastes have been observed to be potentially attractive feedstocks for energy production. Sugar bagasse and coconut shells are part of agricultural residues which abundant in tropical countries [2]. The worldwide supply of sugar bagasse is about 200 million tonnes per annum whereby there is a potential global energy from this resource of about 3.8×10^9 Gigajoules [3], while the global annual production of coconut in was around 11.9 million tonnes [4]. The processing of these wastes has become a technological issue that has attracted the attention of numerous researchers. Both combustion and landfill use cause environmental pollution problems. Novel disposal technologies are in high demand to provide for more energy efficient and environmentally and economically sound solutions. An alternative to these combustion and landfill methods is the thermochemical gasification technology. Thermochemical gasification of biomass is a well-known technology that seems to be a feasible application and has been developed for industrial applications [5]. The process normally converts biomass materials into gasesous component containing carbon monoxide (CO), hydrogen (H_2), methane (CH_4) and carbon dioxide (CO_2). However, prior to set up the full scale gasifier, it is important to secure the desirable working conditions of the equipment. The analysis required can be obtained by making use of mathematical models that allow prediction of the data needed in full scale equipment. This method is fast and inexpensive compared to other methods such as setting up an experimental rig.

The model development for biomass gasification technologies requires a correct application of thermodynamics tools which rely on first and second laws of thermodynamics. The energy and mass balances method emanating from the first law of thermodynamics makes the energy analysis possible by quantifying energy conversion processes and efficiency of energy conversion in a system process. Further thermodynamics analysis involves the use of the second law of thermodynamic which accounts on qualifying the energy degradation through the process due to dissipation [6]. In using the second law of thermodynamics for gasification process, it is possible to detect the maximum energy available from the system. This approach can be done by the application of the thermodynamic analysis concept of exergy. The concept is based on the second law of thermodynamics which represents another step in the plant systems analysis in addition to those of mass and the enthalpy balances. The aim of the exergy analysis therefore is to identify the magnitudes of exergy losses in order to improve the existing systems, processes or components, or to develop new processes or systems

[7]. The analysis allows one to quantify the loss and efficiency in a process due to the loss in energy quality. For a given set of operating conditions the biomass gasification process can be improved through optimization of the operating parameters and efficiencies.

1. METHODOLOGY

1.1 Gasification Process and Reactions Involved

As a least efficient operating unit in the whole biomass to energy conversion technology chain [8], this work therefore involves the evaluation the thermodynamic efficiency of the modeled gasifier system presented in Figure 1. The operating conditions such as temperature from 800K to higher temperature of 1400K and equivalence ratio (ER) between 0.2 and 0.4 using sugar bagasse from a work by Lugano et al. [2] and coconut shells presented by Tsamba [9] with the following formulas: $CH_{1.42}\ O_{0.65}\ N_{0.0026}$ and $CH_{1.6}O_{0.71}N_{0.0018}$. The following assumptions are considered in the model: The chemical equilibrium between gasifier products is reached and evaluated at atmospheric pressure (1 bar); Ashes are not considered (Small amount 1%); Heat losses are neglected (Adiabaticity) and there are no chars with the exit gasifier products. From the Figure, the biomass material is fed into the gasifier together with the pre-heated air from the preheating equipment, recuperator.

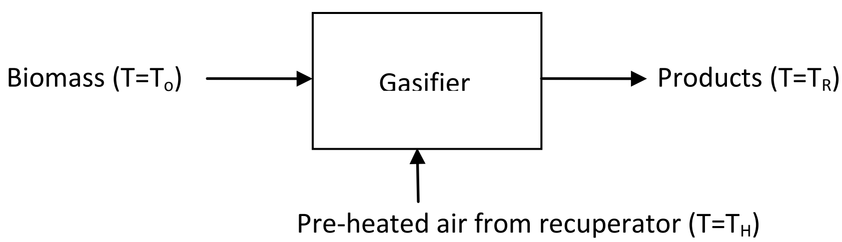


Fig. 1 Schematic diagram of a pseudo-homogenous HTAG

The gasification process taking place in the gasifier, normally involves the following equation:

$$CH_xO_yN_z + wH_2O + m(O_2 + 3.76N_2) \rightarrow$$
$$n_{H_2}H_2 + n_{CO}CO + n_{CO_2}CO_2 + n_{H_2O}H_2O + n_{CH_4}CH_4 + (z/2 + 3.76m)N_2 \quad (1)$$

where x, y, and z are the number of atoms of hydrogen, oxygen, and nitrogen per number of atom of carbon in the feedstock respectively and are derived from the feedstock charaterisation of its chemical composition using a and proximate composition. n_{CO}, n_{CO2}, n_{H2O}, n_{CH4} and n_{H2} are mole concentration of gaseous species species: CO, CO_2, H_2O, CH_4 and H_2; w and m are mole concentrations of water and air. Other chemical reactions which are important in the gasifier as Oxidation, Boudouard, Water gas, Methanation, Water-gas shift, and Methane reforming [10] .

1.2 Expressions for Efficiency Evaluation

(i) Exergic Efficiency

In order to obtain the thermodynamic gasification efficiency (exergy efficiency, η_{ex}), the exergy analysis based on the second law of thermodynamics is used to analyze the thermodynamic efficiencies by evoking equation 2:

$$\eta_{ex} = \frac{\varepsilon_{product}}{\varepsilon_{inputs}} \qquad (2)$$

where $\varepsilon_{product}$ is the exergy of the product, which are the gaseous species and ε_{input} is the exergy of the input material, the biomass.

In evaluating exergy in the absence of nuclear, magnetic, electrical, and surface tension effects, the total exergy of a system (ε) can be divided into four components: physical exergy, kinetic exergy, potential exergy and chemical exergy, each having two parts which are; the thermo-mechanical contribution and the chemical contribution. Thermo-mechanical exergy, or physical exergy, is the maximum amount of work that can be achieved by a state of a substance as it comes into thermal and mechanical equilibrium with the environment. Neglecting kinetic and potential energy contributions, the molar specific physical exergy, ε_{ph} of species at temperature T is defined by Eq. 3:

$$\varepsilon_{ph} = (h - h_o) - T_0 \cdot (s - s_o) \qquad (3)$$

The chemical exergy, ε_{ch} of a gas stream of multiple components can be computed by summation of their partial chemical exergies, as given in Eq. 4:

$$\varepsilon_{ch} = \sum_i \chi_i \varepsilon_{ch,i} + R_o T_o \sum_i \chi_i \ln \chi_i \qquad (4)$$

Where h and s are the molar specific enthalpy and molar specific entropy, and the subscript "o" denotes the state of the environment. χ_i and $\varepsilon_{ch,i}$ are the mole fraction and chemical exergy of individual gas component i respectively, Ro is the universal gas constant and To is the standard temperature.

Hence, by realizing that the biomass enters the gasifier at ambient conditions, only chemical exergy is available in biomass, air do not react therefore shall have no effect on the efficiency value, and the leaving gas from the gasifier shall have the chemical and physical exergy, therefore the exergy efficiency shall result in the expression given in Eq. (5):

$$\eta_{ex} = \frac{\varepsilon_{ch,gas} + \varepsilon_{ph,gas}}{\varepsilon_{ch,biomass}} \qquad (5)$$

(ii) Mole Concentration of Gaseous Species

In order obtain mole concentrations of the gaseuos species from the gasification equation 1, use of first law of thermodynamics in involved where by the analysis of mole balance for the gasification equation is performed and result into the following equations.

Carbon balance: $0 = n_{CO} + n_{CO_2} + n_{CH_4} - 1$ (6)

Hydrogen balance: $0 = 2n_{H_2} + 2n_{H_2O} + 4n_{CH_4} - x - 2w$ (7)

Oxygen balance: $0 = n_{CO} + n_{CO_2} + n_{H_2O} - w - 2m - y$ (8)

Having 5 unknowns, n_{CO}, n_{CO2}, n_{H2}, n_{H2O} and n_{CH4} in the above three equations, more two equations need to be established for this purpose. These are obtained from the equilibrium constant of reactions occurring in the gasification zone which are methanation and water -gas shift reaction, by evaluating the ratio of products to reactants of these reactions. Assuming the thermodynamic equilibrium for all chemical reactions of ideal gases at 1 atm, then using derived equilibrium constant from the Standard Gibbs reaction enthalpy from Probstein and Hicks [11], the following equations are evolved for Methanation and Water-gas shift reactions respectively:

$$0 = K_1 (nH_2)^2 - (nCH_4)(n_{total})$$

$$0 = K_2 (nCO)(nH_2O) - (nCO_2)(nH_2)$$

where K_1 and K_2 are the equilibrium constants of methanation and water-gas shift reactions respectively. Then the five simultaneously equations 6, 7, 8, 9 and 10 are solved to obtain molar concentration values of n_{H2}, n_{CO}, n_{CO2}, n_{H2O} and $n_{CH4.}$
The Matlab equation solver program and Maple program were used to calculate the formulated model equations to obtain the values of molar concentrations for gaseous species and exergy efficiency.

2. MODEL VALIDATION, RESULTS AND DISCUSSIONS

2.1 Validation of the Model

Table 3 shows the comparison between the results of gaseous compositions available in a study by Zainal et al. [12] and predicted values using this model relations. Results are validated at the same temperature of 1073K but each at a different equivalent ratio as presented in the Table. It can be observe in Table 3 that the predicted values are in good agreement with the literature results for CO and H_2. Model results for CO_2 are desirable because are lower than those presented from the literature.

Table 1 Comparison between this model and Zainal et al. [12] model results for biomass material at a temperature of 800^{o}C (1073K) at various equivalence ratios

Ultimate analysis					CO% Mole concentration		CO_2 %Mole concentration		H_2% Mole concentration		Reference
C	H	O	T (^oK)	ER	Predicted	Literature	Predicted	Literature	Predicted	Literature	
47.3	5.8	45.0	1073	0.30	27.90	23.40	6.70	13.20	20.10	12.50	[12]
				0.35	24.20	24.90	8.20	12.50	17.50	13.00	
				0.40	21.04	24.20	9.50	12.80	15.20	13.80	

3.2 Model Results and discussions

3.2.1 Biomass characterization

The sugar bagasse and coconut shells biomass materials derived from studies by [2] and [9] respectively have ultimate and proximate analysis which are presented in Table 2. The sugar baggase biomass material has a formula $CH_{1.42}\ O_{0.65}\ N_{0.0026}$ while that of coconut is $CH_{1.6}O_{0.712}\ N_{0.0018}$. The model results for lower heating value of sugar bagasse was 22,475.49kJ /kg. The experimentally determined value was about 22% lower at 17,330kJ/kg. While the modeled lower heating value of coconut shells was 22,846.26kJ /kg lower for about 20% at experimental value of 18,115kJ/kg. The model results for heating value of these biomasses were higher than the experimentally values determined by respective authors [2, 9]. This variation is because the model assumes steady state condition which is not the case in practice.

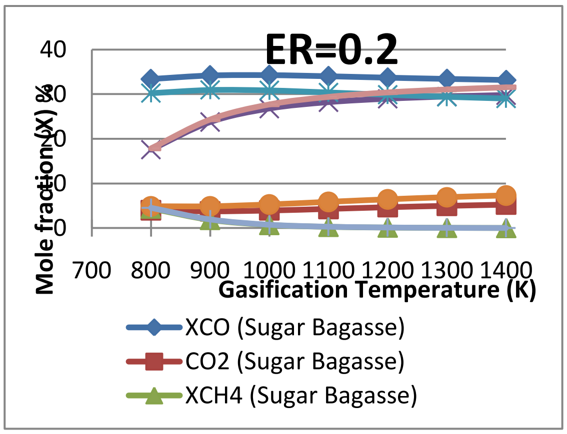
Table 2 Expermental values for Sugar Bagasse and Coconut Shells

Biomass type	Ultimate analysis (%), dry basis				Proximate analysis (%), dry basis				Heating Value
	C	H	O	N	Moisture	Volatile matter	Fixed carbon	Ash	(kJ/kg)
Sugar bagasse	48.10	5.90	42.40	0.15	9.00	80.50	16.20	3.30	17,330
Coconut shells	47.6	6.4	45.21	0.1	11.7	66.2	21.6	0.6	18,115

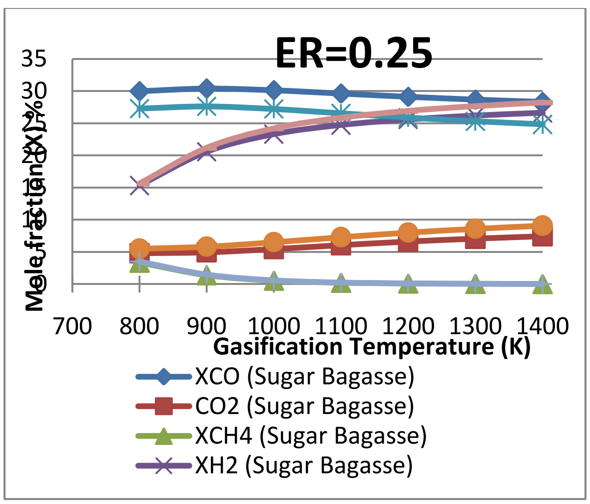
3.2.2 Effect of temperature and equivalence ratio on gaseous species mole concentrations

The simulated results for gaseous species molar concentrations involved the sugar bagasse and coconut shells biomass materials. These were computed from running the model at a temperature between 800K and 1400K at an interval of 100K and equivalence ratio values between 0.2 and 0.4. In contrary, high temperature in the gasification process allows formation of reasonable amount of H_2 and CO mole concentrations for both biomass materials. The mole concentrations of CO_2 are observed to be at lower values while the CH_4 predictions from thermodynamic equilibrium modeling are significantly lower than those encountered in practical gasification tests. Typical CH_4 concentration in downdraft gasifiers is 2-5 % [5].

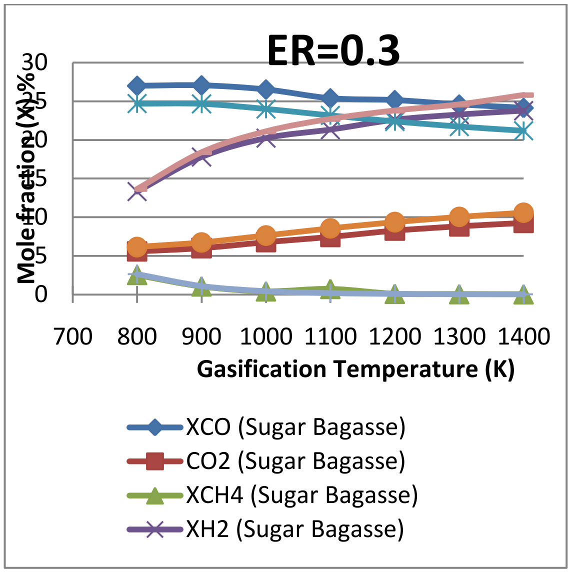
Figure 2 shows that for both biomass materials, the mole concentration of H_2 increased from about 10% to 30% at the change in temperature from 800K to 1400K with also change of equivalence ratio from 0.2-0.4. The formation of mole concentrations of CO_2 had a lower value of about 3% to a higher value of about 13% at the same temperature range and equivalence values. While this is the case for H_2 and CO_2, the CO mole concentration values are high from about 17% to 33% at the change in temperature from 800K to 1400K with also change of equivalence ratio from 0.2-0.4. A similar trend of these results is pronounced by some researchers [13-14]. In this study CH_4 mole concentration reduces as the temperature is increased. The CH_4 mole concentration values reduce from about 4% to 0.02% at an equivalence ratio of 0.2 to 0.4 and temperature range of 800K to 1400K. Similar observations were reported in other thermodynamic modeling studies [10, 15-16].



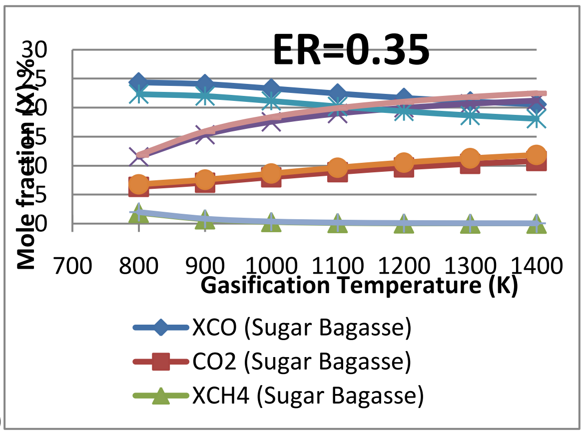
(a)



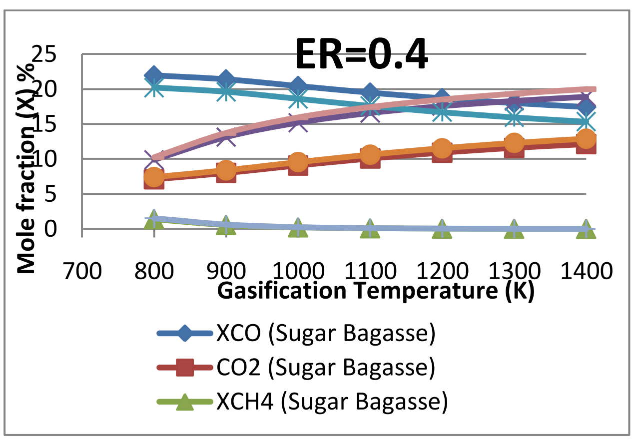
(b)


ER=0.3
Mole fraction (X) %
30
25
20
15
10
5
0
700 800 900 1000 1100 1200 1300 1400
Gasification Temperature (K)
XCO (Sugar Bagasse)
CO2 (Sugar Bagasse)
XCH4 (Sugar Bagasse)
XH2 (Sugar Bagasse)

(c)


ER=0.35
Mole fraction (X) %
30
25
20
15
10
5
0
700 800 900 1000 1100 1200 1300 1400
Gasification Temperature (K)
XCO (Sugar Bagasse)
CO2 (Sugar Bagasse)
XCH4 (Sugar Bagasse)

(d)


ER=0.4
Mole fraction (X) %
25
20
15
10
5
0
700 800 900 1000 1100 1200 1300 1400
Gasification Temperature (K)
XCO (Sugar Bagasse)
CO2 (Sugar Bagasse)
XCH4 (Sugar Bagasse)

(e)

Fig. 2 Effect of temperature on molar composition for CO, CH_4, CO_2 and H_2 gases from sugar bagasse and coconut shells at an equivalent ratio (ER) of (a) 0.2(b) 0.25 (c) 0.3 (d) 0.35 (e) 0.4

3.2.3 Effect of temperature and equivalence ratio on gaseous heating value

From Figure 3, the heating values are observed to increase with an increase in temperature and equivalence ratios. For both biomass materials, the syngas heating values tends to increase from about 3500kJ/kg at 800K to 7500kJ/ kg at 1400K at equivalence ratio from 0.2 to 0.4. The changes in gas compositions are primarily cause by the rise in hydrogen content which causes a progressive increase in the heating value of the resulting producer gas for sugar baggase as well as for the coconut shells.

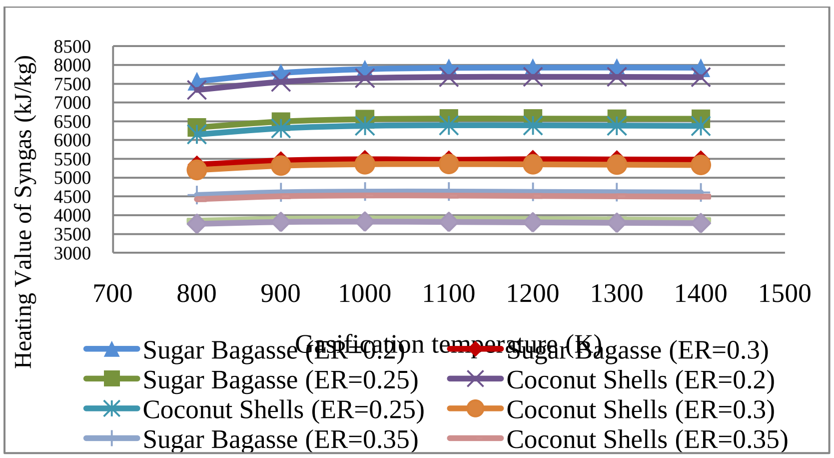


Fig.3 Effect of temperature on syngas heating values at equivalence ratios of: 0.2, 0.25, 0.3, 0.35; and 0.4 for sugar bagasse and coconut shells biomass materials

3.2.4 Effect of temperature and equivalence ratio on exergy efficiency

Figure 4 shows effect of temperature on thermodynamic gasification efficiency (exergy efficiency) at various equivalent ratios. The results show that high temperatures and increase in equivalent ratio favours the exergy efficiency. The exergy efficiency increases from about 70% to 86 for both biomasses. This indicates that the values of irreversibilities (exergy losses) are reduced as the equivalent ratio and a temperature increases, values are less than 30%. These results present a fact that, the increase in efficiency values with an increase in temperature leads to low utilization of the biomass resources.

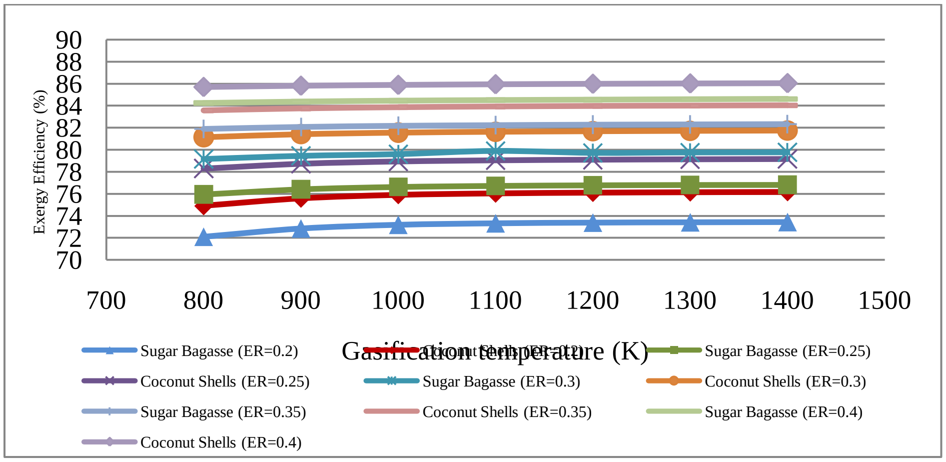


Fig. 4 Effect of temperature on exergy efficiencies at equivalence ratios of: 0.2, 0.25, 0.3, 0.35; and 0.4 for sugar bagasse and coconut shells biomass materials

3. CONCLUSION

The model prepared was used to predict the gasifier performance in terms syngas mole concentrations and exergy efficiencies at different gasification temperatures and equivalence ratios. The following conclusions can be stated emanating from the results of the presented model: The predicted heating value of sugar bagasse and coconut shells biomass materials were 22,475.4873kJ /kg and 22,846.260800kJ /kg respectively. The lower heating value, LHV, of the syngas for both biomasses increases with gasification temperature and equivalence ratios. Generally, CH_4 and CO_2 mole concentrations are lower than those for H_2 and CO. Exergy efficiency of the gasification system increases from about 70% to 86% for both biomasses and tend to increase with gasification temperature and equivalence ratio. The result of this is the low utilization of biomass resources.

4. ACKNOWLEDGEMENT

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Fuel Cells: An alternative source of energy for the Caribbean.

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Abstract:

There has been growing concerns with respect to the depletion of the world's non- renewable resources, hence there is a need to turn to alternative forms of energy, one being fuel cells (FC). Fuel cells are electrochemical energy conversion devices that use hydrogen and oxygen to produce electricity and water. They are very important because of their use in various miniature, portable, transportation and stationary applications. The most common fuel cells used for portable, transportation and portable applications are the proton exchange membrane fuel cell (PEMFC) and Direct Methanol Fuel Cells (DMFC). Trinidad and Tobago is the only oil producing country in the English speaking Caribbean and hence its economy is highly dependent on fossil fuels. With the depletion of the fossil fuel and natural gas reserve it becomes very important for this country to look for alternate energy solutions for sustainable future.

Commercially available fuel cells are expensive due to the use of Nafion based membrane manufactured by Dupont. Although Nafion based fuel cells shows good efficiency at intermediate temperature range, however this membrane itself has its own share of problems such as cost as a result of complex fabrication technique, low working temperature range due to low ionic conductivity and mechanical instability occurring at high temperatures, high

methanol crossover and high water uptake to just name a few. Therefore there is a need to find an alternative electrolyte/membrane to develop the local fuel cell based economy.

In the present manuscript, work done by the Fuel Cell Materials Research Laboratory at the Department of Physics, University of the West Indies, St. Augustine, Trinidad campus to solve the above mentioned problem has been highlighted. Acid-base based electrolytes approach is being used to replace and to overcome the limitations of Nafion Acid-base binary and ternary systems has been studied consisting of Trifluoromethanesulfonic acid (TA), Imidazole (Im) and Polyvinylidenefluoride-co-hexafluoropropylene (PH). The various properties and the fuel cell performance of these electrolyte systems would be discussed.

Keywords: PEMFC, BrØnsted, Acid – Base

1. INTRODUCTION

The Earth's non-renewable energy sources are finite and therefore will eventually run out. The world's life expectancy approximated for oil, natural gas and coal are 40-45 years, 50-65 years and 200-300 years respectively. Apart from running out, these fossil fuels have added to the pollution in the atmosphere which leads to health problems for the global ecosystem. The carbon that is stored in fossil fuels is released as carbon dioxide when they are burnt. The green house effect changes and can cause global warming resulting in more problems. The solution to these problems is to develop alternate sources of energy for future sustainability of the global ecosystem. Alternative and renewable forms of energy like wind energy, energy storage; fuel cells, solar energy, wind energy etc. are the prominent as a replacement to conventional energy systems.

Trinidad and Tobago (twin island nation in the English speaking Caribbean region) is a fossil fuel based economy whereas other Caribbean islands are net importers of fossil fuels for their energy needs. Being a fossil fuel based economy; Trinidad and Tobago is 7th largest producer of greenhouse gases per capita in the world. Trinidad and Tobago is also a signee of Kyoto protocol and has to reduce its carbon footprint. The fuel production capacity of Trinidad and Tobago is also decreasing. In order to have a sustainable energy future there is a need for development of alternate energy sources. Fuel Cells are one such type of energy source which can be very suitable for Trinidad and Tobago and for the Caribbean. Fuel Cells don't have mechanical parts and hence will not require periodical maintenance which is the case in wind energy. They have higher efficiencies unlike solar cells which are very low in efficiency and also high in cost. Fuel cells can be easily integrated in to grid system and does not require large land area. Since fuel cells can be used as stationary systems and also for transportation application, makes them suitable for Caribbean region.

Direct Methanol Fuel Cells (DMFC's) are one of the feasible technologies which can be implied in Trinidad and Tobago and later can be used for other Caribbean islands. Trinidad and Tobago is the world's leading exporter of methanol. With this readily available supply of methanol, it provides an incentive for pushing for the introduction of DMFCs not just in Trinidad and Tobago but in the Caribbean as well since it is strategically located at the southern end of the chain of Caribbean islands and just off the north-eastern shoulder of South America. Infrastructure is readily available since methanol can be stored in the same tanks as petrol in vehicles and in gas station pumps as well. The installment of a Fuel Cell based alternative power source by TSTT at their cell site at St. Lucie Road, Diego Martin, Trinidad is the stepping stone to introducing this technology on the island. With the development of fuel cell research infrastructure in the country itself, will lead to cheap and ready availability of the technology for future use in various applications.

A fuel cell is a device that converts chemical energy to produce electricity and heat continuously, once fuel and oxidant are supplied. The prospect of high efficiencies, absence of gaseous pollutants like SO_X and NO_X, the absence of moving parts, ease of operation, ease of fabrication, high output efficiency compared to internal combustion engines, wide temperature workability and availability in various power ranges are some of the merits which make fuel cells the choice of energy devices for the 21st century. Fuel cells tend to attract a lot of attention since they are designed for portable power supply and transportation, as well as large and small stationary applications [1].

There are various types of fuel cells which are characterized based on the type of electrolyte employed in them as well as their operating temperatures. Polymer Electrolyte Membrane Fuel Cells (PEMFCs) and Direct Methanol Fuel Cells (DMFCs) are considered as preferred option for portable, transportation and even stationary applications. Although PEMFCs and DMFCs are mostly suitable because of their portability and transportation purposes at low and ambient temperatures, DMFC is considered the more desirable fuel cell since it has low–intermediate temperature workability, requires no hydrogen management, has a good power density, available infrastructure already existing, has a faster start up time, is a simpler system with a lower weight and volume, has a longer membrane lifetime due to operating in aqueous environment, low emissions and can be miniaturized. The main advantage of DMFC is it does not require a fuel processor/reformer and the fuel i.e. methanol can be directly fed for its operation.

A fuel cell is made up of several components, the polymer electrolyte membrane being the heart of it. DuPont has produced the most prevalent commercially available membrane, Nafion117, but many challenges are faced by this membrane such as high cost, methanol crossover, degradation of the membrane, water uptake and instability at high temperatures [2-4]. High temperature operation is desired for higher energy conversion efficiencies; higher activity and decreased poisoning of the platinum (Pt) electro catalyst and direct use of the high-temperature reformate gases derived from hydrocarbons and alcohols [5-11]. Hence, there is a need to improve this component in order to overcome all these obstacles.

Various approaches and strategies have been taken by researchers who have developed novel membranes or modified Nafion to improve its properties. Several membrane system techniques studied by researchers are perfluorinated ionomers, partially fluorinated polymers, non-fluorinated membranes with aromatic backbone, non – fluorinated hydrocarbons and acid - base blends to name a few [2, 12-15]. Some membrane designs incorporate ionic liquids (ILs) into their polymer matrices as proton conductors and presently these very ILs by themselves are attracting a lot of attention as a result of their unique properties, such as, high ionic conductivity, low volatility, high thermal stability and electrochemical stability [16-23]. Simple protic ILs consisting of combinations of Bronsted acids and bases, are a sub-class of ILs and have several characteristics of ILs, but sluggish O_2 reduction for poor activity and high melting temperatures have hindered further development [16,24,26,31-34]. Another challenge faced today in ILs is while they are intrinsic ion conductors, their ion conductivity often falls short of that of solvent-based electrolytes because of the high viscosity. The viscosity is a consequence of the electrostatic interactions that are intrinsic to their ionic nature [35]. Acid –base blends has been shown quite a lot of interest by researchers who have done work with low molecular weight systems, high molecular weight systems and have even incorporated both techniques. The problem with the low molecular weight systems is that they don't form good film formations and even though they have good properties, introduction into polymer matrices have resulted in a decrease in their properties. With high molecular weight systems, there is problem with compatibility between the acid and base polymers. Work done by the incorporation of both the high and low molecular weight systems have resulted in some good systems. What happens in this system is that an acid base ionic liquid is entrapped within a polymer matrix and the properties of these membranes formed has shown very good characteristics such as high proton conductivity of 10^{-2} S/cm at high temperatures of 180°C, low methanol swelling, low water uptake, thermal stability up to 300°C, high tolerance to methanol and good flexibility [36-38]. The simplicity and cost effective nature of this technique has rendered it an attractive approach to membrane manufacturing.

In this study, the membranes were formed by synthesizing ionic liquids in-situ in the polymer matrix. Ionic conductivity and practical fuel cell testing results of these systems were studied. The results obtained on the above mentioned newly designed systems were done at the Fuel Cell Materials Research Lab at Department of Physics, University of West Indies, St. Augustine, Trinidad.

2. EXPERIMENTAL DETAILS

2.1 Materials

The base, acid and polymer used were Imidazole (Im) (Aldrich Chemicals, USA), Trifluoromethanesulfonic acid (TA) (Aldrich Chemicals, USA) and Polyvinylidenefluoride-co-hexafluoropropylene (PH) (Aldrich Chemicals, USA,

M_w = 400,000) respectively. The solvent used was Tetrahydrofuran (THF) (Aldrich Chemicals, USA).

2.2 Membrane formation

Ternary system electrolyte membranes were formed by measuring the polymer, acid and base in stoichiometric quantities depending on the ternary composition. They were dissolved in THF until a homogeneous solution was obtained by stirring the mixture using magnetic stirrer at 40°C until forming a clear solution. The homogenous solution was then formed into membranes using solution casting technique by drying it in a temperature and vacuum controlled oven in two stages of 40°C and 60°C respectively. Preactivated Nafion membrane from (Ion Power Inc, UK) was used for comparison with these newly developed ternary system membranes.

2.3 Impedance Spectroscopy

The ionic conductivity of the ILs was measured using an Eco-Chemie precision Impedance analyzer bridge model 302N over the frequency range of 1MHz to 100 Hz. The binary system samples were placed in a glass vial and two stainless steel electrodes 0.35cm apart were submerged in the mixture occupying of area 0.5cm by 0.5cm. For the ternary systems the films were sandwiched between two stainless steel electrodes each having an area of 0.81cm^2.Temperature variable electrical studies have been done by placing the conductivity cell into a temperature and vacuum controlled oven over the range of 30°C to 150°C.

2.4 Fuel Cell Testing

The MEA was made by sandwiching the developed membranes between two Etek electrodes having 20% Platinum on Vulcan XC-72. It was then assembled in a 25cm^2 fuel cell having graphite flow fields and Teflon reinforced gasket. The stoichiometric ratio was set to 1.4/3. The polarization curves were measured using hydrogen and air as fuel for H_2/Air fuel cell using Hydrogenics Fuel Cell Test Station FCATS over various relative humidity conditions of 60 and 100% respectively.

3. RESULTS and DISCUSSION

In the present study, the electrical properties of both the binary and ternary systems were studied and the results are shown in Fig. 1 below.

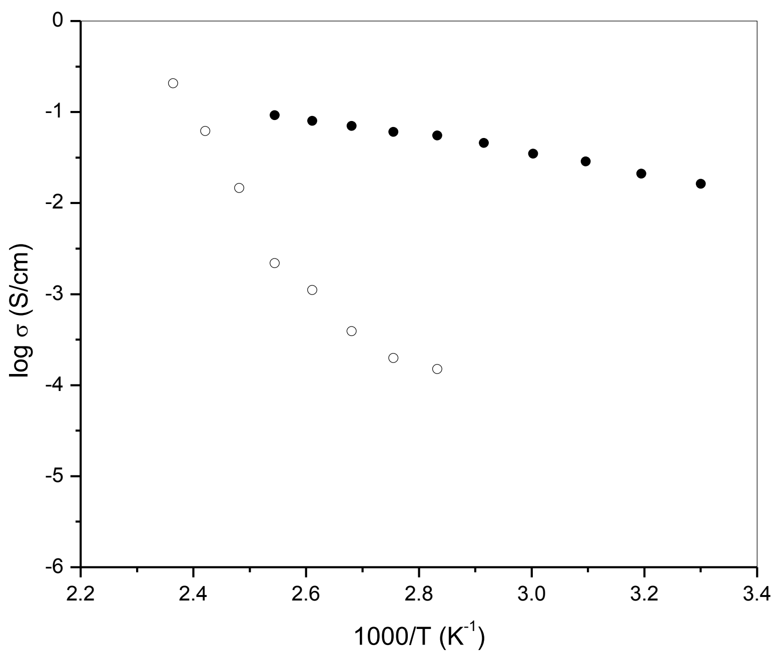

Fig. 1 Conductivity vs. temperature for ionic liquid (●) having composition TA:IM (8:2) and ternary polymer membrane having composition PH:TA:IM (5:4:1) (○).

For the binary system, the conductivity test was carried out at room temperature as well as varied from 30°C to 150°C. Samples were placed in a glass vial with two stainless steel electrodes parallel to each other occupying an area of (0.5 × 0.5) cm^2 of sample. From conductivity testing data it was found that the composition with TA:Im (8:2) had the highest conductivity. For this system the conductivity was of the order 1.6×10^{-2} S/cm at room temperature. The conductivity showed to have increased with an increase in temperature giving a value of 9.2×10^{-2} S/cm at 120°C. At room temperature, this high conductivity is believed to be due to effective acid – base pairing occurring between TA and Im. This pairing results in the availability of free protons which promotes the increase in conductivity. The increase observed over the temperature range was by a fraction of order and hence wasn't very high. This increase in conductivity could be attributed to the increase in the mobility of the proton species at higher temperatures due to the decrease in the viscosity of the ionic liquids.

For the ternary system the electrical conductivity was carried out for the same temperature range, however the films were sandwiched between two stainless steel electrodes each having an area of 0.81cm^2.The ternary system that had the highest conductivity was PH:TA:Im(5:4:1) having values of 10^{-4} S/cm at 60^{o}C and 10^{-1} S/cm at 150^{o}C. This membrane conductivity value was comparable to that of the ionic liquids at high temperatures and has even increased to higher values at temperature around 150^{o}C. The increase of the conductivity over three orders in this case was not as a result of the increase in TA with the inclusion of Im. It may be as a consequence of the base and the polymer host liberating more protons for free conduction in the presence of the acid. For polymer in salt technique, it is usually found that the conductivity obtained for the ionic liquid is lower by an order or two when it is introduced into the polymer matrix. In this case the trend is not the same. Instead the conductivity increases when the ionic liquid is introduced into the polymer host and the conductivity of a certain base concentration and increase of the acid concentration resulted in the conductivity of the ternary system formed being even higher that the ionic liquids itself. This behaviour observed maybe due to the polymer as well as other interactions that are occurring between the different constituents. Further studies would better help understand in detail the behaviour of these electrolytes.

The next step was to test the fuel cell performance of this system. Based on the conductivity data, the highest conducting membrane PH:TA:Im(5:4:1) was used to test its performance. The polarization behaviour was recorded at 60 and 100% relative humidity at 60^{o}C. A typical polarization curve was obtained that is generally expected for solid polymer electrolyte membranes. In comparison to Nafion, it was observed that these ternary system membranes out performed Nafion at both humidification conditions. The cell performed very good and produced an open circuit voltage (OCV) of 0.96V. When a load was applied to the cell the membrane performance was exceptional even up to current densities of 70mA/cm^2, clearly better than Nafion. Fig. 2 shows the polarization curve for this ternary system membrane at 100% relative humidity. Further studies are needed to increase these membrane performances and the work is under way.

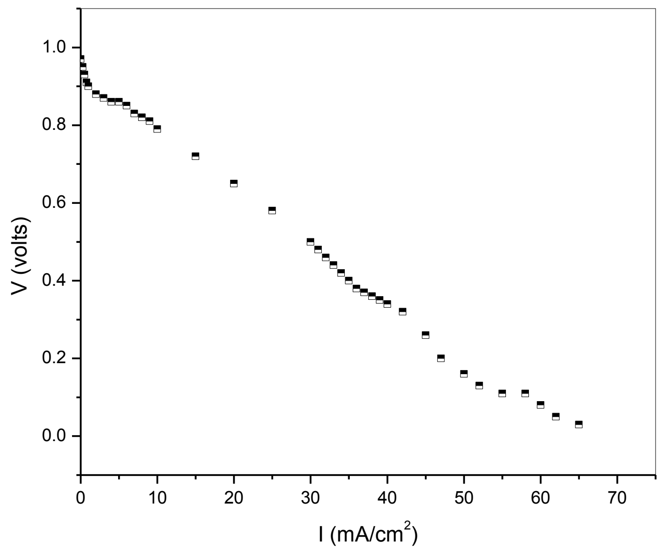

Fig. 2 Polarization curves for ternary system membrane having composition PH:TA:IM (5:4:1) at 100% RH.

4. CONCLUSION

The paper shows how fuel cells can benefit Trinidad and the Caribbean by being an alternative source of energy for the future. It highlights some of the work carried out in the Fuel Cell Material Research laboratory at the University of the West Indies St Augustine campus which can be very crucial in developing fuel cell commercialization for the region. The acid – base ternary system studied had a high ionic conductivity of the order 10^{-1} S/cm and showed good fuel cell performance, thereby outperforming Nafion in both tests. These systems show much promise as electrolyte materials for fuel cell applications.

5. ACKNOWLEDGEMENTS

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BIO-FUEL

Anaerobic Digestion of Vegetable Wastes using Biochemical Methane Potential Assays

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Abstract:

Solid wastes generation is a major problem in Mauritius in terms of wastes disposal with vegetable wastes representing 40-46% the organic waste stream by mass. This study focused on the anaerobic digestion (AD) of vegetable wastes using biochemical methane potential (BMP) assays to assess the performance of AD processes in treating these wastes in a sustainable manner. 2000-mL plastic bottles were used as anaerobic digesters for the assays and the vegetable wastes comprising of carrots, potatoes, cabbage and beetroots were ground and seeded with inoculum in a ratio 4:1 (volume basis). The inoculum used was mature sludge taken from an anaerobic digester treating cattle wastes. The inoculated substrates were then fed in the digesters, purged with N_2 and sealed with rubber septum. The AD process was allowed to run over a hydraulic retention time (HRT) of 20 days. Results showed a total solids (TS) reduction of 62.1%, volatile solids (VS) reduction of 66.4% and COD reduction of 64.9% which demonstrated effective degradation of the substrates during the digestion process. The biogas yield was 0.360 L/g VS fed and this value was in agreement with published data. These results hence showed that vegetable wastes can be effectively treated by AD. The next phases of the study consist in investigating the AD process of wastewater treatment sludge and the effects of sonication on AD of vegetable wastes and sludge, with special emphasis on process parameters.

Keywords: Anaerobic Digestion, Biogas, Biochemical Methane Potential Assay, Chemical Oxygen Demand, Volatile Solids.

1. INTRODUCTION

Solid wastes generation is a major problem in Mauritius in terms of wastes disposal. In 2009, 415,948 tons of wastes were generated and this value is expected to increase to 510,000 tons by 2034 [1]. This increase in waste generation represents a major burden on the sole landfill in Mauritius. The Mare Chicose Sanitary Landfill started operation in 1997 and was originally receiving about 6800 tons of wastes but is now receiving more than 400,000 tons of wastes annually [2]. This has caused the landfill at Mare Chicose to reach full capacity and since there are no other suitable sites for the construction of a new landfill for wastes disposal in Mauritius, there is a major problem of disposing about 400,000 tons of wastes annually and more dramatically, this value will keep on increasing [1, 3].

Solid wastes generation in Mauritius can be classified mainly into Municipal Solid Wastes (MSW), industrial non-hazardous wastes, construction and demolition wastes, health care wastes, hazardous wastes and sludge [1]. MSW contributes the highest proportion of the solid wastes going to the Mare Chicose Sanitary Landfill and is in the order of 70% [1]. Furthermore, the organic fraction of MSW (OFMSW) in Mauritius is 80% [4] and this comprises of paper, yard, fruit and vegetable wastes and food wastes with vegetable wastes representing about 40-46% by mass of OFMSW [4-5]. Due to the easy biodegradability of vegetable wastes and their high moisture content [6], this paper is proposing and investigating the potential of Anaerobic Digestion (AD) as the treatment technique for the high amount of vegetable wastes generated in Mauritius.

AD can be defined as the breakdown and stabilisation of organic materials by microbial organisms in the absence of oxygen to produce methane, carbon dioxide and a stable, innocuous sludge that can be used as soil conditioner or fertiliser [7-10]. AD has long been used for treatment of domestic wastewater [11], treatment of Waste Activated Sludge (WAS) [8, 12], application to agricultural wastes [10, 13] and treatment of primary and secondary sludges [14-15]. It is now being used for the treatment of vegetable wastes. With AD, biogas is produced and this can be burnt to produce energy and electricity which is in line with the Maurice-Ile-

Durable concept. Furthermore, with the reduction in the volume of wastes possible with AD, this will decrease the burden on the Mare Chicose sanitary landfill and provide the solution to the waste problem in Mauritius.

Anaerobic digestion, as stated previously, involves the breakdown of organic materials by microorganisms in the complete absence of oxygen. This breakdown takes place through 4 phases which are hydrolysis, acidogenesis, acetogenesis and methanogenesis [7-8, 10, 14]. In the hydrolytic phase (1st phase), insoluble organic materials and high molecular weight compounds like polysaccharides, carbohydrates, proteins and fats are hydrolysed or cracked by exoenzymes of facultative and obligatory anaerobic bacteria into monomers or water-soluble components such as amino and fatty acids [8, 16]. During acidogenesis, the monomers obtained from the hydrolytic phase are further broken down by acidogenic (fermentative) bacteria into short-chain organic acids C_1-C_5 molecules (e.g. butyric acid, propionic acid, acetic acid), alcohols, hydrogen and carbon monoxide [8,16]. In the acetogenic phase (3rd phase), the higher organic acids and alcohols produced in the acidogenesis phase (2nd phase) are further digested by acitogens into mainly acetic acid, carbon dioxide (CO_2) and (H_2) [7] and during methanogenesis, methanogens, which are strict anaerobes, convert the acetic acid, CO_2 and H_2 from the 3rd phase to methane (CH_4) and carbon dioxide (CO_2) [7, 16]. For AD to perform properly, there are some process parameters that need to be monitored and these are the concentration of microorganisms and retention time, the type of substrate used, pH, volatile fatty acids (VFA), alkalinity, temperature, nutrients, particle size and disintegration and inhibitors.

2. APPROACH AND METHODOLOGY

2.1 Substrate

The substrate used for this research study was vegetable wastes obtained from a nearby market comprising of carrots, potatoes, cabbages and beetroots. All these vegetable wastes were shredded and characterised in terms of total solids (TS) and moisture content, volatile solids (VS) and ash content and pH in accordance with the procedures recommended in the Standard Methods for the Examination of

Water and Wastewater [17]. The shredded vegetable wastes were then mixed in equal proportions and tested for pH, VFA and alkalinity according to the above standard procedures [17]. The alkalinity was adjusted by adding $NaHCO_3$ until it reached the maximum permissible value of 5000 mg/L $CaCO_3$ [18-20] required for proper AD. This substrate was then ready to be used for the AD process.

2.2 Inoculum

The inoculum used was mature sludge taken from an anaerobic digester treating cattle wastes. The inoculum was tested for pH, TS and moisture content, VS and ash content, chemical oxygen demand (COD), VFA and alkalinity according to the procedures recommended in the Standard Methods for the Examination of Water and Wastewater [17].

2.3 Biochemical Methane Potential (BMP) Assays

Biochemical methane potential (BMP) assays serve as a good method to evaluate the performance of AD processes. The BMP test consisted of two 2000-mL plastic bottles placed in dark plastic bags to prevent light from affecting the AD process [16]. One plastic bottle served as the anaerobic digester for biogas collection and measurement while the second anaerobic digester was used for sampling purposes during the AD process. The inoculum and the ground vegetable wastes were mixed in a volume ratio (1:4). 1000 mL of this inoculated substrate was placed in each of the 2000-mL anaerobic digesters which were purged with N_2 to ensure anaerobic conditions. The digesters were then sealed with rubber septum which consisted of drilled holes and tubing systems to allow for biogas collection and for sampling purposes. The biogas from the digester was bubbled through an acidified solution to ensure that all the biogas generated was collected during the downward displacement of water as illustrated in Fig. 1. The anaerobic digestion process was allowed to run over a hydraulic retention time (HRT) of 20 days at room temperature and pressure (RTP). At regular intervals during the AD process, sampling was done from one of the digesters and the sample was tested for pH, TS and moisture content, VS and ash content, VFA and alkalinity and COD in accordance with the procedures recommended in the Standard Methods for the Examination of Water and Wastewater [17].

2.4 Statistical Analysis

For each of the parameters tested during the AD process (TS, VS, VFA, alkalinity, pH, COD and biogas yield), the error bars inserted in Figs. 2-7 were computed based on absolute and relative errors. For those parameters involving mathematical equations such as TS, VS, VFA, alkalinity, COD and biogas yield, the relative errors (± ΔE/E) were calculated and used to estimate the error bars. As for those parameters not involving mathematical equations such as pH, the absolute errors (±ΔE) were used to work out the error bars.

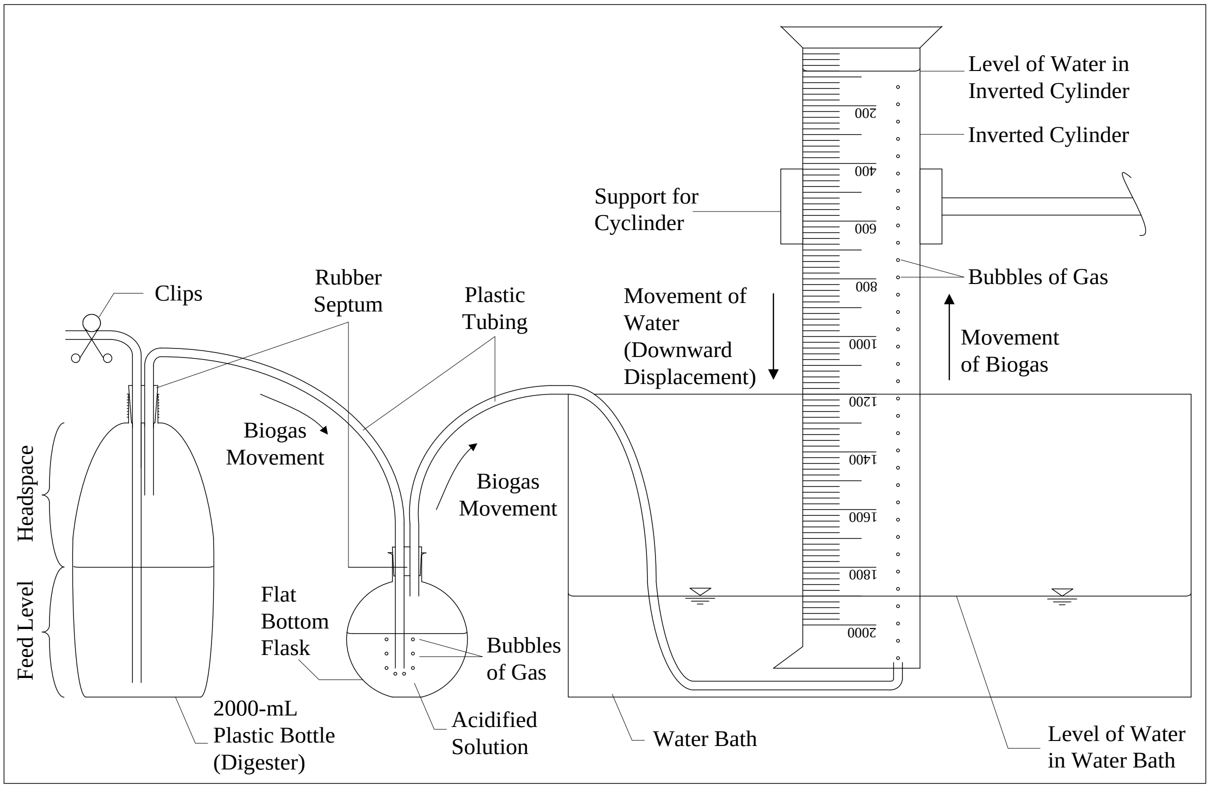

Fig. 1 Anaerobic Digestion Set-up

3. RESULTS AND DISCUSSIONS

3.1 Characterisation of vegetable wastes, inoculum and inoculated feed

The different characteristics of the vegetable wastes, inoculum and feed to the digesters are presented in Table 1.

Table 1 Characterisation of vegetable wastes, inoculum and inoculated feed

	Vegetable Wastes	Inoculum	Feed
Total Solids (%)	11.98	3.88	10.12
Volatile Solids (%)	93.93	69.29	91.77
pH	7.88*	7.85	8.25
Alkalinity (meq/L)	253	8.3	88
Volatile Fatty Acids (meq/L)	179.4	10	208.5
Chemical Oxygen Demand (mg/L)	33846	3759	27692

* Before adjusting for alkalinity, pH was 6.19

It can be observed from Table 1 that the total solid content of the feed was 10.12 %. Hence, the AD process was performed at a medium solid content [18-19]. The pH of the feed was 8.25 and this was slightly above the specified limit for AD processes [16]. However, the alkalinity was 88 meq/L (4400 mg/L $CaCO_3$) and this was within the permissible range for anaerobic digestion [18-20]. It can also be observed that the COD of the feed was quite high indicating the high amount of organic matter available for degradation.

3.2 Total Solids and Volatile Solids

The total solids and volatile solids variation during the AD process are illustrated in Fig. 2.

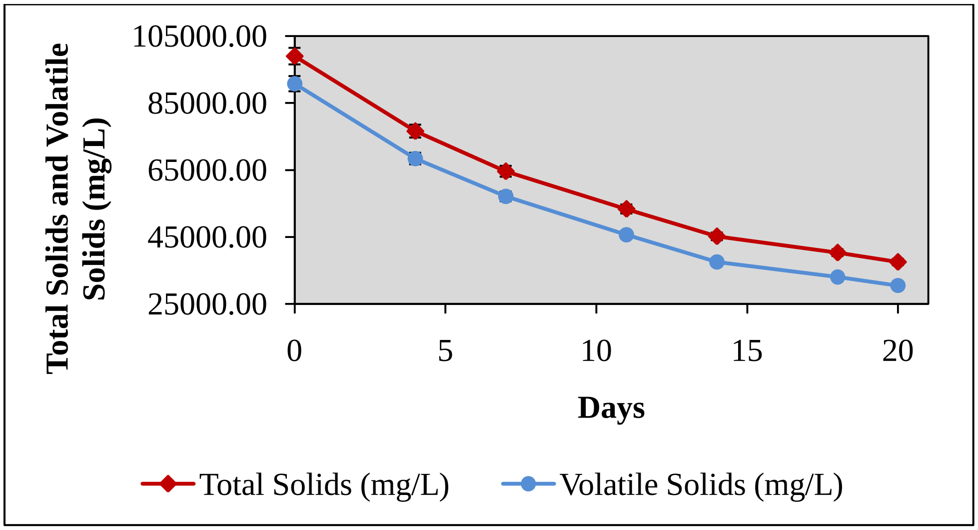

Fig. 2 TS and VS variation during AD

From Fig. 2, the total solids decreased from 99000 mg/L to 37500 mg/L representing a TS reduction of 62.1%. Total solids are normally classified as fixed solids (ash) and volatile solids. During AD, the fixed solids remained unchanged while the volatile solids were converted into biogas [19]. During the hydrolytic phase of AD, the microorganisms break down the large molecules in the substrate and dissolve the resulting smaller molecules into solution [14, 21]. Consequently, the total solid content was reduced due to the large amount of molecules going into solution by hydrolysis. Additionally, the conversion of volatile solids into biogas in the methanogenic phase of AD also contributed to the reduction in total solids. It can also be observed from Fig. 2 that the volatile solids decreased from 90765 mg/L to 30500 mg/L representing a VS reduction of 66.4%. The decrease of volatile solids, as explained previously, was due to the conversion of the volatile solids into biogas. However, not all of the VS were converted into biogas. The main reason for this was due to the fact that volatile solids can be divided into biodegradable volatile solids (BVS) and refractory volatile solids (RVS). Only part of the BVS could be degraded by the acidogens, acetogens and methanogens under the operating conditions of this research study while the RVS did not degrade at all.

3.3 Alkalinity and VFA variation

The alkalinity and VFA variation during the AD process are shown in Fig. 3.

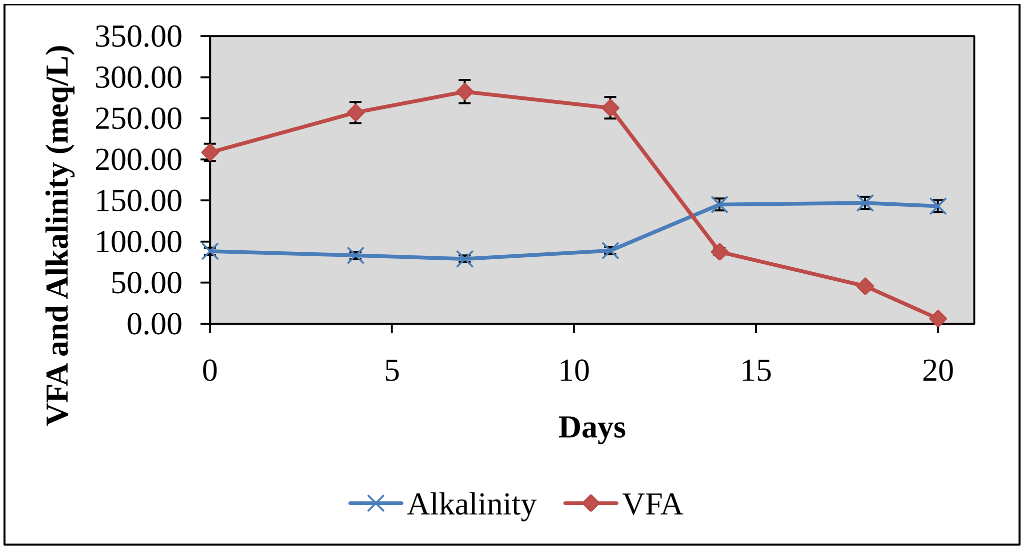

Fig. 3 Alkalinity and VFA variation during AD

The general trend of the VFA concentration in Fig. 3 was an increase and then a decrease during the AD process while the trend of the alkalinity was completely opposite. The initial increase of the VFA concentration could be attributed to the acidogenetic and acetogenetic phases of AD. During these two phases, the acitogens convert the monomers from the hydrolytic phase into short-chain organic acids and subsequently, acetogens convert these short-chain acids into acetic acid, CO_2 and H_2 [7-8, 16]. Since the acidogenesis and acetogenesis were initially dominant over methanogenesis, the production of the short-chain organic acids and acetic acid caused an increase in VFA concentration as illustrated in Fig. 3. The subsequent decrease of the VFA concentration was due to the methanogenetic phase of AD which started to dominate over acidogenesis and acetogenesis. During methanogenesis, methanogens convert the acetic acid, CO_2 and H_2 to CH_4 and CO_2 [7, 16]. As this CH_4 and CO_2 escaped from the system and were collected as biogas, the VFA concentration decreased as depicted in Fig. 3. As for the alkalinity, the general trend was a decrease followed by an increase. The decrease in the alkalinity values coincided with the increase in the VFA concentrations. As the VFA concentrations increased, the H^+ ions generated in the system increased. To counter this effect and prevent any major pH change in the AD process (so that the methanogens are not suppressed), the alkalinity present in the system provided the buffering capacity. The HCO_3^- reacted with this excess of H^+ ions and buffered the system against this pH change as illustrated in Eq. (1). Subsequently, the HCO_3^- ions concentration decreased and this caused the alkalinity to decrease [19]. Another reason for the decrease in the alkalinity was due to the escape of CO_2 in the biogas collected. As soon as the CO_2 was produced in the system, it escaped immediately with the biogas collected. To counter this decrease in CO_2, the HCO_3^- had to react with H^+ ions to generate more CO_2 so as to maintain the equilibrium in the system as shown in Eq. (1) and this caused the alkalinity to decrease. As for the increase in the alkalinity, this was mainly due to the breakdown of organics present in the digesters [8, 16]. The breakdown of organic-nitrogen compounds such as proteins and amino acids and the production of CO_2 from organic compounds contributed to an increase in alkalinity due to the formation of HCO_3^- [18].

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \qquad (1)$$

3.4 pH variation

The pH variation during the AD process is illustrated in Fig. 4. The pH variation during the AD process was quite erratic as illustrated in Fig. 4. This variability was due to various factors such as VFA concentrations, alkalinity and the buffering capacity of the system. The pH decreased initially during the acidogenesis and acetogenesis phases of anaerobic digestion. During these phases, the concentration of volatile fatty acids increased causing an increase in H^+ ions generated in the system and a decrease in pH. At that point, the acidogenesis and acetogenesis phases were dominant over the methanogenesis phase. The rate of VFA formation was much higher than the rate of degradation of these VFA into CH_4 and CO_2. This led to an accumulation of VFA in the system and a decrease in pH [20]. However, the alkalinity initially present in the system did provide the buffering capacity against this pH change and that was why the pH did not drop too low but was maintained well above the minimum permissible limit of 6.2 for proper AD [18]. Eventually, as the rate of methane formation started to increase, the pH then stabilised and stayed almost constant towards the end of the AD process. This was due to the buffering capacity of the system and the degradation of the VFA into CH_4 and CO_2. Furthermore, at some points during the AD process, the pH was observed to increase. This was due to the degradation of the organics present in the system increasing the alkalinity, decreasing the VFA concentration and increasing the pH as discussed previously.

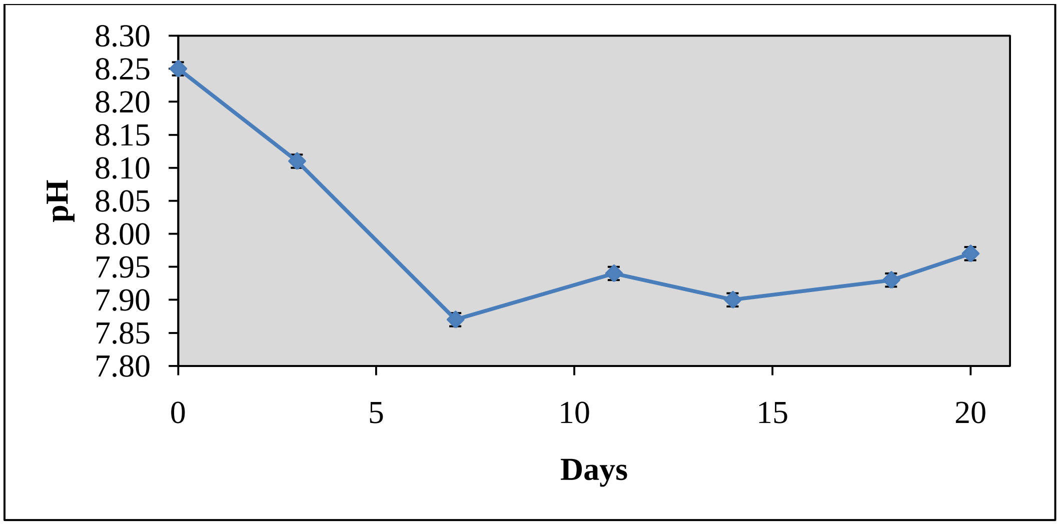

Fig. 4 pH variation during AD

3.5 COD
The COD variation during the AD process is depicted in Fig. 5.

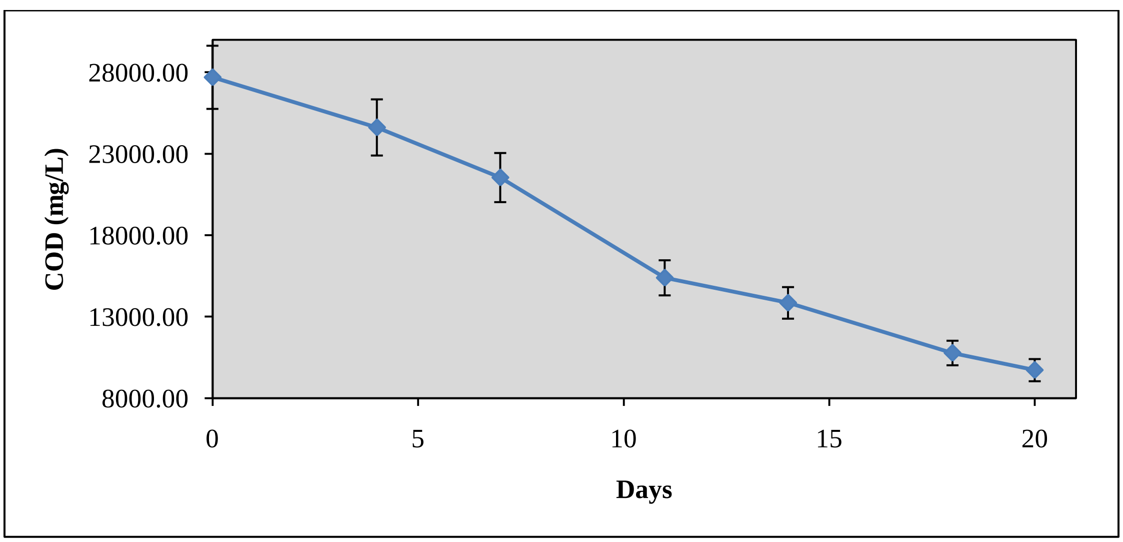

Fig. 5 COD variation during AD

Chemical Oxygen Demand is an indication of the amount of organic matter present in a particular system. When there is high organic matter, the oxygen demand is high and the COD gets a high value. It can be observed from Fig. 5 that the COD decreased during the BMP assay representing a net COD reduction of 64.9%. This degradation of COD occurred due to methanogenic activities whereby the methanogens degraded and converted the solubilised organic matter into CH_4 and CO_2 [8]. However, not all the COD could be degraded by the methanogens as indicated by the 64.9% COD reduction. COD is classified into soluble and particulate COD. During AD, only soluble COD is easily degraded by the microorganisms while particulate COD which consists of inert COD, slowly biodegradable COD is hard to degrade unless solubilised during hydrolysis. Due to the presence of particulate COD in the system, the net COD reduction was 64.9%. It can also be observed from Fig. 5 that the highest rate of COD reduction occurred between days 7 to 11. The main reason for this was due to a larger amount of solubilised organic matter present. From Fig. 3, the maximum VFA concentration occurred during the same period as the maximum rate of COD reduction from Fig. 5. The high VFA concentration can be correlated to a large amount of solubilised organic matter in a system [22]. Due to a larger amount of solubilised organic matter, the methanogens had a more easily degradable feed to digest and hence, the COD reduction rate was higher during that period. Finally, it can be observed that the VS reduction and COD reduction were quite close. Since both VS and COD gave an indication of the amount of organic matter present, it seemed logical that both the VS and COD reduction were quite close due to degradation of organic matter during anaerobic digestion.

3.6 Biogas Production

The individual and cumulative biogas yield during the AD process are illustrated in Figs. 6-7.

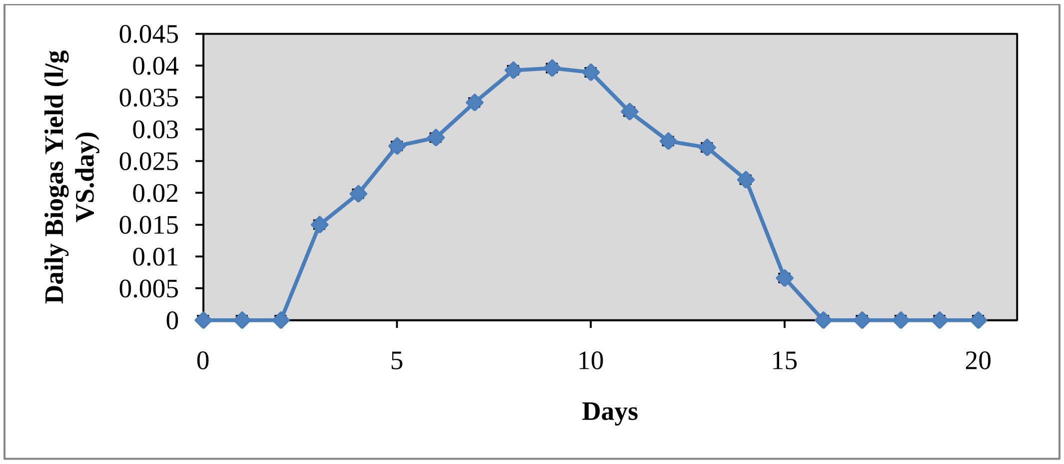

Fig. 6 Daily biogas production

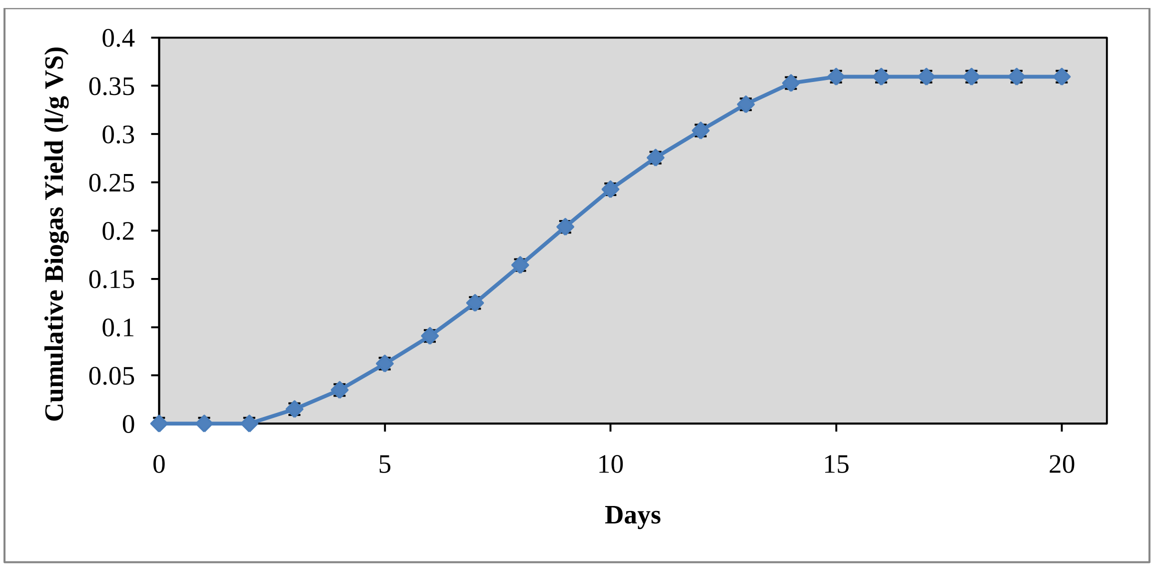

Fig. 7 Cumulative biogas production

Biogas production started as from day 2 as illustrated in Figs. 6-7. During the initial 2 days of the BMP assay, the inoculum used was getting acclimatised to the new environment and the substrates were being hydrolysed while the acidogenetic and acetogenetic phases of AD were also starting. During those 2 days, the methanogens did not have any feed to digest and convert into biogas. This was the reason for the delay in biogas production. As from day 2, the biogas production started to increase achieving its peak on day 9. It can be observed from Fig. 3 that the maximum VFA concentration was around the same period. With a high concentration of VFA, the methanogens had higher feed to digest and convert into biogas and hence, the biogas production was highest by day 9. As from day 9, the biogas production decreased due to the lower amount of VFA produced and due to the lower amount of organic matter remaining to degrade in the BMP assay. Eventually, by day 16, the biogas production ceased. The anaerobic digestion process was completed in terms of the available organic matter to degrade. From Fig. 7, it can be observed that the cumulative biogas yield obtained was 0.360 L/g VS fed. This was in accordance with published data from literature indicating that the biogas yield for AD of vegetable wastes lie in the range 0.3-0.6 L/g VS [10, 20]. The biogas yield obtained for this research study was on the lower limit with reference to the above range since this research was performed at RTP (below mesophilic temperatures). The higher limit of biogas yield referred to those anaerobic digestion set-ups performed under mesophilic or thermophilic conditions whereby it has been observed that biogas yield is higher under those two operating temperature conditions due to higher solubilisation of organic matter [8, 16].

4. CONCLUSIONS

BMP assays were used to evaluate the performance of AD of vegetable wastes under an HRT of 20 days at RTP. The pH and alkalinity remained above the minimum limit required for stable AD while a TS reduction of 62.1%, VS reduction of 66.4% and COD reduction of 64.9% were achieved. These results showed that vegetable wastes can be effectively treated by AD. With a biogas yield of 0.360 L/g VS, vegetable wastes were a potential source for energy production.

5. FUTURE WORKS

The next phases of this study consist in investigating the AD of wastewater treatment sludge. The effects of sonication on AD of vegetable wastes and sludge will also be investigated, with special emphasis on process parameters. These will help evaluate the feasibility of using sonication as a pretreatment technique prior to anaerobic digestion.

6. ACKNOWLEDGMENTS

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Investigations on vegetable oil conversion by deoxygenation and cracking for the use as alternative biofuels

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Abstract

The shortage of worldwide resources, the discussion about the global warming as well as energy independence policies are driving forces for developing new alternative fuel technologies based on renewable sources. One possibility is the conversion of vegetable oil into cracked vegetable oil (CVO) by cracking and deoxygenating in small decentralized plants. The conversion has been investigated on laboratory scale under atmospheric pressure in the absence of catalysts at temperatures from 350°C to 400°C. Under these conditions different feedstocks have been tested such as refined rapeseed oil, crude rapeseed oil, palm oil and used frying oil. Resulting yield of CVO is about 70-80 wt.-%. The measured physical properties of CVO are well complying with the specifications of the diesel standard DIN EN 590. Due to chain length reduction by cracking viscosity is decreased and cold stability is improved in CVO. In case of palm oil the resulting CVO stays liquid at room temperature. The kinetics of the deoxygenation of the raw material can be described by the decrease of the oxygen content in the oil during reaction time. The oxygen content can be calculated at the net calorific value which has been confirmed by elemental analysis. In case of rapeseed oil the oxygen content can be reduced from 11 wt.-% to a level of 3-5 wt.-% while the net calorific value is increased from 37 MJ/kg to a level above 41 MJ/kg. The results indicate that there is a chance to produce alternative fuels from vegetable oils with improved properties compared to biodiesel.

Keywords: deoxygenation, cracking, palm oil, rapeseed oil, cracked vegetable oil, CVO, kinetics, physical properties

Viability of using cassava as feedstock for bioethanol production in Fiji

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Abstract:

Ethanol production from renewable resources has received attention due to increasing petroleum shortage. One such renewable resource that has been identified is cassava starch. Cassava starch is extracted from root crop, cassava (*Manihot esculenta* (*Crantz*)) and is readily available in Fiji. Many countries such as China, Thailand and India are already having success in producing high starch yielding cassava varieties that can be used for ethanol production.

The current paper investigates the viability of producing ethanol from locally available cassava varieties in Fiji. Starch was extracted from the roots of ten different cassava varieties available at two different research stations in Fiji. The sedimentation technique was used to extract starch from cassava roots and some properties of the extracted starch were also determined. In the case of Koronivia Research Station (KRS) the variety Nadelei had the highest starch yield (23.1 %) whereas Coci had the highest starch yield (23.3 %) for Dombuilevu Research Station (DRS). The paper discusses and compares starch yield obtained from Fiji cassava varieties with some other countries and make recommendations on how starch yield from Fiji cassava varieties can be increased.

Finally, the paper provides recommendations on enhancing the viability of cassava as a source of bioethanol in Fiji. It also assesses the resources available in Fiji currently to make cassava bioethanol in Fiji a viable proposition.

Keywords: Cassava, Starch, Ethanol yield, Bioethanol

1. INTRODUCTION

Cassava, *Manihot esculenta* (*Crantz*) is a perennial plant widely grown in many tropical countries including Fiji Islands. The importance of cassava is derived from its diverse use for human consumption, animal feed and industrial application. It is currently the sixth world food for more than 500 million people in the tropical and the sub-tropical Africa, Asia and Latin America [1].

Cassava generally grows in many soil types. However, cassava does not tolerate saline or persistent water-logged conditions and it also does not tolerate temperature at or below 10°C [2]. It is usually propagated vegetatively from mature woody stem cuttings however, cassava can also be propagated from seeds. According to Ceballos et *al*. [3] seeds are generated through crossing in breeding programs and this result in creating new genetic variation. The use of seeds in commercial cassava production is a promising option to obviate constrains, particularly diseases associated with vegetative propagation [4].

The roots of cassava typically consists of moisture (70%), starch (24%), fibre (2%), protein (1%) and other substances which also includes minerals (3%) [5]. Starch is an important source of carbohydrate that is synthesised by cassava roots and can not only be used as food but also as a source of chemical reagent, feedstock for fermentation processes and adhesive substance. The use of cassava starch as feedstock for ethanol production as fuel is already being exploited and the results shown by many researchers are quite promising.

Therefore, it becomes essential that high starch yielding cassava varieties are identified. The classification of cultivars (variety) is usually based on pigmentation and shape of the leaves, stems and roots [6]. The cassava varieties in Fiji are also identified using these classifications.

Currently, Koronivia Research Station (KRS) in Fiji have identified the following twenty-eight cassava varieties; Vulatolu, Vulatolu 2, Merelesita, Merelesita 2, Yabia Damu,Yabia Vula, Niumea, Coci, Sokobale, Aikavitu, Kasaleka, Katafaga,, Belesilika, Manioke, Yasawa Vulatolu, Malaya (Macuata), Ro Tubuanakoro, Coci (selection), Vulatolu (Dalip Singh), H.165, H.97, Tilomuria No.3, Tavioka Falawa, Navolau, New Guinea, Lomaivuna, Beqa, Hawaii and Kadavu [Nauluvula, 2009, pers. Comm.].

The objective of this study was to identify the starch yield from ten different varieties of cassava found in Fiji and to determine some properties of the starch obtained from these varieties. Another objective was to compare starch yield of Fiji cassava with cassava starch yield in other countries.

2. MATERIALS AND METHODOLOGY

The cassava varieties that were used for ethanol production were obtained from two different research stations of the Ministry of Primary Industries in Fiji. One was KRS situated 18˚ 32'811" S and 178˚ 32'133" E and the other was Dombuilevu Research Station (DRS) situated 17˚ 33'620" S and 178˚ 14'736" E. These two locations are indicated in the map of Fiji in Fig 1.

Fig. 1 Map of Fiji showing the collection points of cassava varieties

[Source: Fiji Map: http://www.worldatlas.com/]

The ten cassava varieties obtained were; Niumea, Sokobale, Beqa, New Guinea, Coci, Vula Tolu, Yabia Damu, Merelesita, Nadelei and Navolau. The variety Sokobale was not available at DRS therefore; only nine varieties were used for ethanol production from this location. The cassava varieties obtained from KRS and DRS were approximately 12 months old. The two sites were chosen to determine whether geographical location played a part in determining starch yield which will then influence the ethanol yield.

2.1 Dry Matter Content of Cassava Roots

Dry matter content of cassava roots has become an important character for the acceptance by researchers and consumers who boil or process them [7]. The percentage of starch and starch yield are closely related to dry matter percentage. Therefore, this is one of the factors that need to be determined in order to identify the best cassava variety for starch and ethanol yield.

Dry matter content was determined according to the procedure described by Benesi [8]. The roots of different cassava varieties were analyzed for dry matter content within 12 hours of harvesting. The roots were peeled, cleaned and then shredded into fine slices before 100 g of these were weighed in a Petri dish (w_1). The Petri dish was then placed in an oven at a temperature of 65 ˚C for 72 hours. The samples were removed after 72 hours and weighed immediately (w_2). Dry matter content was calculated using the Eq. (1):

$$\text{Dry matter content (\%)} = \frac{w_2}{w_1} \times 100\% \qquad (1)$$

2.2 Starch Extraction from Cassava Roots

The extraction of starch from cassava was done according to the method described by Birse and Cecil [9]. However, some parts of the method were modified. A flowchart of starch extraction is shown in Fig. 2. Cassava roots were washed, peeled then washed again before the roots were chopped into approximately 1 cm cubes. The weight of the chopped cassava (w_3) was taken before pulverizing it in a high speed blender for 5-10 minutes. The pulp was then suspended in ten times its volume of water, stirred for about 5 minutes before filtering using a double fold cheese cloth. The filterate was left to stand for about 6 hours before the starch settled and the liquid portion discarded. The water was then added to the sediment and the whole process was repeated. The starch was then dried at 50 ˚C for 24 hours and its weight measured (w_4).

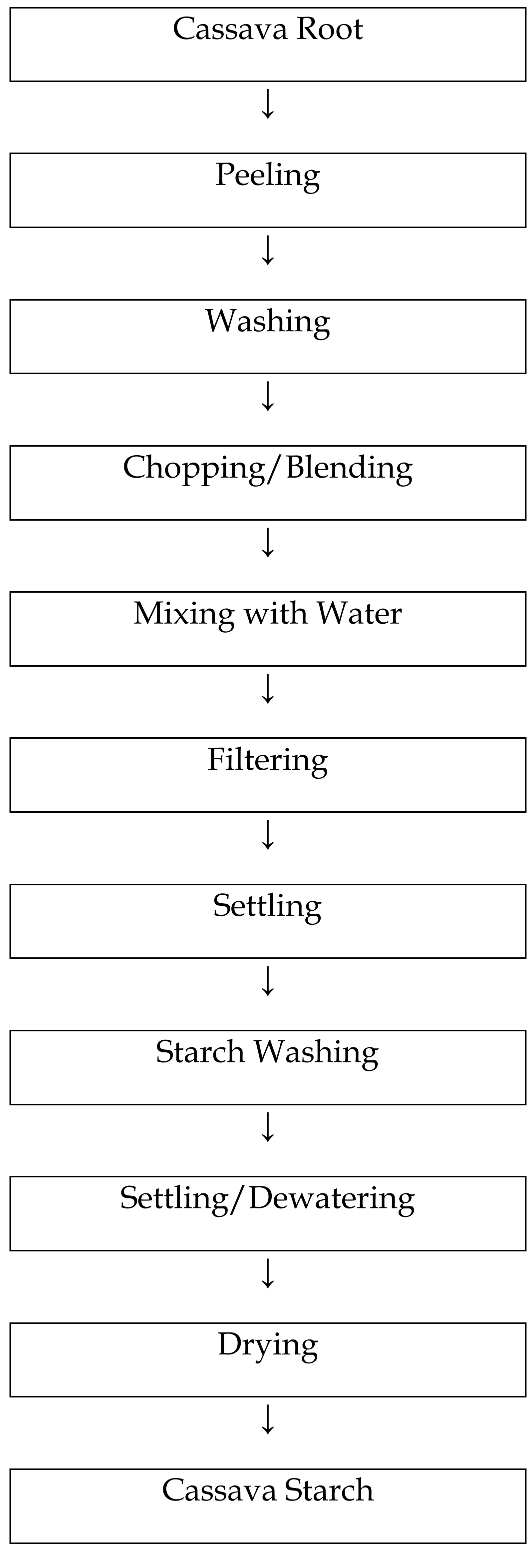

Fig. 2 Flowchart for cassava starch production

The starch yield was determined using the Eq. (2):

Starch Yield (%) = $\frac{w_4}{w_3} \times 100\ \%$ (2)

2.3 Moisture Content of Starch

Moisture content of the extracted starch was determined according to the method described by Benesi [8]. However the quantity of cassava starch to be analyzed was increased.

Approximately 10 g of cassava starch (w_5) was dried in an oven at 105 ˚C for 24 hours. After 24 hours the samples were cooled in a desiccator and weighed immediately (w_6). The moisture content was determined using Eq. (3):

Moisture content (%) = $\frac{w_5 - w_6}{w_5} \times 100\ \%$ (3)

2.4 Ash Content of Starch

Ash content was determined according to the method described by International Starch Institute [10]. Clean ashing crucibles were heated in the furnace for approximately half an hour at 900 ˚C. The crucibles were cooled in a dessicator to room temperature and weighed (w_0). Approximately 5 g of the starch sample was uniformly distributed in the ashing crucible and weighed (w_7). The samples were then incinerated on a bunsen burner until it completely carbonised before placing the ashing crucibles in the furnace for 5 hours at 900 ˚C. After incineration the samples were cooled to room temperature in a dessicator and weighed (w_8). Ash content of starch was determined using Eq. (4):

Ash content (%) = $\frac{w_8 - w_0}{w_7 - w_0} \times 100\ \%$ (4)

2.5 pH determination of Starch

The pH of starch was determined according to the method described by International Starch Institute [11]. Approximately 5 g of starch was mixed with 20 ml of distilled water. The starch was then allowed to settle for 15 minutes before the pH of the water phase was measured using a calibrated pH meter.

3. RESULTS AND DISCUSSION

The starch yield from different cassava varieties obtained from two different locations in Fiji is shown in Table 1 below. The starch yields for cassava varieties obtained from both the stations ranges from 17 to 23 %.

Table 1: Starch Yield from Cassava Varieties

Cassava Variety	Koronivia	Dombuilevu
	Starch Yield (%)	Starch Yield (%)
Niumea	18.3	19.9
Sokobale	17.7	*
Beqa	21.9	17.0
New Guinea	20.9	19.5
Coci	20.5	23.3
Vula Tolu	17.3	18.1
Yabia Damu	19.6	17.9
Merelesita	18.6	18.8
Nadelei	23.1	22.1
Navolau	17.0	19.8

The results show that the yields are dependent on the sites of the plantations. They show that Beqa, New Guinea, Yabia Damu, and Nadelei are more suited to the Koronivia site with regard to their starch yields. On the other hand Niumea, Coci, Vula Tolu and Navolau performed better at the Dombuilevu site for their starch yields. The Merelesita starch yield did not show much variation with site. Therefore, it is seen that location is one of the factors that influence starch yield.

Benesi's [8] result indicated that the genetic constitution of the plant is the most influential factor. However, sites, rounds of starch extraction and their interaction also have appreciable influence. Similar observations were also made by Ngendahayo and Dixion [12] who found that after six months, the starch content in plants are influenced by genotype, harvesting time and rainfall pattern.

The dry matter content obtained from two different locations is shown in Table 2. The cassava from Koronivia had a dry matter content as high as 41 % (New Guinea and Beqa) whereas the ones from Dombuilevu had a maximum of 38 % (Nadelei).

Table 2: Dry Matter Content of Cassava Varieties

Cassava Variety	Koronivia	Dombuilevu
	Dry Matter Content (%)	Dry Matter Content (%)
Niumea	37.9	36.2
Sokobale	36.3	*
Beqa	41.2	32.2
New Guinea	41.5	32.3
Coci	37.0	36.8
Vula Tolu	31.1	35.6
Yabia Damu	35.7	36.0
Merelesita	40.9	35.6
Nadelei	40.8	38.0
Navolau	33.7	33.8

Dry matter content is very much related to rainfall during six to eighteen months of plant growth [12]. This suggests that the difference in dry matter content between the sites could be contributed to the rainfall received during plant growth.

However, Benesi *et al*. [13] have reported that the root dry matter content of cassava in Malawi is in the range 38.24 to 46.48 % and that dry matter content was not as much influenced by the environment as by the genetic differences.

The mineral elements and inorganic salts present in starch are referred to as ash. Table 3 shows that the ash content for cassava varieties obtained from Koronivia is 0.10 to 0.17 % and for Dombuilevu it was 0.1 to 0.21 %.

Table 3: Ash Content of Cassava Varieties

Cassava Variety	Koronivia	Dombuilevu
	Ash Content (%)	Ash Content (%)
Niumea	0.17±0.01	0.19±0.03
Beqa	0.17±0.03	0.21±0.02
Sokobale	0.11±0.02	
New Guinea	0.09±0.01	0.15±0.04
Coci	0.14±0.02	0.13±0.01
Vula Tolu	0.10±0.02	0.12±0.02
Yabia Damu	0.10±0.02	0.17±0.03
Merelesita	0.12±0.02	0.13±0.01
Nadelei	0.10±0.02	0.10±0.02
Navolau	0.14±0.02	0.16±0.04

Means of three replicates (± SD)

According to Thomas and Atwell [14] ash content is typically less than 0.5 % of dry mass and this agrees with the results obtained for all the cassava varieties obtained from Koronivia and Dombuilevu. Variations in ash content depend upon source of raw material, agronomic practices, extraction and milling procedures and types of chemical modifications [8].

The pH of cassava starch as reported in Table 4 ranged from 4.07 to 5.23 for the varieties obtained from Koronivia and 5.03 to 6.20 for those varieties obtained from Dombuilevu. Benesi [8] indicated a pH range of 5.0 to 5.5 for the native starch obtained from ten elite Malawian cassava genotype. The recommended pH range stated by the National Starch and Chemical Company is between 4.5 and 7.0 [15].

Table 4: pH of Cassava Varieties

Cassava Variety	Koronivia	Dombuilevu
	pH	pH
Niumea	4.07±0.02	5.98±0.05
Sokobale	4.18±0.02	*
Beqa	4.89±0.01	5.81±0.04
New Guinea	5.23±0.02	5.03±0.02
Coci	4.47±0.01	5.04±0.03
Vula Tolu	4.63±0.03	5.17±0.01
Yabia Damu	4.44±0.01	6.20±0.02
Merelesita	4.53±0.03	5.21±0.03
Nadelei	4.53±0.02	5.48±0.03
Navolau	4.37±0.01	5.34±0.02

Means of three replicates (± SD)

The moisture content for Koronivia cassava variety as shown in Table 5 ranged from 12.4 to 14.7 % whereas for Dombuilevu it was from 12.0 to 14.5 %. The results obtained are consistent with the results reported by Nuwamanya *et al*. [16] and Benesi [8]. Nuwamanya *et al*. [16] reported moisture content ranged from 14.09 and 16.49 % for the parental lines and 14.80 to 16.11 % in the progenies. The native cassava starch moisture content that Benesi [8] found for the ten varieties investigated ranged from 10.47 to 12.83 %.High moisture content in cassava starch is not a desired property. High moisture content in cassava starch leads to growth of micro-organisms that are capable of degrading starch [17]. Moorthy [18] reported that high moisture content affects the pasting properties of cassava starch and Willet and Doane [19] stated that the tensile properties and overall granular structure of starch are also affected by high moisture content.

Table 5: Moisture Content of Cassava Varieties

Cassava Variety	Koronivia	Dombuilevu
	Moisture Content (%)	Moisture Content (%)
Niumea	12.6±0.5	12.9±0.9
Sokobale	14.7±0.6	*
Beqa	14.1±0.8	14.5±0.4
New Guinea	13.9±0.6	13.6±0.9
Coci	13.1±0.5	12.5±1.0
Vula Tolu	13.9±0.6	13.7±1.2
Yabia Damu	12.9±0.3	12.8±0.5
Merelesita	12.4±1.0	13.0±0.4
Nadelei	13.7±0.4	13.6±0.9
Navolau	12.5±1.0	12.0±1.2

Means of three replicates (± SD)

4. COMPARISON OF STARCH YIELDS FROM FIJI CASSAVA WITH OTHER COUNTRIES

In Fiji, cassava has primarily been cultivated for food. More recently, cassava has gained importance as a possible fuel commodity in countries such as China, Thailand, Indonesia, and other countries which have more advanced national biofuel programs. The Fiji government is also looking at improving the country's energy security by developing biofuels to reduce the dependence on diesel and petrol. Some renewable resources that have been identified for bioethanol production in Fiji include sugarcane, molasses and cassava.

4.1 Cambodia [20]

In Cambodia cassava is mostly used for human consumption while little is used for animal feed and industrial purposes. Cassava is usually harvested 6-8 months after planting in flood plain regions. Farmers usually plant the cassava stems into the soil during November and harvest the crop before flooding in June. In the upper lands cassava is planted during wet season and harvested 9-12 months later. Results obtained from major cassava factories in Cambodia showed an average starch content of 24-28% in roots. Most provinces in Cambodia plant cassava for human consumption therefore cultivation practices are limited to minimum land preparation, weeding and fertilizer. However, there are provinces where farmers earn money by selling cassava and cultivation is intensive giving high average yield and production.

4.2 China [21, 22]

In China more than 60% cassava is used for industrial purposes, 30% for animal feed and 10% for human food. Planting of cassava is usually done in the tropical/subtropical extremes of the southeast corner of the country [23]. The mean temperatures in this region are 20-24 °C with clay Oxisols or Alfisols soil of low fertility and pH of 4.5 to 6.6 being used [23]. Crops are grown on flats or ridges and usually intercropped with groundnut or rubber. Stem cutting are placed horizontally [23]. The roots can be processed to make different products due to their high starch content of 28-35%. Over the past years China has been successfully able to introduce new varieties to replace older ones. These new varieties have high starch content and high yield fulfilling the most important breeding objectives in response to China's fast development of cassava processing industry. Most owners of starch factories in China have recognized the importance of raw materials supply. Therefore, they have started to support cassava cultivation with farmers by signing contracts and introducing farmers to varieties that have high starch content and high yield.

4.3 India [24, 25]

India has a unique status on the cassava map for its high yield per hectare among the Asian countries. This has been made possible due to the availability of high yielding varieties, willingness of farmers to adopt these varieties and improved management practices. A large number of varieties are grown in different regions of India and the starch content for these varieties range from a minimum of 22% to as high as 48%. Cassava is grown in India under varying agro-climatic conditions and different soil types. In most states it is grown as rain-fed crop but in some districts like Tamil Nadu it is grown as irrigated crop. Previously, cassava was mostly grown in uplands either on open slopes or in coconut-based cropping systems. However, in the recent years it has shifted to lowland rice-based cropping systems

4.4 Thailand [26]

Thailand over the years has been trying to look for varieties that are most suitable to the environment and with good traits. The desired varieties should have high yield capacity, high harvest index, high root starch content and early harvest time. Thailand had limited cassava genetic diversity therefore, to improve those local varieties and to widen the genetic base, the country introduced many varieties from abroad. Varieties that are present in Thailand have a high starch content of 27.6%. Most of these varieties have other good characteristics such as high fresh root yield, can be planted in late rainy season and more.

Cassava in Thailand is mostly grown as a sole crop [27]. However; occasionally it is intercropped with maize, groundnut, rubber or coconuts. Planting occurs during May to November with most planting done between May to June [23]. Planting is done on flat or ridges by placing the stems vertically in soil. The soil in which cassava is grown is mostly Ultisols of loamy sand or sandy loam texture [23]. Temperatures are usually 27 °C with rainfall of 1100-1500 mm in central plain and 900-1400 mm in the northeast region [23].

4.5 Vietnam [28]

Vietnam is one of the major exporters of cassava. This has been made possible due to their extensive research in identifying varieties that are suitable to the agro-climatic condition and varieties that are high yielding as well as adopting sustainable production practices. The use of farmer participatory research in development and transfer of new technologies to cassava households have been a success. With introduction of high yielding cassava varieties and improved or sustainable production practices have raised the economic effectiveness of cassava production especially in Southeastern region of Vietnam. Several cassava cultural practices have been developed which include, 1.) erosion control by growing vetiver grass and other plant species, 2.) balanced fertilizer application, 3.) intercropping cassava with peanut and/or mungbeans, 4.) planting new high yielding varieties, 5.) using the herbicide Dual, 6.) using silage of cassava leaves and roots to feed animals. All these practices are supported by farmers. In most areas cuttings are planted vertical however, in sandy soils horizontal planting is practiced. Cassava roots in Vietnam can give high starch contents of 25-30%.

4.6 Fiji

In Fiji cassava is predominantly grown for human consumption. There is almost no processing of cassava into dried form for human or animal use. However, apart from food cassava is exported to Australia and New Zealand as frozen tubers. Cassava is grown in most parts of Fiji. As it is tolerant to a range of climatic conditions as well as growing in marginal land, limited effort is currently being placed in improving conditions for planting. There is minimum land preparation, weeding is hardly done and limited fertilizer applied. In 2007 cassava yield was 13.80 t/ha [29]. This yield can be increased with sustainable cultivation practices and also by identifying high yielding varieties. Cassava research in Fiji is mostly done by KRS and other stations of the Ministry of Agriculture, Fisheries and Forest. The maximum starch yield obtained from cassava available in Fiji was 23.3 % and a minimum of 17 %.

Bioethanol is produced by fermenting sugars or substances that contain sugar. Cassava roots contain starch that can be converted to sugar. As seen in the starch results obtained, cassava in Fiji can be used for bioethanol production. The Fiji Government has plans to produce bioethanol from agricultural sources available in Fiji namely sugarcane, molasses and cassava. Experts have pointed out that cassava is the best crop to be used for bioethanol production. The reason being that ethanol yield of cassava per unit land area is higher than any other known energy crop as seen in Table 6, it is also much cheaper to set up a cassava ethanol factory because of lower investment and much simple processing technology due to special characteristics of starch [21]. The cost of cassava ethanol can be lowered due to production of useful by-products from different parts of cassava plant [21].

Table 6: Comparison of ethanol yield made from various energy crops

Crop	Yield (t/ha/year)	Conversion rate to sugar or starch (%)	Conversion rate to ethanol (L/tonne)	Ethanol Yield (kg/ha/year)
Sugarcane	70	12.5	70	4,900
Cassava	40	25	150	6,000
Carrot	45	16	100	4,500
Sweet sorghum	35	14	80	2,800
Maize	5	69	410	2,050
Wheat	4	66	390	1,560
Rice	5	75	450	2,250

Source: [30]

However, since cassava is primarily produced in Fiji for food by the people, an approach needs to be taken that would balance out the use of agricultural land for food and fuel. The use of food crops for fuel usually drives the prices of these crops. For this reason governments in many countries are now ensuring that biofuels do not increase the price of staple foods. The Fiji Government has dismissed the threat to food security on the grounds that more than half of Fiji's almost 2 million hectares of land is idle according to FAO 2006 figures [29]. As stated in the FAO report [29], promoting diversification and setting aside land for food production is one strategy. However, governments need to make a national-level decision as to what extent staple crops should be used for biofuel production.

5. CONCLUSIONS

Cassava roots have a number of end-uses, such as for food and feed processing, starch industry, bioethanol production and for export. The ten varieties of Fiji cassava showed difference in starch yield and dry matter content suggesting that high starch yields could be obtained by selecting suitable varieties for starch extraction. Cassava can be grown in poor soil conditions and in many areas. However, with suitable farming practices cassava root yields as well as starch yield can be increased.

Further research on starch yield and dry matter content needs to be carried out on the other varieties of cassava that are available in Fiji and from various other locations. Also other possible root crops such as yams should be considered for starch and bioethanol production. The Ministry of Agriculture in Fiji should do research on new and better varieties of cassava that are more suitable to the climatic condition and are high yielding. They should also monitor the new varieties released on large scale farming and promote the use of the superior varieties of cassava to farmers.

Finally, in order to consider cassava for bioethanol production a comprehensive feasibility study needs to be conducted. Bioethanol production should only be considered if food versus fuel crisis does not arise.

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Bio-ethanol production from readily available lignocellulosic biomass in Mauritius through Enzymatic hydrolysis.

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Abstract :

Bio-ethanol production from biomass is attracting attention all over the world in view of its use as an alternative source to petrol in the transportation sector. With the aim of having a clean environment, the Government of Mauritius has set out the goal of using ethanol blends, in all vehicles in Mauritius by end of 2012. Thus, the purpose of this study was to find out the potential of obtaining bio-ethanol under the most favorable processing conditions from other types of locally available lignocellulosic biomass to meet the demand for 2012. For that reason, five most readily available feedstock in Mauritius, namely peels of cane stalk (PCS), cane tops and leaves (CTL), elephant grass (EG), coconut husk (CH) and Acacia leaves were used to produce bio-ethanol via the enzymatic hydrolysis technology using the ACCELERASE TM 1000 enzyme. The hydrolysis was carried out at a temperature of 50 ^{0}C and a pH of 5.0. Maximum fermentable sugars were obtained respectively when an enzyme loading of 0.10 ml/gram dry peels of cane stalk were hydrolyzed for 48 hours; an enzyme loading of 0.20 ml/gram dry cane tops and leaves, an enzyme loading of 0.20 ml/gram dry elephant grass both hydrolyzed for 72 hours, enzyme loading of 0.25 ml/gram dry coconut residues hydrolysed for 96 hours and enzyme loading of 0.15 ml/gram dry acacia leaves were hydrolysed for 72 hours. A maximum bio-ethanol yield of 361 Liter/ton peels of cane stalk, 259 Liter/ ton cane tops and leaves, 228 Liter/ton elephant grass, 208 Liter/ton Acacia leaves and 196 Liter/ton coconut husk were obtained when enzymatic hydrolysate were fermented at 35^{0}C and a pH of 6.5.

Keywords: Hydrolysis, Enzyme, ACCELERASE, lignocellulosic, bio-ethanol

1.0 Introduction

The energy consumption has been increasing progressively over the last century due to population growth and industrialization. The use of fossil fuel oil is projected to reach its zenith around the year 2007 and the supply is then projected to be extremely scarce in the coming 40–50 years (Duncan and Youngquist, 1999; Youngquist and Duncan, 2003; Pimentel et al, 2004). It has also been predicted that annual global oil production would decline from the current 25 billion barrels to approximately 5 billion barrels in 2050 (Cheng, 2001). As a result, significant efforts have been made towards the conservation of fossil-based fuels and the exploration and exploitation of new renewable resources (Graham et al, 1998). The focus primarily has been on the outlook for alternatives to the petroleum products. In this spectrum, alcohol manufacture from biomass has attracted a large attention all over the world which could be used as an alternative source to petrol or in blends with petrol (Chandrakant and Bisaria, 1998; Gong, 1999). The commercial feasibility of ethanol production from locally available renewable lignocellulosic resources depends both on its ease of availability and its low cost (Nigam, 2000). Hence, locally produced renewable fuel; ethanol, has the potential to broaden the energy portfolios, lower dependence on foreign oil and to improve trade balances in oil-importing nations (Cheng, 2001).

Lignocellulosic biomass such as agricultural, forest products (hardwood and softwood) and their residues are renewable resources of energy (Wyman and Hinman, 1990). Approximately 90% of the dry weight of most plant material is stored in the form of cellulose, hemi-cellulose, pectin, and lignin. Conversion of cellulose and hemi-cellulose from waste materials to sugars provides a feedstock for the production of fuel ethanol and substantially reduces the amount of wastes that would otherwise exert pressure on municipal landfills (Jamshid et al, 2001). Furthermore, the production of ethanol from lignocellulosic biomass results in a no net contribution to global warming, since the carbon dioxide produced by the combustion of ethanol is consumed by the growing raw material (Sivers & Zacchi, 1995; Galbe et al, 2005).

1.1 Lignocellulosic biomass composition

Lignocellulosic biomass represents the major fraction of most plant matter. Common examples of lignocellulosic biomass include agricultural and forestry residues, organic fraction of municipal solid waste (MSW), industrial processing residues such as wastes in the paper and pulp industry, and herbaceous and woody plants grown as fodder for animals or as feedstocks for the production of fuels (Wyman, 1994; Buss et al, 1992; Lambert et al 1990, Wright, 1988). Lignocellulosic biomass basically consists of three major fractions: cellulose, hemicellulose and lignin (Janick and Whikey, 2002). In general in most types of lignocellulosic biomass, cellulose, the largest fraction of biomass and the primary component of most plants consisting mainly of glucose, appears to be of the order of 35-50% (Updegraff, 1969), hemicellulose, consisting predominantly of the five carbon sugar xylose, appears in the order of 20-35% (Prasner et al 1986; Glodstein and Nelson, 1992), while lignin, a polymer of complex composition that cannot be broken down to form sugar molecules appears to be of the order of 15 to about 25% (Wyman, 1994).

Lignin provides the structural support of a plant and contains no sugar. It encloses the cellulose and hemicellulose thus minimizing their accessibility to microbial enzymes (Martone et al, 2009). Normally, trees have higher lignin content than grasses (Boerjan et al, 2003). A number of other compounds such as plant oils, proteins, and ash make up the remaining fraction of the lignocellulosic biomass structure. However, the composition and percentages of the cellulose, hemicellulose and lignin vary from one plant species to another. Moreover, the composition within a single plant varies with age, stage of growth and other conditions (Jeffries, 1994).

1.2 Ethanol from lignocellulosic biomass

Lignocellulosic biomass represents a vast resource that could be used for production of ethanol. This can be represented in a generalized flowchart as shown below:

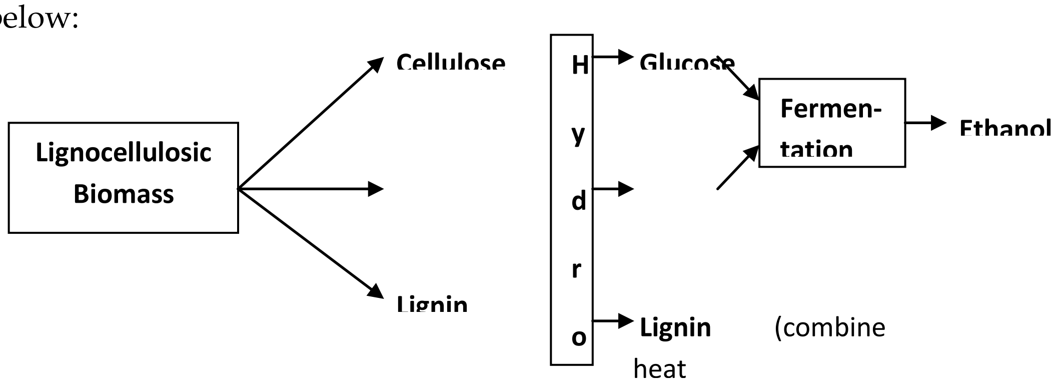


Fig 1: Lignocellulosic biomass to Ethanol flowchart

1.3 Hydrolysis principle

The hydrolysis principle can be thought of as a two-step namely pretreatment and hydrolysis process with production of monomeric sugars. The hydrolysis process can be performed via acid, alkali or enzyme as depicted in the figure below:

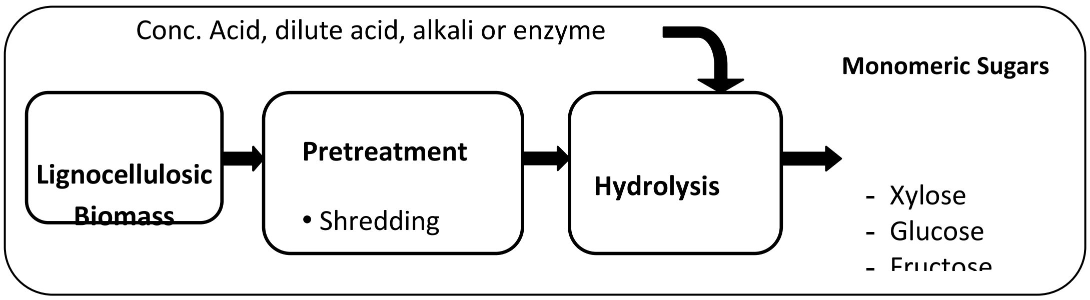


Fig 2: Steps of Hydrolysis

To attain higher efficiency, both physical and chemical pretreatment are required. Physical pretreatment consists of size reduction while chemical pretreatment consists of removing chemical barriers so that the enzymes can access the cellulose easily for microbial destruction. In the pretreatment phase the lignocellulosic material are made amenable to the subsequent hydrolysis step. During hydrolysis, the cellulose and hemicellulose in lignocellulosic biomass are broken down to form individual sugar molecules which can be fermented into ethanol. These sugars are thereafter separated from the residual materials which are the lignin part. The latter can then be burnt as boiler fuel to provide energy to power the process, converted into octane boosters, or used as feedstocks for production of chemicals.

1.4. Enzymatic hydrolysis technology

This study has explored the enzymatic hydrolysis potential for bioethanol production. Enzymes that catalyze the breakdown of cellulose into glucose are known as cellulose. Enzymatic hydrolysis provides a method to convert cellulose to glucose at high yields without sugar product degradation (Gil et al, 1991). Enzymatic hydrolysis of cellulose proceeds in several steps to break glycosidic bonds by the use of cellulase enzymes. Factors effecting hydrolysis of cellulose include type of substrate, cellulase loading, and reaction conditions such as temperature and pH, and end-product inhibitors (Grohmann, 1993; Grohmann et al, 1985). Because enzymes are highly specific in the reactions that they catalyze, formation of by-products as found in dilute acid hydrolysis is avoided, and waste treatment costs are reduced (Wayman et al., 1992). Furthermore, enzymatic reactions take place at mild conditions and achieve high yields with relatively low amounts of catalysts (Mohagheghi et al., 2006). Enzymes have the further advantage in that they are naturally occurring compounds which are biodegradable and environmentally benign (Doran at al, 1994). Advances in enzyme-based technology for ethanol production have been substantial over the years, and as a result, ethanol production costs have been reduced considerably (Jeffries, 2000; Davis et al., 2005).

2.0 Methodology

For this study, five most easily available feedstocks were used. These were cane tops and leaves, Acacia branches and leaves, elephant grass, coconut husk and cane stalk. Sugar cane tops and leaves are generally left in the field after harvest where only a minor amount is collected for fodder for ruminants or treated to be used for thatch roofs and handicrafts. Acacia and elephant grasses are also used as fodder and are highly abundant as they are found everywhere throughout the island. As regards coconut husk, they are found in large quantities near seaside and in markets which are thrown as only the water and the white-cream part are consumed. Only a small amount is being used for artisanal work while the rests consequently add on the pressures of disposal in the landfill. It must be noted that, cane stalk have also been used as one of the feedstock though it is not available that straightforwardly. But since peels of cane stalk have some readily available sugars, it was a potential feedstock.

2.1 Enzymatic Hydrolysis

The feedstock were first pretreated for 15 minutes (Spindler et al, 1991) at 121 ^{0}C in the autoclave with the optimum diluted acid concentration determined in the dilute acid hydrolysis part to expose the cellulose and catalyze the hemicellulose removal for enzymatic hydrolysis. The resulting mixture was filtered and brought to a pH of 5.0 by addition of NaOH. The enzyme ACCELERASE 1000 was then utilized for the hydrolysis.

As per the Product Information sheet the optimal conditions were found to be: a pH of 4.0 – 5.0 and a temperature in the range of 50 – 65 ^{0}C and an enzyme loading of 0.05 - 0.25 ml per g of dry feedstock and a hydrolysis period of 24 hrs or more.

2.2 Fermentation

The hydrolysates were fermented for 24, 48 and 72 hours at a temperature of 32 ^{0}C and pH of 4.0, 5.0 and 6.0 and the best possible fermentation pH and period were determined for each feedstock used via statistical analysis. It must be noted that for Alcodis Limited, normally 1 gram distiller's yeast is used per litre of diluted molasse. For this study, 1.5 gram distiller's yeast was used instead so as to ensure maximum ethanol yield as there might be presence of toxic chemicals that can inhibit the fermentation process since hydrolysis was necessary to obtain the fermentable sugars. Before fermentation, the distiller's yeast has to be cultured in the medium to be fermented. For that purpose, hydrolysates for each feedstock from the various hydrolysis technology was prepared using the optimal conditions.

2.3 Ethanol percentage determination

Ethanol was determined through a precise equipment called the Ebulliometer that bears the standard EC (European Community) marking.

3.0 Results and Discussions:

3.1 Optimum reaction time for Enzymatic hydrolysis

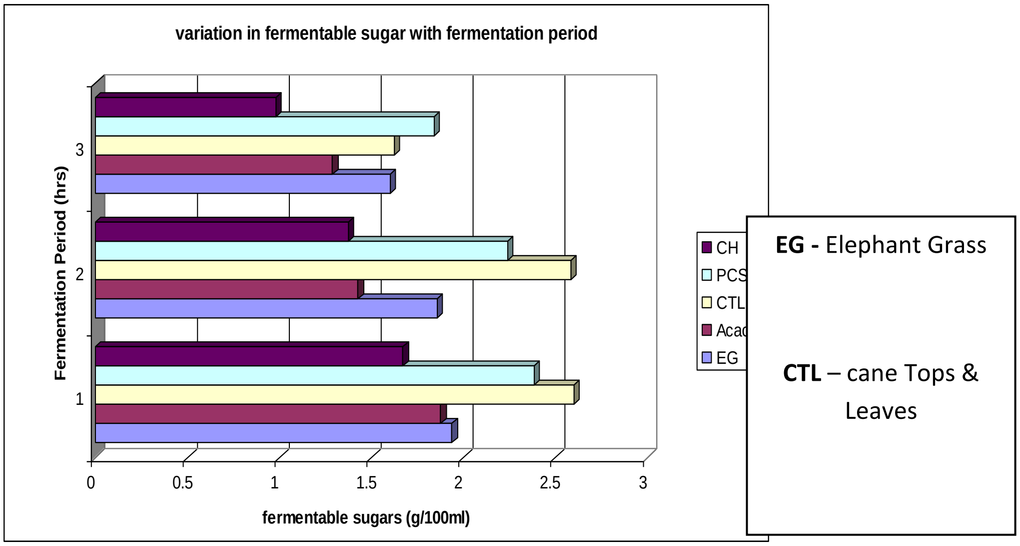


Fig 3: Variation in fermentable sugar with fermentation period.

The 5 types of lignocellulosic biomass reached their best yield when hydrolysed for 72 hours. The topmost yield was a sugar content of 2.684 g/100ml released from the cellulosic and hemicellulosic structure of PCS when hydrolysed for 72 hrs. For the first 24 hrs of enzymatic hydrolysis, the fermentable sugar content reached an amount of 1.842 g/100ml. Subsequently, an increase of 14.87 % and 16.5 % in the yield was noted for 48 hrs and 72 hrs of enzymatic hydrolysis respectively. As regards elephant grass biomass an increase in 11.93 % and 13.14% of fermentable sugar yield was obtained when fermented for more than 24 hrs and 48 hrs respectively. CTL showed an augmentation of 23.31 % and 9.08 % in yield for 48 and 72 hrs of fermentation while for coconut husk, for the same fermentation periods, the yield increase was 23.46 % and 17.77 %.

3.2 Optimum enzyme loading for Enzymatic Hydrolysis

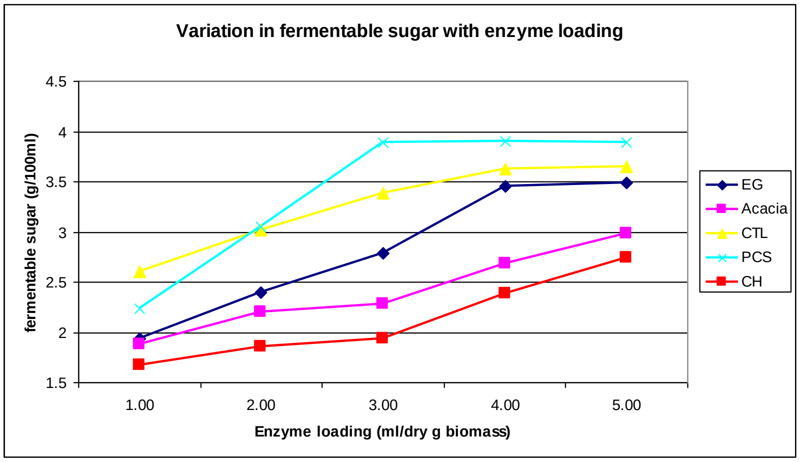


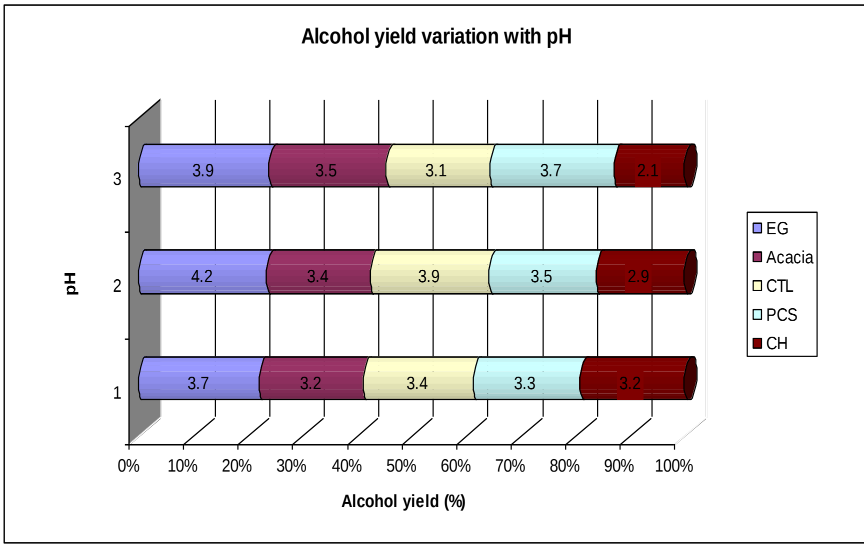
Fig 4: Variation in fermentable sugar with Enzyme loading

The fermentable sugar yield for EG feedstock i9ncresed with increasing enzyme loading, at higher rate of around 13.36 with loadings of 0.05 to 0.20 and a lower rate of 0.7 with loading of 0.25ml/dry g biomass. A loading of 0.25 ml enzyme mash/ dry g biomass resulted in the highest yield. As regards acacia feedstock, highest yield was obtained with 0.25 enzyme loading. Enzyme loading from 0.20 to 0.25 resulted in an increase in 0.16 times implying an increase in yield by 10.11 % with a further loading of 0.05 ml/g dry biomass. CTL feedstock reached its maximum fermentable sugar yield at a loading of 0.20 ml/g dry biomass itself. Concerning the feedstock PCS, 0.15 ml/g dry biomass was taken to be the best enzyme load. Even though, the highest yield was obtained with an enzyme loading of 0.20, it was observed that the net increase in yield that resulted from a further 0.05 loading was < 1 % (0.31 %) and thus was considered to be uneconomical. For the CH, 0.25 enzymes loading resulted in the maximum sugar yield of 2.746 g/100ml solution. From ANOVA single factor, the p value was < 0.05, hence variations in enzyme loading to fermentable sugars yields are significant.

3.3 Fermentation of hydrolysates

After hydrolysis stage, the hydrolysates of all the five lignocellulosic biomass obtained from enzymatic hydrolysis, the optimal conditions determined were fermented with Distiller's yeast.

3.4 Optimum pH for fermentation



EG - Elephant Grass

CTL – cane Tops & Leaves

Fig 5: Variation in ethanol yield with pH

Highest alcohol yield was obtained at pH of 5 for EG (■) – 4.2 % and CTL (□) – 3.9% after 48 hours of fermentation, pH of 6 for Acacia (■) – 3.5 % and PCS (□) – 3.7 % after 72 and 48 hours of fermentation respectively and pH of 4 for CH (■) – 3.2 % after 48 hours of fermentation. These pH values were subsequently used for the rest of the fermentation process.

3.5 Optimum fermentation period for enzymatic hydrolysates

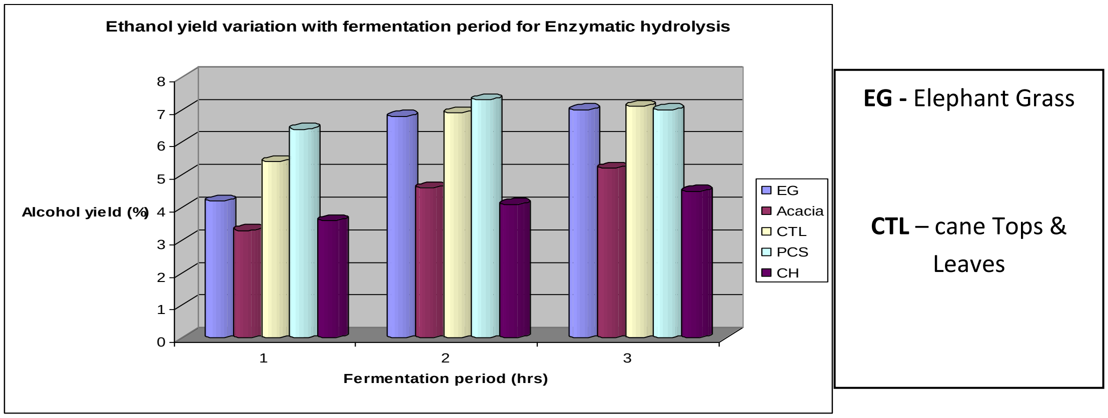


Fig 6: Variations in ethanol % with fermentation period

From the Enzymatic hydrolysis, the feedstock that yielded the most ethanol % was PCS (7.3%) followed by CTL (7.1%), EG (7.0 %), Acacia (5.2%) and CH (4.5%). These topmost yields have been achieved within 72 hours of fermentation except for PCS where maximum yield was already reached after 48 hours of fermentation.

4.0 Conclusion

This study investigated the optimal enzymatic hydrolysis conditions as well as optimal fermentation conditions of five different lignocellulosic feedstocks which are summarized in the table below:

Table 1: Amount of Ethanol at optimal operating conditions for pretreatment, hydrolysis and fermentation of enzymatic hydrolysates (EL – Enzyme loading)

Waste type	Amount of Ethanol (L/ton dry biomass)	Optimal Conditions		
		Dilute Acid pretreatment	**Enzymatic Hydrolysis**	**Fermentation**
Elephant grass	228	4 % Acid, 121 ^{0}C, 15mins	0.20 EL, 72 hrs	pH 5, 72 hrs
Acacia	208	2 % Acid, 100 ^{0}C, 15mins	0.25 EL, 72 hrs	pH 6, 72 hrs
Cane T & L	259	4 % Acid, 121 ^{0}C, 15mins	0.20 EL, 72 hrs	pH 5, 72 hrs
Cane stalk's Peel	361	2 % Acid, 100 ^{0}C, 15mins	0.15 EL, 48 hrs	pH 6, 24 hrs
Coconut husk	196	6 % Acid, 121 ^{0}C, 15mins	0.25 EL, 72 hrs	pH 4, 72 hrs

The highest ethanol yield after undergoing a dilute acid pretreatment was 361 L/ton dry PCS biomass followed by 259 L/ton dry biomass for CTL, 228 L/ton dry biomass for EG, 208 L/ton dry biomass for Acacia and 196 L/ton dry biomass for CH. The experiment carried out on corn stover by Miroslave and Nancy (2004) using genetically engineered yeast gave an ethanol yield of 165 L/ ton corn stover after 24 hours of fermentation. Study carried out with pretreated sugar cane bagasse by Danisco Division at a pH of 5 using ACCELERASE 1000 gave an ethanol yield of 311 L/ ton dry biomass when fermented for 72 hours at an enzyme loading of 0.24. This value can be compared to CTL of the present study. The result obtained from Danisco Division was a little higher to that obtained in present study which can be accounted by the difference in enzyme loading and the biomass structure. However, higher ethanol results were obtained with ACCELERASE 1000 as compared to that of corn stover using genetically engineered yeast.

Hence, all the five biomass are potential feedstock that can be used for effective ethanol production to yield more than 150 L/ton dry biomass from enzymatic hydrolysis. Moreover, PCS and CTL have been found to be the most favorable feedstock for enzymatic hydrolysis.

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Investigating the Potential of Using Coconut oil-Diesel Blends in a Diesel Engine in Rodrigues Island

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Abstract:

The transportation sector of Rodrigues Island is fully dependent on petroleum products, mainly diesel and to a lesser extent gasoline. As an alternative solution to reduce the consumption of petroleum product over the island, this study was thus conducted to assess the performances of coconut oil-diesel blends in a diesel engine in Rodrigues Island. The fuel properties of coconut oil blends in this study were comparable to those of diesel. The engine performance showed that the mechanical efficiency of diesel was 71% and that of the blends were around 71- 77 %. The brake specific fuel consumption (BSFC) for both diesel and blends were around 0.5 kg/kWh with engine revolution below 1500 rpm; but above 1500 rpm the BSFC of the blends were twice as much as that of diesel. A reduction in carbon dioxide and carbon monoxide emissions were achieved up to 16.46 % and 22.81 % respectively. The land requirement for the production of coconut oil to substitute 5% and 25% of actual diesel consumption was 0.95% and 4.73% respectively of the total area of Rodrigues Island. The economic analysis showed that a coconut oil production plant was profitable with payback periods ranging from 4.16 years for 5%-COCO to 1.82 years for 25%-COCO. Potential savings on diesel importation could range from Rs 8,630,400 to Rs 43,152,000.

Keywords: Transportation, Coconut oil, Diesel oil Blends, Engine performance, Rodrigues Island, CO_2 emissions avoided, Economic analysis.

1 Introduction

The transportation sector of most countries has evolved from wheel carts to petroleum fuelled vehicles. The petroleum fuel cars are usually run by gasoline and diesel. It has been observed that the transportation sector is the leading energy consuming sector of almost all countries. The economies of these countries are heavily bonded to their respective transportation sector. A particular fluctuation of the price of the petroleum products can create a chaos in the economy of a country. The exponential increase and abrupt fluctuation of the price of petroleum products has aroused the awareness of the leaders of the world. Furthermore, the use of petroleum products enhances environmental problems such as the global warming effect on the world.

The first countries of the world to suffer from a future oil crisis will be the developing and underdeveloped countries such as Mauritius and consequently Rodrigues Island as well. Rodrigues Island is the second largest island of the Republic of Mauritius. The transportation sector of Rodrigues Island is fully dependent on petroleum products, mainly diesel and to a lesser extent gasoline. The number of vehicles is increasing considerably each year resulting in an increase in the fuel consumption.

The actual petroleum dependency and consumption trend will certainly lead the island to a disaster point of not having a single drop of fuel oil in their engine. The alternatives proposed to avoid this chaos are to either substitute the actual transportation fleet with hybrid vehicles or to substitute the petroleum fuels with vegetable oils, biofuel, synthetic fuels or biogas. The price of hybrid vehicle is quite expensive and unaffordable for the Rodriguans. Since most of the actual electricity production of the island is from heavy fuel oil, hybrid vehicles will not be a sustainable option. The only solution left is to opt for clean alternative fuels which can be produced locally such as coconut oil. The production of coconut oil fuel locally will effectively have a positive impact on the island economy and unemployment rate.

2 Coconut oil as a fuel

Coconut oil can be used in four ways in a diesel engine, namely:

- As a blend to diesel
- As a direct substitute to diesel
- As the base ingredient of the bio-diesel
- As a blend to bio-diesel

The different ways in which the coconut oil is used in a diesel engine is illustrated in Fig. 1. The study is focused on Route 1 only, i.e., Coconut oil blended with diesel There is no or minor alteration on the diesel engine with coconut oil concentration below 20 % [1].

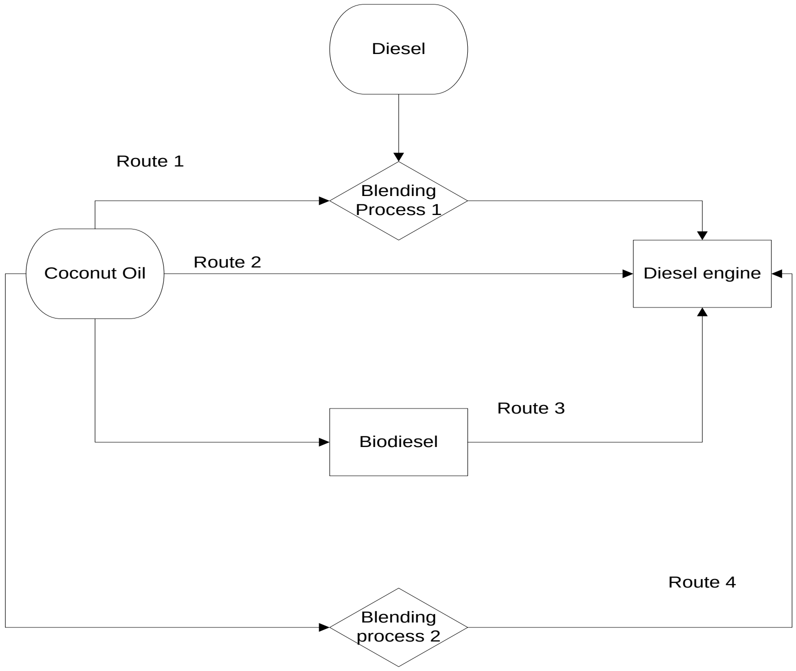


Fig. 1 Illustration of Coconut oil as Fuel

3 Comparison of Chemical and Physical Properties of Diesel and Coconut oil

Table 1 Chemical and Physical Properties of Diesel and Coconut oil

Property	**Diesel**	**Coconut oil**
Composition C/H/O ratio	0.357/0.643	0.317/0.631/0.0517
Sulphur (% wt)	0.100	< 0.009
Iodine Value	-	6.3 – 10.6
Specific Gravity	0.82 – 0.88	0.9 - 0.915
Density (kg/m^3)	820 – 880	900 – 915
Viscosity @ 40 ^{o}C(cSt)	2 - 4	31.59
Cetane Number	40 - 55	37 - 66
Surface Tension (N/m)	0.0318	0.0348
Boiling Point (^{o}C)	160 – 366	> 450
Freezing Point (^{o}C)	-40 – -34	23- 26
Flash Point (^{o}C)	> 52	315
Auto-ignition Temperature (^{o}C)	257	190 - 232
Heating Value (MJ/kg) ▪ High Calorific Value ▪ Low Calorific Value	 45.5 42.8	 37.3 –

The percentage composition of carbon and hydrogen is almost the same for both fuels. Oxygen is present in coconut oil which is not the case for diesel and there is a higher concentration of sulphur in diesel than in the oil.
The specific gravity and density of diesel are 5-10 % superior to coconut oil while there is a slight difference in the surface tension of the fuels. On the other hand, the viscosity of coconut oil can be 10 times greater than that of diesel at 40^{o}C. However, the viscosity of coconut oil can be decrease by either blending or heating.

Cetane number (CN) is a measurement of the combustion quality under diesel engine conditions. Coconut oil has a comparable CN to diesel. The difference in the boiling, freezing, flash and auto-ignition points are mainly due to the molecular bonding of each fuel. The higher calorific value of diesel is greater than that of coconut oil and can reach up to 10 MJ/kg difference.

4 Experimental Set-up and Procedures

A Petter diesel engine coupled with a hydraulic dynamometer was used to determine the performance and exhaust emissions of the engine and fuel blends respectively. The characteristics of the engine are shown in Table 2.0. The Petter engine was connected to a Froude hydraulic dynamometer of type D.P.X non reversible. A hydraulic dynamometer used the resistance offered by water within the system in order to measure the corresponding force, torque or power. The main shaft of the dynamometer was fixed by the bearing found in the casing.

The engine was directly coupled to the main shaft transmitting power to a rotor revolving inside the casing, through which water was distributed. The heat developed was carried away by the water. The hydraulic resistance applied a force upon the casing which turned on its anti-frictional support. This action was counteracted by a lever arm connected to a weighing balance. The resistance of the hydraulic dynamometer was varied by rotating a hand wheel as shown below.

Table 2 Engine Description

Description	**Specification**
Combustion chamber	Direct injection
No. of cylinders	2
No. of stroke per cycle	4
Cooling system	Water-cooled
Compression ratio	16.5:1
Bore x Stroke	80 mm x 110 mm
Cubic capacity	1106 cc

Maximum Rated Power at 1800 rpm	8.95 kW
Compression pressure	37.6 kg cm^{-2}
Maximum firing Pressure	73.8 kg cm^{-2}
Fuel injection release	176 kg cm^{-2}

The fuels used in this study were conventional diesel, coconut oil and coconut oil-diesel fuel blends. The conventional diesel and coconut oil were the parent fuel of the blends. The fuel blends were categorised as shown in Table 3. There was 5 % coconut oil by volume in the first blend and the percentage concentration was gradually increased to 25%.

Table 3 Fuel Composition

Fuel	Composition
Diesel (D)	100 % Diesel
5%-COCO	5 % Coconut Oil + 95 % Diesel
10%-COCO	10 % Coconut Oil + 90 % Diesel
15%-COCO	15 % Coconut Oil + 85 % Diesel
20%-COCO	20 % Coconut Oil + 80 % Diesel
25%-COCO	25 % Coconut Oil + 75 % Diesel
COCO	100 % Coconut Oil

The test procedures were classified as follows:

1. Fuel Properties
2. Engine Performance
3. Exhaust Emissions

The Land requirement for coconut plantation in Rodrigues Island and an economic evaluation of locally produced coconut oil were also assessed.

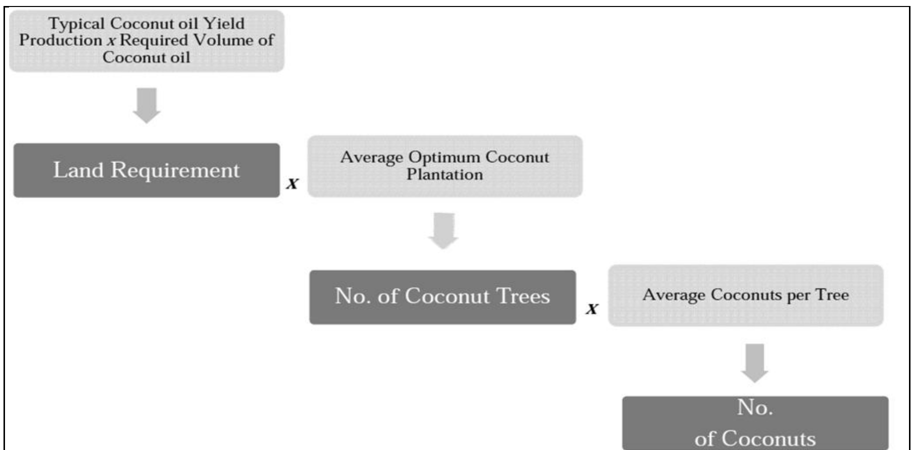
Experiments were carried out to determine the Fuel properties such as density, viscosity and free fatty acid concentration of the different fuel blends. The calorific value and Cetane number of the coconut oil were derived from literature experiments data. The density, viscosity and free fatty acid concentration were measured by weighing a fixed volume of blend on an electronic balance, Brook-Field Synchro-Lectric RVT Model viscometer, titration with potassium hydroxide respectively. The Cetane number of the coconut oil was obtained from the Krisnangkura Equation [2]. The engine performance and exhaust gas emission of the different blends were evaluated using by the Froude hydraulic dynamometer and infra-red Kane automotive gas analyzer. The flue gas of the fuel blends were compared to that of conventional diesel.

The land requirement for the coconut cultivation was estimated from literature review data as shown in Equation 1. The amount of coconut oil needed was obtained by using the importation data of diesel in Rodrigues Island for 2010 as a point of reference. The energetic factor is a ratio of the calorific value of diesel to that of coconut oil. It catered for the difference in calorific value of the two fuels.

Equation 1

$$Required\ Volume\ of\ Coconut\ Oil\ per\ year = \%\ Concentration\ of\ coconut\ oil\ x\ Annual\ Diesel\ Consumption\ \ x\ Energetic\ Factor$$
.

The number of coconuts trees and coconuts were also estimated by using the relations shown in Fig. 2.



	Typical Value	Source
Coconut oil yield production per hectare	2,470 Litres	ASTAE, 2009
Average optimum coconut trees per hectare	175	Fernando & Bandaranayake, 1996
Average coconuts per coconut tree	67	Kumar, 2006

Fig. 2 Land Requirement Calculations

An economic analysis was performed for a local coconut oil production. The raw material was dried copra and the sales of the by-products of the coconut were not taken into account. The estimation of the cost of the raw materials and coconut oil produced were based on literature review data, quotations as well as taking local constraints into consideration. The size and throughput of the equipment were determined for the respective blends based on the amount of dry copra and coconut oil processed. The total capital investment, profit, payback period and internal rate of return were evaluated for the different coconut oil production percentage.

5 General Findings

5.1 Fuel Properties

Table 4 Fuel Properties

	Diesel	5%-COCO	10%-COCO	15%-COCO	20%-COCO	25%-COCO	COCO
Density (kg/m^3)	804	809	814	819	823	826	904
Viscosity (cSt)	2.24	2.35	2.46	2.63	2.73	2.91	8.41
Calorific Value (MJ/kg)	45.5	45.0	44.5	44.0	43.6	43.1	35.8
Acid value/Oil Quality	-	-	-	-	-	-	3.77
Cetane Number	-	-	-	-	-	-	59

There was a slight increase in the density of the fuel blends as the coconut oil concentration was increased. A graph of density against coconut oil concentration was plotted and a straight line was generated with a gradient of 1 kg m^{-3}. The kinematic viscosity had a likewise change as the density with an increase of coconut oil concentration. The kinematic viscosity was significantly higher than that of diesel. Although coconut oil was 3 times more viscous than diesel, the viscosity of 25%-COCO was only 30 % greater than that of diesel. The viscosity of coconut oil was reduced when blended to diesel. The calorific value of the blends acted differently from the density and viscosity scenarios. The calorific value of the COCO blend decreased by 0.096 MJ/kg for each percentage increases in the concentration of coconut oil. The coconut oil was of moderate quality as it had an acid value of 3.77. The Cetane number of the coconut oil was close to that of diesel.

5.2 Engine Performance

The variation of brake power at different speed of the engine of all the fuels is shown in Fig. 3. Almost all the fuel lines generated the same trend line except for 20%-COCO fuel blend. It was observed that as engine speed tended to infinity, the brake power reached zero. The highest brake power of 4.5kW was recorded with 25%-COCO blend which was greater than that of diesel. However, diesel had a constant brake power over a larger range of engine speed tested than any other fuel. 10%-COCO blend yielded a greater brake power over a wider range of engine speed than 5%-COCO, 15%-COCO and 20%-COCO blends. The brake power of all the fuel blends at around 1530 rpm was about 0.254 kW while the brake power of diesel at the same range of engine speed was twice as much, 0.506 kW. These values were obtained with the minimum amount of brake load applied ranging from 1 to 2 pounds.

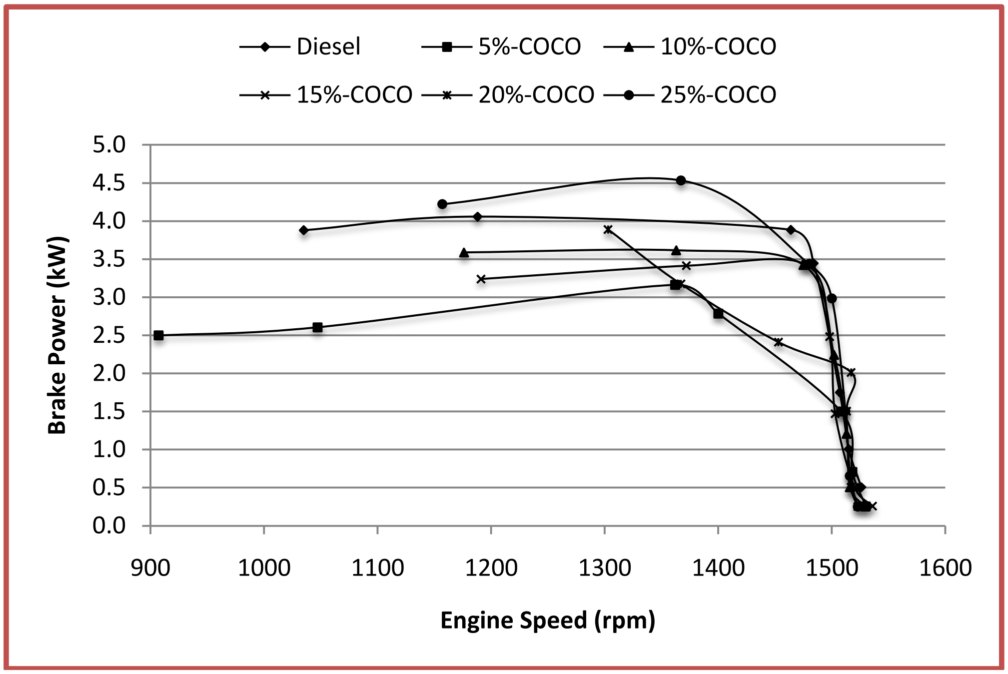


Fig. 3 Brake Power v/s Engine Speed

The brake specific fuel consumption (BSFC) of the fuels at different engine speed and brake power is shown in Fig 4-5 respectively. In Fig. 4, all the fuel lines had BSFC of less than 0.75 kg/kWh up to 1500 rpm. However, as the engine speed was increased up to 1530 rpm, the BSFC of the fuels consequently increased abruptly with a steep gradient. The BSFC of diesel was lower than that of the fuel blends. Since, coconut oil had a lower calorific value than diesel; the engine consumed more fuel to obtain the desirable power to operate at high engine speed.

All the fuels had greater BSFC at their respective minimum brake power or load in Fig. 5. The BSFC of the fuel blends at minimum load ranged from 2.7 – 2.8 kg/kWh while the BSFC of diesel at corresponding load was 1.4 kg/kWh. The maximum BSFC was obtained with 15%-COCO blend which was 2.836 kg/kWh followed by 25%-COCO blend with 2.808 kg/kWh. The BSFC of all fuels decreases below 1 kg/kWh when brake power was greater than 1 kW. The BSFC of the fuels decreased slightly even though after reaching the maximum brake power point. The maximum brake power of diesel was 4.06 kW with a BSFC of 0.444 kg/kWh while that of 25%-COCO blend was 4.532 kW with a BSFC of 0.478 kg/kWh. The engine consumed almost the same amount of diesel and 25%-COCO blend to generate 1kWh at maximum brake power.

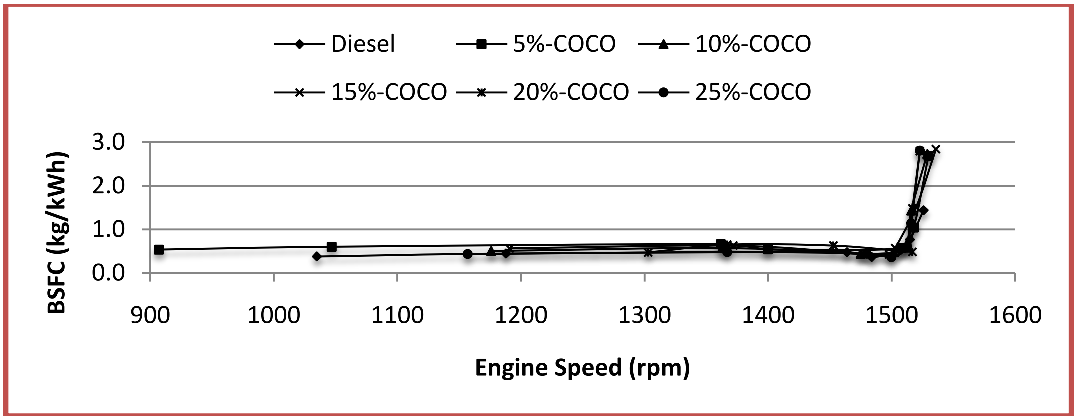


Fig. 4 BSFC v/s Engine Speed

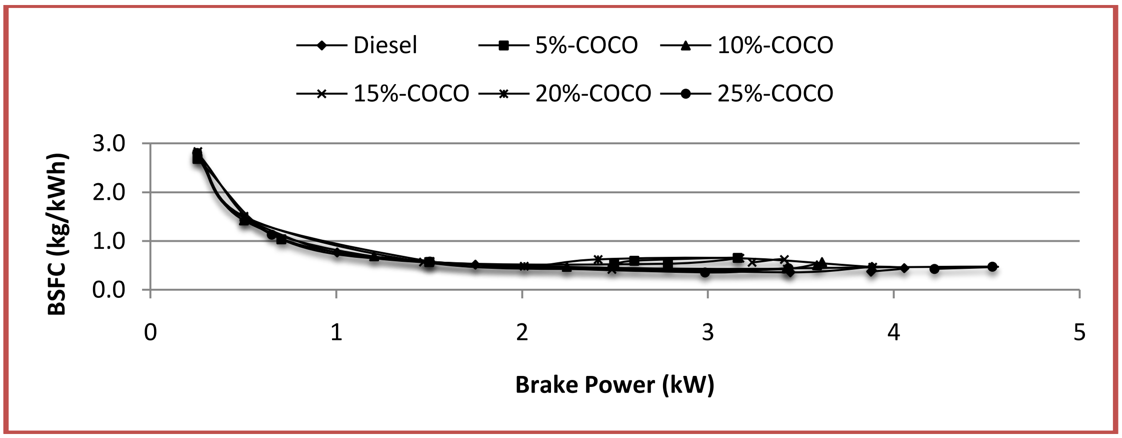


Fig. 5 BSFC v/s Brake Power

The linear relationship of average fuel consumption and brake power is called William's Line. An extrapolation of the William's Line to zero on the horizontal axis yields to the frictional losses within the engine. The William's Lines of the fuels are shown in Fig. 6 and their corresponding gradient and y-intercept are tabulated in Table 5.

The fuel consumption-brake power data did not generate a perfect straight line as it turned up slightly at low loads and considerably at full loads. The frictional power of the fuels ranged from 0.96 kW to 1.66 kW. The fuel consumption required by the engine to overcome frictional power was around 1.7 x 10^{-7} m^3 s^{-1} with most of the blends. The exception was obtained with 5%-COCO. The slope of the William's line of diesel was 0.1 m^3 s^{-1}/kW which meant that 0.1 m^3 s^{-1} of diesel was required to produce 1 kW of power. 25%-COCO was the more energy effective blend while 5%-COCO was the least energy effective blend. The engine blends had similar consumption pattern 10%-COCO and 15%-COCO.

Table 5 William's Line Results

	Fuel Consumption per kW ($m^3\ s^{-1}\ kW^{-1}$)	Fuel Consumption for Frictional Power ($x\ 10^{-6}\ m^3\ s^{-1}$)
Diesel	0.100	0.166
5%-COCO	0.149	0.143
10%-COCO	0.122	0.168
15%-COCO	0.123	0.172
20%-COCO	0.130	0.173
25%-COCO	0.108	0.167

The experimental fuel consumption-brake power data obtained for the different fuels followed the profile stated in the literature review. Hence, the requirements which were set in order to generate the William's Line were achieved. The trend of the fuel consumption with increasing coconut oil concentration in order to generate 1 kW of power was not constant, but was still greater than that of diesel. The reason for that irregular trend could be explained by the different frictional power obtained for the fuels.

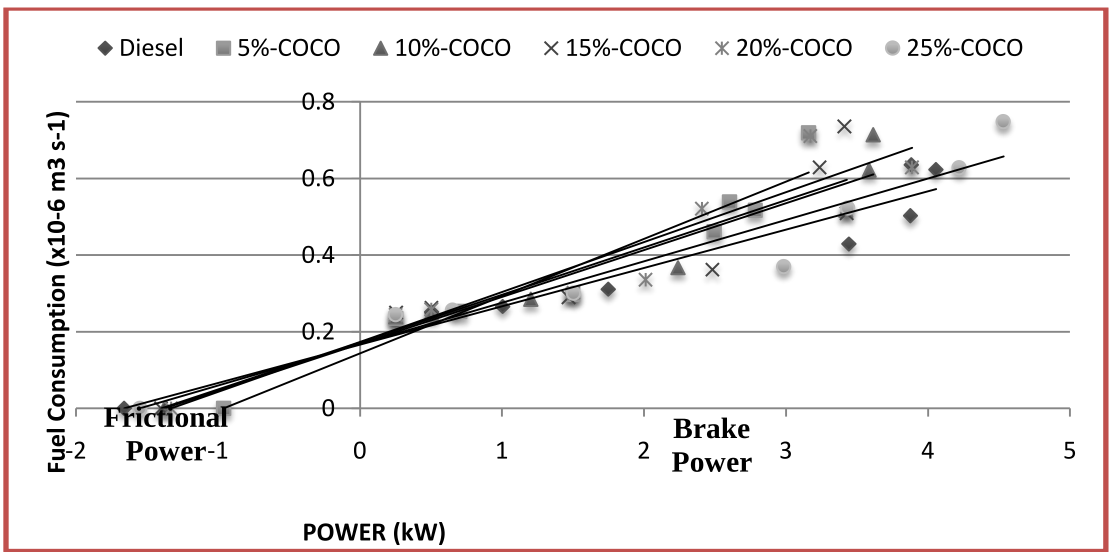


Fig. 6 William's Line Diagram of the fuels

The mechanical efficiencies of the fuels at varying brake power are shown in Fig. 7. All the fuel blends had greater mechanical efficiency than diesel. 5%-COCO blend had the greatest mechanical efficiency of all fuels. The mechanical efficiency curves of 10%, 15% and 20%-COCO blends were relatively similar. The mechanical efficiency curve nearer to diesel was obtained with the 25%-COCO blend.

The total power produced increased with the addition of coconut oil in the mixture. The maximum power generated was obtained with 25%-COCO blend with 6.08 kW. The brake power of diesel was 0.36 kW lesser than that of 25%-COCO. 5%-COCO blend had the least maximum brake power and frictional power of all fuels. The power generated by 10%-COCO was higher than 15%-COCO but lower than 20%-COCO blend. The maximum mechanical efficiency that was obtained with the different fuels was tabulated below.

Table 6 Mechanical Efficiency Results

	Frictional Power (kW)	**Maximum Brake Power (kW)**	**Maximum η_{mech} (%)**
Diesel	1.66	4.06	71.0
5%-COCO	0.96	3.16	76.7
10%-COCO	1.38	3.62	72.4
15%-COCO	1.40	3.43	71.1
20%-COCO	1.33	3.89	74.5
25%-COCO	1.55	4.53	74.6

The maximum mechanical efficiency was recorded with 5%-COCO although it had the lowest brake power of all the fuels. On the other hand, 5%-COCO had the lowest frictional power of the fuels by a greater margin which compensated its small brake power. The higher mechanical efficiency recorded was explained by the positive effect of the COCO blends on the frictional power.

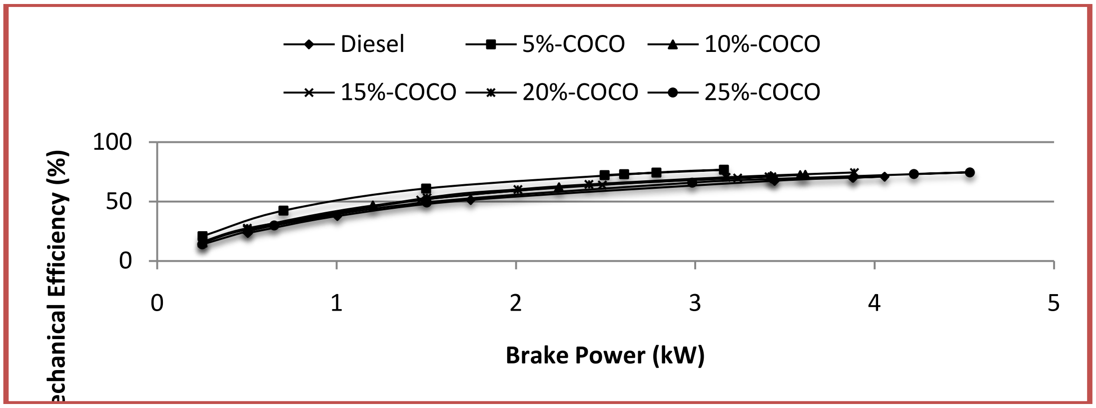


Fig. 7 Mechanical efficiency

5.3 Flue Gas Emission

The relative flue gas emission was based on the exhaust emission obtained with diesel fuel. The percentage volume composition recorded by the flue gas analyser with diesel as fuel is shown in Table 7. The percentage volume of carbon monoxide and oxygen decreased with an increase in the brake load. Conversely, the percentage volume of carbon dioxide and nitrogen oxide increased with additional load. The average percentage composition of nitrogen gas in the exhaust was 80.7 %.

Table 7 Diesel Flue Gas Emission

Flue Gas	No Load		With Load		Average
Carbon Monoxide (% vol)	0.17	0.18	0.09	0.13	0.14
Carbon Dioxide (% vol)	3.30	3.30	8.30	8.80	5.93
Oxygen (% vol)	16.77	16.84	9.89	9.29	13.20
Nitrogen Oxides (ppm)	152	148	674	726	425

The relative emissions of carbon monoxide and carbon dioxide for the different blends are shown in Fig.8. The carbon monoxide and carbon dioxide decreased up 22.81 % and 16.46 % respectively with a 25%-COCO blend. The line generated by the carbon monoxide line had a steeper gradient than that of carbon dioxide. The relative emission of carbon dioxide almost stabilised at 16 – 17 % while that of carbon dioxide continued to diminish. The presence of oxygen molecule in the coconut oil favoured complete combustion thus decreasing the carbon monoxide emission.

The relative emission of nitrogen oxides were not accounted for since no data were recorded for nitrogen oxides emission by the flue gas analyser. There could have been a technical problem with the apparatus or the nitrogen oxides emission was below the standard limit of the flue gas analyser. The smoke intensity of the exhaust was visually assessed and there was a noticeable decrease with increasing coconut oil concentration. A pleasant coconut oil smell was detected with 15%, 20% and 25%-COCO blend.

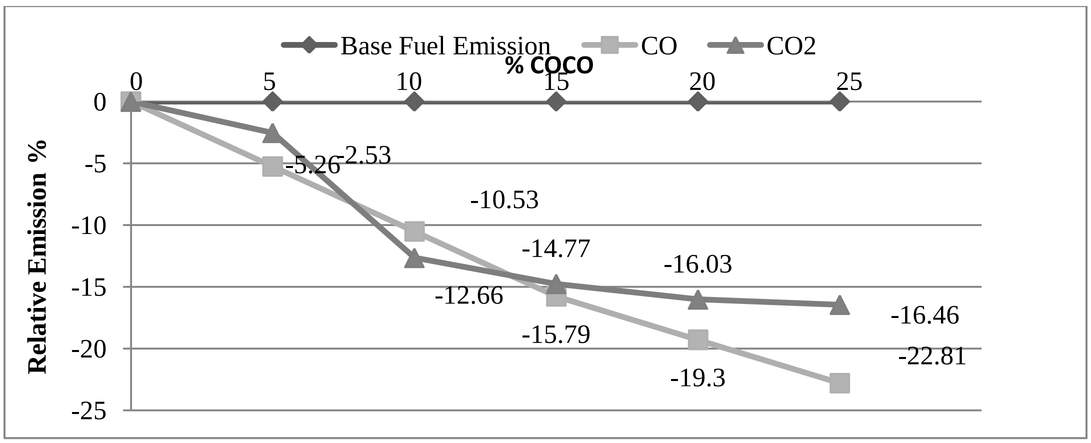


Fig. 8 Relative Flue Gas Emissions

The exhaust emissions were reduced with increasing COCO in blends except for carbon dioxide [3]. However, a reduction in all the exhaust gases including carbon dioxide was observed with increase COCO in blends during the experiments. It could be explained by the higher carbon percentage composition present in Diesel.

5.4 Land Requirement for Coconut Plantation

The land required for coconut plantation was calculated for production of coconut oil for different scenarios. The land requirement eventually increased as the production of coconut oil was increased. The minimum land requirement for the production of coconut oil would be about 102 ha, which is less than 1 % of the total surface area of Rodrigues. It was estimated that 102 ha was required for each 5 % increase in the production of coconut oil. The number of coconuts needed per year for the production of 252,156 to 1,260,782 litres would range from 1,196,975 to 5,984,886. A total of 357,307 coconut trees would be required to meet the actual demand of diesel on the island with a corresponding percentage land requirement was about 19%.

Table 8 Land requirement Data

% COCO	Required Volume of COCO (Litres/year)	No. of Coconuts/ year	No. of Coconut Trees	Land Required (ha)	%Land Requirement (%)
5	252,156	1,196,975	17,865	102	0.95
10	504,313	2,393,955	35,731	204	1.89
15	756,469	3,590,931	53,596	306	2.84
20	1,008,626	4,787,911	71,461	408	3.78
25	1,260,782	5,984,886	89,327	510	4.73
100	5,043,128	23,939,547	357,307	2,042	18.91

However, unoccupied agricultural land of Rodrigues island should be determined in order to find out the actual potential of the coconut plantation. It is worth noting that Table 8 data represented land requirement for the cultivation of coconut trees only. The area needed for coconut oil processing and extraction were not included in the study. The land requirement for these processes was dependent on the type of equipment used. Fig. 9 gives a broad overview of the actual land requirement for the different case scenarios.

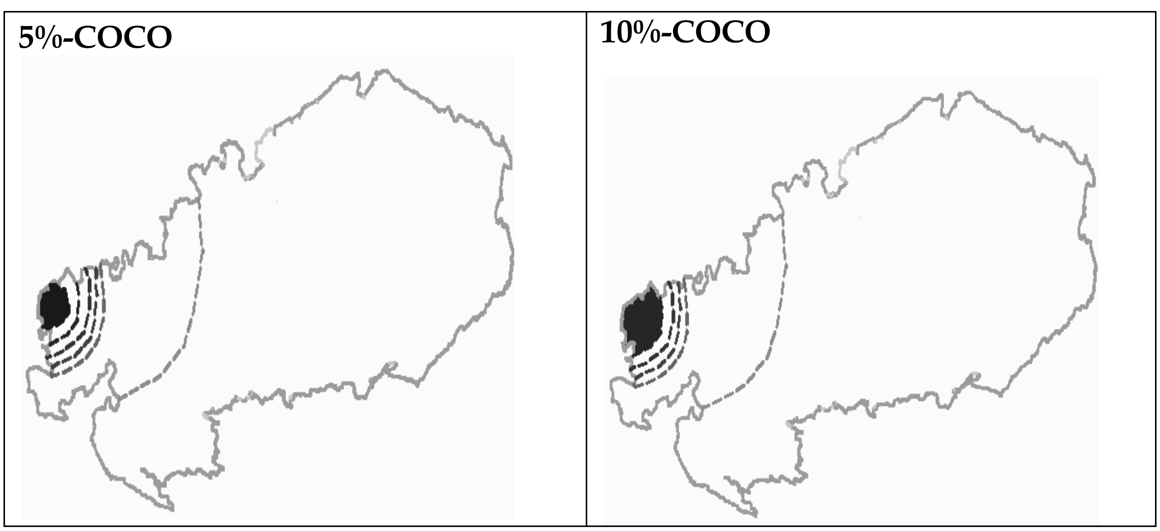


Fig. 9 Land Requirement

5.5 Economic Analysis

The economic analysis was performed for a plant producing coconut oil with dry copra as raw material. The sales of the valuable by-products of the coconut and the relevant cost incurred previous to the dry copra production were not taken into account. The estimation of the cost of the dry copra was based on the price of coconut on the local market as well as taking in consideration that there would be additional revenue from the sales of the by-products. On the other hand, the selling price of the coconut oil coconut oil produced was based on literature review data and quotations.

A positive economic response was obtained for all the blends. However, the minimum TCI required for starting a COCO plant was Rs 1,151,822. The average cost of raw material and labour cost per litre of oil production were Rs 18 and Rs 4 respectively while the average profit was estimated to be around Rs 1.38 per litre. The payback period of 5%-COCO and 25%-COCO was 4.16 and 1.82 years respectively. There was a subsequent increase in the IRR with an increase in coconut oil production. The savings on the importation of diesel ranged from Rs 8,630,400 to Rs 43,152,000. A summary of the economic evaluation of the fuels is shown below.

Table 9 Economic Evaluation Results

	5%-COCO	**10%-COCO**	**15%-COCO**	**20%-COCO**	**25%-COCO**
Revenue (Rs/year)	9,329,772	18,659,575	27,989,353	37,319,162	46,648,934
Total Product Cost (TPC) (Rs/year)	9,052,735	18,050,592	27,038,000	36,024,771	44,997,292
Profit (Rs/year)	277,037	608,983	951,353	1,294,391	1,651,642
Total Capital Investment (TCI) (Rs/year)	1,151,822	1,738,223	2,216,971	2,634,655	3,012,101
Pay Back Period (PBP) (year)	4.16	2.85	2.33	2.08	1.82
IRR (%)	23%	35%	43%	49%	55%
Savings on Diesel (Rs/year)	8,630,400	17,260,800	25,891,200	34,521,600	43,152,000

6 Conclusion

The conclusions that were drawn from this study are:

1. The properties of coconut oil were comparable to that of conventional diesel.
2. The engine ran smoothly with coconut oil-diesel blends tested and no engine modification was required.
3. BSFC for both diesel and blends were around 0.5 kg/kWh with engine revolution below 1500 rpm; but above 1500 rpm the BSFC of the blends were twice as much as that of diesel.
4. The mechanical efficiency of the engine obtained with the blends was greater than diesel since coconut oil had a positive effect on the frictional power of the engine.
5. The presence of coconut oil in the blends considerably reduced the emission of carbon dioxide and carbon monoxide as well as the smoke intensity. The percentage carbon composition and the presence of oxygen in the coconut oil contributed to a reduction of carbon dioxide and carbon monoxide up to 16.46 % and 22.81 % respectively.
6. The land requirement for the production of coconut oil to substitute 5% to 25% of actual diesel consumption was 0.95% and 4.73% respectively of the total area of Rodrigues Island.
7. The production of coconut oil would be economically feasible in the island with all case scenarios.

A general conclusion is that all the tested coconut oil-diesel blends can be used safely in the diesel engine. The only limitation is that at high loads, the fuel consumption of the engine with the blends is much higher than with diesel. Since all the economic case scenarios of coconut oil production are feasible, the island can start replacing the actual diesel consumption by 5% and gradually increase to 25% diesel consumption displacement. There will be numerous job creations from craftsmen to engineer which will help to decrease the actual high unemployment rate on the island. Moreover, the plantation of coconut trees not only reduce the carbon emissions but also act as a barrier to sand and soil erosion which is actually a major problem in Rodrigues island. The evaluation of the economical, environmental and social aspects of the project showed that the project is a sustainable and will greatly improve the well-being of the Rodriguans.

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Remote sensing and GIS techniques for the assessment of biofuel and biomass energy resources

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Abstract:

The Pacific Island Countries (PICs) are faced with energy challenges arising from the lack of availability of fossil fuel sources in the region. Renewable energy has been identified as a primary means by which these challenges could be met. The successful utilization of renewable energy resources of the region will, however, depend on several factors. Among these are the availability of the relevant resources, and the political and legal framework, human capacity, and institutional mechanisms required to develop and implement renewable energy projects.

Biomass and biofuels are two important resources available to many of the PICs. However, before these forms of renewable energy can be used, a necessary first step is the assessment of the availability of these resources, and the land area required to produce them. Remote sensing and GIS are two important techniques that can be employed for this purpose.

In the technique of remote sensing, satellite imagery is used to quantitatively assess the biomass cover and available land area over large areas of a country. The information thus collected is conveniently stored in GIS systems which can be used for decision-making.

This paper begins by showing why there is a need for a quantitative assessment of the biomass and biofuel resource potentials of the region before decisions about the use of such resources can be made. The techniques of remote sensing and GIS are then introduced, and examples of their potential application in the assessment of biomass and biofuel resources provided. The need for a biofuel resource assessment for Fiji is then considered in detail. Finally, recommendations are made for a biomass and biofuel assessment strategy for the Pacific region.

Keywords: Remote sensing, GIS, Pacific Island Countries (PICs), resource assessment, biofuel resources, biomass resources.

1. NEED FOR BIOMASS/BIOFUEL RESOURCE ASSESSMENT

Biomass and biofuels are important renewable energy options for the PICs in their endeavor to reduce their dependence on imported fossil fuels. While biomass is used traditionally as cooking fuel, it also provides the feedstock for biogasification plants and biomass-fired thermal power plants. Biofuels can be used either directly, or after conversion to biodiesel, for transportation and power generation.

An assessment of the biomass and biofuel resources of a PIC is therefore an important pre-requisite to the development of an effective national energy strategy for the country. These resources are, however, determined by the geography and geology of the country. While the rich alluvial soils which are often characteristic of volcanic islands are capable of supporting a variety of biomass and vegetation providing feedstocks for biofuels, the same cannot be said of the coral atoll states.

As the geography of the PICs vary widely, ranging from volcanic islands such as PNG, Solomon Islands, Vanuatu, Fiji and Samoa to coral atolls such as Kiribati. RMI and Tuvalu, the potential within these states for these resources will vary. It is therefore necessary to carry out quantitative measurements to ascertain the extent of these resources in these countries.

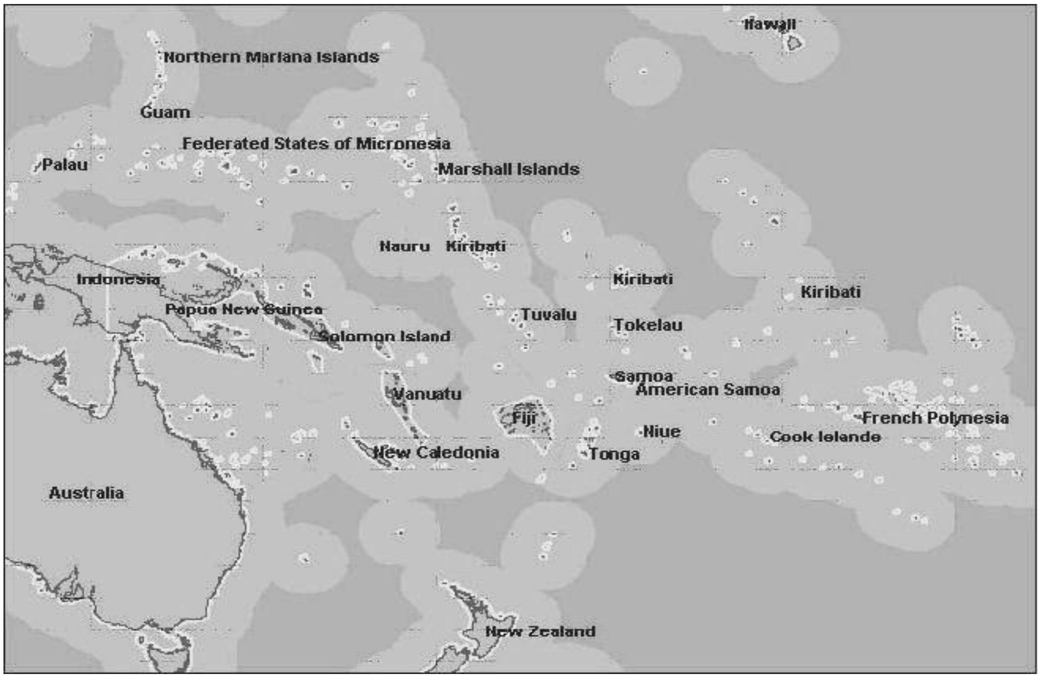

Figure 1: Map of the Pacific, indicating the volcanic chain of islands to the West and the coral atoll nations to the North East.

Two important biofuels that can be produced from indigenously-derived feedstock in the PICs are coconut oil and ethanol. The former is derived on commercial scales from coconut plantations. The latter can be obtained either from sugar or molasses produced from sugarcane plantations, or from root crops such as cassava. It is therefore of interest to determine the extent of the existing crops of such feedstock, and to assess the potential for expanding these stocks further.

Some data for the quantities of these biofuel feedstock already exists [1-4]].

Table 1: Data on available or proposed biofuel feedstock crops in Fiji

Feedstock or crop	Land area (ha)	Volume harvested p.a.(tonnes) (2010)
Sugarcane	45,000 (2010) [1]	132,000 [1]
Cassava	2,600 [2]	34,500 [2]
Coconut	15,000 (2009)[3]	4,977 (2009) [4]

However, additional information is needed for the further development of these resources. For instance, one requires an assessment of the land resources and their distribution. Further information needed to inform the process of the energy strategy development, includes

- How much land area is available for further biofuel feedstock development
- The suitability of such land for biofuel feedstock crops
- Other issues, including land availability and access.

Not all of such information is currently available. There is therefore a need to collect the additional data to better inform the biofuels development program for the region.

Much of such data can be obtained through Remote Sensing (RS). This data can then be combined with the other forms of information mentioned above in the layers of Geographical Information System (GIS) models.

2. GIS and REMOTE SENSING TECHNOLOGIES

2.1 Introduction

Timely data at appropriate scales is critical for the management of natural resources. Remote Sensing provides the means to collect data at broad scales and at variable resolutions for input into GIS based models so that the satellite data can be integrated with other ancillary data for modelling purposes.

A thorough knowledge of the spatial distribution and quantity of resources is critical to any decision making process. In regions with limited resources, there is always competition between interested groups for the utilisation of such resources. In the Pacific Islands there is the added problem of the geographic spread of such resources and their accessibility.

Remote Sensing, which uses satellites or other airborne sensors is a technology that has made great strides in the last 20 years in terms of resolution and repeatability. There are many more satellites from which data can be obtained, and the spatial resolutions are much better than when the first environmental satellites were launched. The repeat cycles (i.e. number of days to repeat capture) have also improved greatly.

In areas with limited resources there is always competition between interested groups for food and resources. Timely data at appropriate scales is critical for conflict resolution and management of the resources. Remote Sensing (RS) provides the means to collect data at broad scales and at variable resolutions for input into GIS-based models so that the satellite data can be integrated with other ancillary data for modelling purposes.

2.2 Biomass estimation

2.2.1 Methods of biomass estimation

In general, biomass includes both the aboveground and below-ground living mass, but due to the difficulty in field data collection of below-ground biomass, RS researchers mainly focus on aboveground biomass [5-7].

Biomass can be measured using 3 different methods: a) direct methods (destructive sampling), b) indirect methods (tree measurements and models), and c) remote sensing approaches. To reduce the need of destructive sampling and develop a rapid and relatively accurate method, non-destructive approaches are usually used. Houghton *et al*. [8] compared different estimation biomass methods in the Brazilian Amazon. The methods included three field measurements, two environmental gradients methods, and two remote sensing techniques. The results indicated that, among the 3 methods, the Olsen method [9] estimated the lowest and the Fearnside method [10] the highest rank of total biomass, but they concluded that a combination of satellite data together with field measurement could have better results for above ground biomass.

A stand growth model, called the 3-PG (use of Physiological Principles in Predicting Growth), have been used in a number of studies. This model can calculate the total carbon from different factors such as solar radiation, temperature and rainfall and converts the carbon to total biomass [11]. Biomass can also be calculated by generalized biomass expansion factors (expanding the total stem volume to total biomass). The expansion factors vary depending on tree species, wood density, site fertility, and climate conditions [12]. Under fieldwork conditions, the diameter at breast height (DBH) and total height, are the most common variables for measuring biomass because of their estimation reliability ([13]. Some studies have shown correlation between tree height and stem diameter variables [14] .

2.2.2 Biomass prediction with remote sensing approaches

A number of studies have used the remote sensing techniques for estimating the aboveground biomass [15-21]. Different approaches such as multiple regression analysis, neural network, and K nearest-neighbour have been used for estimating above ground biomass by remote sensing data [22-23].

The aboveground biomass mapping of the Mediterranean oak forest was done by De Jong *et al*. [24] by using digital airborne imaging spectrometer (DAIS7915), for collecting and analysing data; and spectral indices and multiple regression, for biomass prediction. The biomass map of the Wisconsin national forest was created by Zheng *et al*. [23] by using various vegetation indices from Landsat 7 ETM+ and regression analyses. They concluded that forests stand age map, together with above ground biomass map, could help forest classification and further help to quantify carbon budget, to construct fire modelling and to determine fuel accumulation.

2.2.3 Jatropha: Yield prediction with remote sensing and GIS

Many countries have established or are in the process of establishing Jatropha (*Jatropha curcus Linnaeus*) plantations as an alternative source of energy. The Fiji Department of Energy (FDoE) has a biofuel development program that will access the productivity of this crop as feedstock for Fiji's biofuel industry.

Jatropha has several advantages as an alternative energy crop:

(i) it has a high yield content [25-27],
(ii) (ii) it is drought tolerant
(iii) (iii) it requires only low levels of nutrients [28],
(iv) (iv) is highly adaptable to marginal lands [28], and
(v) (v) emits very low levels of greenhouse gases [29].

The techniques of Remote Sensing and GIS can be used to obtain, store and analyse critical information on the viability of such crops over regions of the globe. Li *et al*. [30] have used GIS to estimate the biological productivity and potential dry seed yield of Jatropha. They used a number of GIS layers to further classify yield according to levels of water and nutrient supply. To identify the spatial locations of future plantations, the yield levels were overlaid with global land cover types (data routinely generated from remote sensing). They then summed the potential area and production in each zone at the national, regional and global scales. The results are presented in Figure 2 below..

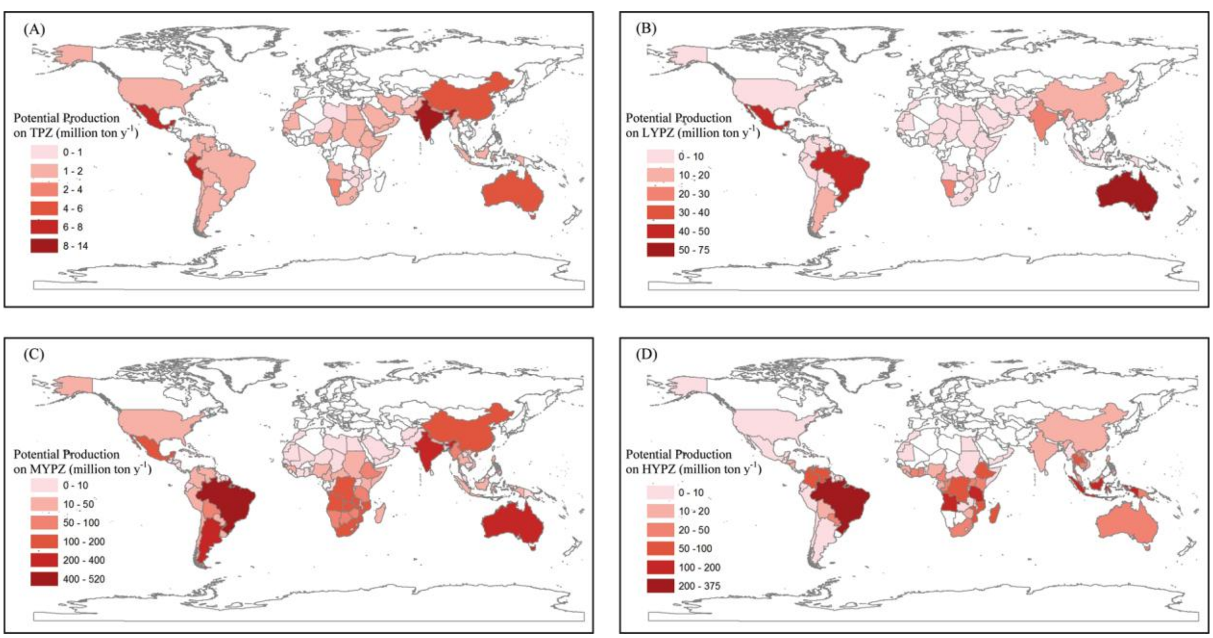

Figure 2 Jatropha dry seed production potential at different zones at a national level (A) Potential production on a tentative plantation zone, (B) Potential production on a low-yield plantation zone (C) Potential production of a medium-

yield plantation zone (D) Potential production of a high-yield plantation zone. (Source: [30]).

Figure 3 shows the dry seed yield of Jatropha based on latitude, annual mean temperature and annual mean precipitation, found by the above workers. An analysis of the location, temperature range and rainfall zones of the Pacific Island Countries shows that most of them would be ideal for Jatropha production. This however has to be linked to current land use and opportunities for conversion of this land for biomass plantations.

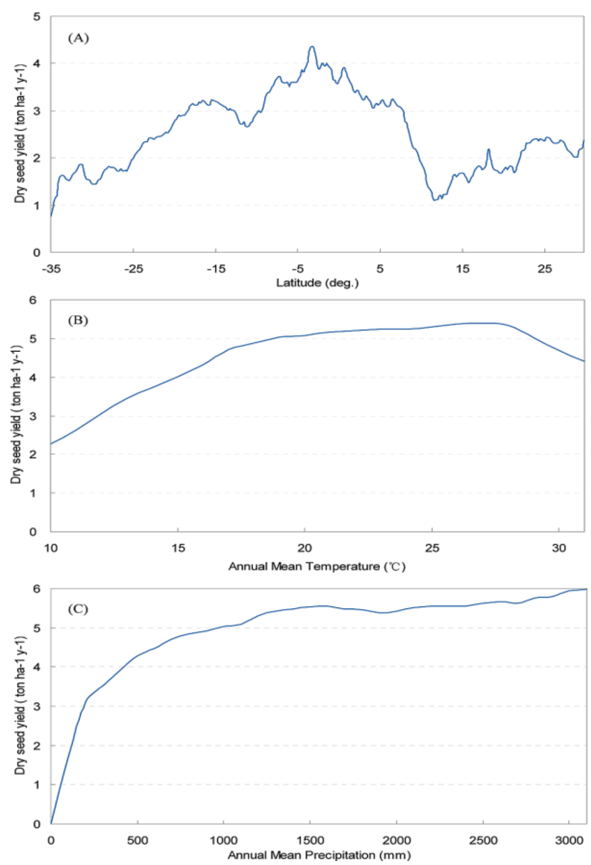

FIGURE 3. Estimated Jatropha dry seed yield depending on the latitude (A), annual mean air temperature (B), and annual mean precipitation (C). (Source: [30])

3. ASSESSING FIJI'S BIOFUEL RESOURCES

3.1 Introduction

Interest in biofuels as renewable energy alternatives to fossil fuels in the Pacific is currently confined to the r first generation biofuel feedstocks. These include sugar-cane derived sugar and molasses, and cassava for the production of ethanol, and a range of existing or potential vegetable oils including coconut oil (CNO), jatropha, pongamia and castor oil for the production of biodiesel.

Ample data is available on the potential for producing ethanol from sugarcane-derived feedstocks. Information on sugarcane plantations and the tonnage of cane, sugar and molasses produced has been carefully maintained by the Fiji Sugar Corporation since the beginning of the industry nearly a hundred years ago. Summaries of such data is available from the Fiji Bureau of Statistics [1].

The annual national production of cassava (an ethanol feedstock) is also available [31]. However there is little documentation of the location of the plantations and other details affecting the productivity of these farms.

While the sizes (areas) of CNO plantations as well as their productivity are known, there is a need to determine regions of plantations and scattered trees and road access to these. Information is also required on suitable land for further development of such plantations. In the case of new crops such as jatropha, a complete resource assessment will have to be undertaken starting from land availability, soil type and climatic conditions, as well as ownership and access issues.

3.2 Applcation of RS and GIS to biofuel resource assessment..

The techniques of remote sensing and GIS are useful devices for the assessment, storage and analysis of data on biofuel crops and a range of parameters that determine their productive yields. Table 2 exemplifies the utility of these techniques in the case of indigenous biofuel feedstock of the Pacific Island Countires (PICs).

Table 2: Application of RS and GIS to the determination and analysis of biofuel feedstock data

Feedstock	Location, terrain and land area	Soil type	Rainfall, temperature	Land ownership, road access
Ethanol feedstock				
Sugar	known	known	known	Known
Cassava	New areas (RS)	(GIS)	(GIS)	(GIS)
Biodiesel feedstock				
Coconut	Area, no. of trees (RS)	GIS	GIS	GIS
New vegetable oil crops	RS	GIS	GIS	GIS

Sugarcane, which produces molasses as a feedstock for ethanol production, is only cultivated in Fiji and information on its production details is well documented by the Fiji Sugar Corporation. In the case of cassava, while summary data on the total amount of production is available for the whole region [Krishna], little is known about the geographical distribution of the plantations. In addition, no information is available on possible new areas where this crop could be grown. Remote Sensing will be instrumental in providing data for the further investigation of such new sites, while GIS provides a suitable technology for the storage and analysis of information on the soil types, rainfall, temperature and land ownership and road access details. Both these techniques can complement each other in the acquisition and analysis of data required for the production of new vegetable oil crops such as jatropha, pongamia and castor throughout the region.

3.3 Jatropha Cursis – Fiji Government development programme

The Fiji government has an ambitious programme for the trialing and cultivation of Jatropha as a potential feedstock for biodiesel production [32].

The program will include the

- establishment of germplasm
- collection of promising progenies as future seed source
- establishment of nurseries for growing jatropha seedlings
- identification of suitable locations for jatropha plantations
- documentation of agri-techniques for the jatropha cultivation
- establishment of demo plots,
- production of bodiesel, and the
- evaluation of the economics of the whole program.

The following data can be provided and managed through RS-GIS for this proposed program:

- Identification of suitable location, including terrain and soil types
- Rainfall data
- Road access and land ownership

The simple examples presented above illustrate the significant utility of RS-GIS techniques in the assessment of biofuel resources in the PICs.

4. A STRATEGY FOR REGIONAL BIOMASS/BIOFUEL RESOURCE ASSESSMENT

It is clear from the above examples that RS-GIS techniques can play a pivotal role in the resource analysis of existing or proposed biofuel crops in Fiji. A similar need exists for the rest of the region, as exemplified by the Samoan interest in bio-gasification [33], and the proposed use of CNO by the Tongan government in their energy roadmap (TERM) [34]. A region-wide assessment of biomass and biofuel resources is thus in order.

A regional resource assessment strategy can use either a broad spectrum approach or a focused approach. In the former, a systematic assessment is carried out of all potential resources in all PICs, whereas in the focused approach, a selective assessment is considered, based on the stated requirements of the individual PICs. These requirements can be obtained from the individual National Energy Roadmaps of the PICs. If budget considerations are kept in mind, the latter approach is clearly a more viable alternative

A suitable methodology will involve

- Determining the assessment requirements of each PIC through actual consultation
- Collecting initial data from individual lands departments
- Planning detailed satellite imagery based on the above information
- Looking for funding from, e.g. from regional development partners
- Preparing funding proposal (with, if possible, the involvement of trainee students), and
- Project implementation

Whatever the method adopted, the value of such a resource assessment to the development of energy policies in the region cannot be under-estimated.

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Optimization of biogas production to use in cooking stove

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Abstract:

The objective of this project is to enhance the biogas production from anaerobic digestion of resources, like organic wastes, which are readily available on the island. The project laid emphasis on the optimization of the process which includes methods available up to date to enhance the biogas production.

Anaerobic Digestion is the biological treatment of biodegradable organic waste in the absence of oxygen, utilizing microbial activity to break down the waste in a controlled environment. Anaerobic digestion results in the generation of biogas; which is rich in methane, were used to generate heat in a cooking stove. The digestate which is nutrient rich can potentially be used as a soil conditioner or as fertilizer.

The digestion process took place in a sealed airtight container (the digester) which was the ideal conditions for the bacteria to ferment the organic material in oxygen-free conditions. A pilot anaerobic digester of 1 m3 was designed proposed whereby cow dung was used as feed to operate the digester. The digester consisted of a mixing unit integrated inside. The digester was then connected to a holder whereby it was used as a biogas storage system. From there on, the biogas was sent to a stove for cooking purposes. Plastics tank were selected as the main material for the design since it was easily available on the market and had low investment cost. This kind of project would be implemented at farmers or lower middle class people who reared cows, since the feed is readily available. This project was feasible for typical Mauritian family in terms of technical, social and economical factors.

Keywords: Small Developing Island, Renewable Energy Knowledge, Technology Transfer

1.0 INTRODUCTION

Controlled anaerobic digestion is by no means a radical or new concept. Large scale industrial digesters and small domestic digesters are in operation in many places around the world. The purpose of all these digesters is to produce combustible biogas which can be burned to provide energy for a whole range of uses. Here in Mauritius, there is quite a bit of ideological interest in anaerobic digestion and biogas production, particularly from intensive farmers, but there are not many examples of digesters in operation. These farmers are interested in this topic primarily as an alternative energy source (biogas), and secondly, as part of an efficient effluent waste disposal system for the farm.

Somehow there seems to be a problem in finding ways to put controlled anaerobic digestion into practice on the average Mauritian farm. The reasons why this concept is not being realized more could be a number of possible reasons such as the capital cost of setting up an anaerobic digester project, a lack of working models and / or a lack of a source of ideas to base individual projects on, i.e. - trouble shooting and project development at a technical 'on farm' level.

A given amount of volatile solids of a particular waste can be converted to a maximum amount of biogas at a given temperature provided optimum conditions are prevalent. This conversion can be accounted by two factors i.e. biodegradability at a specified temperature and operating conditions that depend on kinetics, reactor configuration, the flow pattern within the digester, digestion stage as well as the presence of the inhibitory substances.

This project is definitely not supposed to be revolutionary or radically new, but rather to be a starting point for further research and development in this area.

2.0 METHODOLOGY

2.1 Objectives

The purpose of this project was to develop a small scale working prototype possibly suited to operate on the average farm. The focus of this project was the production of combustible biogas. The main objective of this research is to employ anaerobic digestion process as a sustainable technology for minimizing the animal solids waste and to provide the renewable source of energy as well as to reduce the potential greenhouse gases emission. The specific objectives of this study are; to construct a pilot-scale anaerobic digester, to optimize the methane yield of substrate with different techniques, to analyze the operational parameters for the stability of Anaerobic Digestion system, to investigate the optimization of the anaerobic digestion system and to analyze biodegradability of organic materials.

2.2 Design

The methodology adopted was firstly the digester was designed and constructed using locally available materials. The design and construction phase is consisted of selecting the basic parameters to be assumed during the construction of the biodigester. The biodigester being the main part of the stand alone system has similar features as the fixed dome digester. It is typically a high density polyethylene plastic tank. This tank was chosen since it is normally readily available in the local market and it is cost effective. Considering the low budget criteria of this project, the mixing part cannot be run with a motor installed with the biodigester. It is going to be very expensive. Thus to design a manual mixing system, Archimedes's screw principle is proposed. The biogas purification is another phase in this project. The scrubbing of the biogas in order to remove impurities that are generated during the digestion process such as CO2 (carbon dioxide) and H2S (hydrogen sulphide) is very important. The scrubbing is viewed as very important as hydrogen sulphide is highly corrosive to the cooking and heating systems that would utilize the biogas, and the presence of carbon dioxide makes the gas more difficult to compress and store, although it does not increase the volatility. A simple method for hydrogen sulphide utilizing steel wool in a glass bottle is modelled and to remove carbon dioxide from biogas, 1M sodium hydroxide is used for scrubbing.

After scrubbing, the can be directed to the cooking stove via pipelines. To measure the biogas releasing from the biodigester, the method of an inverted measuring cylinder is proposed.

2.3 Analysis

Following the construction phase was the analysis phase which comprised of testing the parameters concerned during the anaerobic digestion process. Most of the lab works were performed either in the UOM Chemical Engineering laboratories found in phase 2 building or on the sixth floor of Engineering tower. The samples, from feed, sludge and biogas streams were collected for analytical tests. Parameters such as chemical oxygen demand, total solids, volatile solids, carbon to nitrogen ratio, moisture content, ash content, pH, volatile fatty acids, volume of biogas produced daily and heating value of biogas were analyzed using standard laboratory techniques.

3.0 CONSTRUCTION

3.1 Biodigester

The mechanism of system included the biodigester, mixing system, scrubbing system, gas measuring system and the cooking stove for the combustion purpose of biogas. The biodigester is mainly a plastic tank in which a mixing unit is integrated in it. The feed and output system will be also mounted. The plastic tank is a high density polyethylene plastic water tank having dimensions of 110 cm by 96 cm by 92 cm.

Table 1: Characteristics of the HDPE tank.

Characteristics	Value
Type	Plastic
Material	High density polyethylene
Volume	1050 L
Weight	70 kg
Pressure	100 kPa

Volume of gas occupied	0.2 m3
Volume of substrate mixture	0.8 m3

3.2 Mixing system

The design of the mixing unit is derived from the principle of working of the Archimedes screw. The Archimedes 'screw consists of a screw inside a hollow pipe. The screw is turned usually by manual labour. As the bottom end of the tube turns, it scoops up a volume of liquid. This amount of liquid will slide up in the spiral tube as the shaft is turned, until it finally pours out from the top of the tube. Based on the handbook of the design and operation of Archimedes screws, the geometry of the mixing unit is calculated [1 & 2].

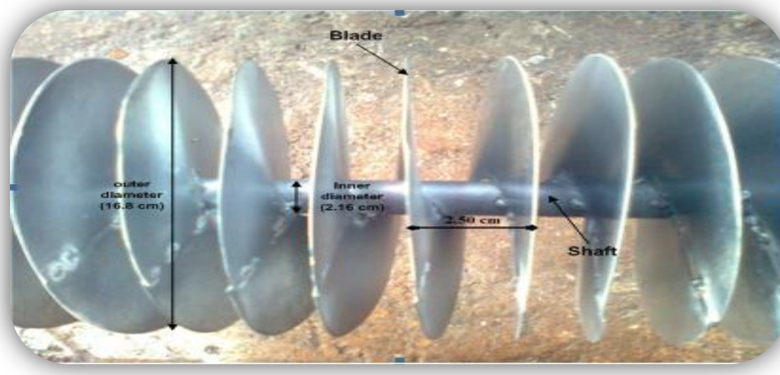

Figure 1.0: Labeled view of the mixing unit.

At the end of the screw, a three-bladed propeller is fixed to enable mixing of the substrate found at the bottom of the digester. The figures below show picture of the final construction of the digester.

Figure 2.0: Three-bladed propeller

Figure 3.0: Side view of digester

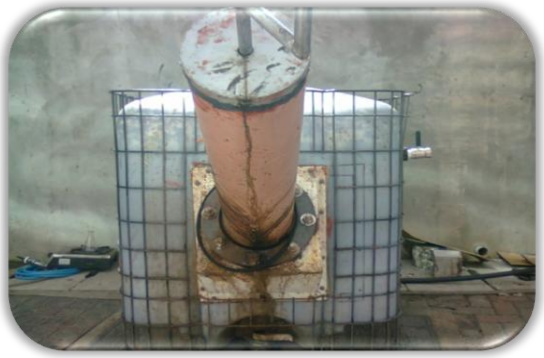

Figure 4.0: Front view of digester

3.3 Materials of construction

The selection for the materials of construction was done keeping in mind that this project is to be implemented in farms or in at houses of low income. The table below summaries the different materials selected for the different parts of digester and reasons.

Table 2.0: Summary of the materials of construction

Components		Material of construction	Reason(s)
Tank		HDPE (high density polyethylene)	▪ The plastic material is found to be able to meet the stringent demands of the chemical compability of digestion process. ▪ The plastic tank is virtually impervious to acids and alkalis, flexible, and durable. ▪ Low cost
Mixing unit	Inner part	Galvanized steel	▪ Zinc coatings prevent corrosion of the protected metal by forming a physical barrier. ▪ Low cost compared to other materials locally available.
	Outer part	PVC (polyvinylchloride)	▪ Resistant to chemicals. ▪ Offers high quality standards.

Fittings & piping	Reinforced flexible hoses	▪ Suitable due to their strength and inertness towards fluids.

4.0 RESULTS AND DISCUSSION

4.1 Substrate characteristics

The physical and chemical characteristics of the organic waste are important for the design and operation of anaerobic reactors as they have an effect on the biogas production and process stability during anaerobic digestion [3]. The parameters analysed for the characterization of dairy manure and agricultural residues were: moisture content, total solid content, volatile solid, pH, chemical oxygen demand and C/N ratio. All these analytical determination for the characteristic of the dairy manure were performed according to the standard method [4].

The findings as per the survey are displayed in this chapter together with some pictures taken on site. Results obtained from burning of the biogas is also discussed and the carbon dioxide emissions avoided are discussed in this chapter.

The physical and chemical characteristics of cow manure were analysed according to the standard method [4]. The result obtained for the total solid, volatile solid, pH, chemical oxygen demand and C/N ratio are summarized below.

Table 3.0: Substrate characteristics.

Parameters	Value
Moisture Content (%)	85.0
Volatile Solids (%)	84.6
Total Solids (%)	15.0
Chemical Oxygen Demand (g/ml)	78,125

pH	6.79
C/N ratio	26.57

The value for C/N ratio reported in the literature review for stable and better biological conversion of organic waste to biogas during anaerobic digestion lies within the range of 20 – 30. The carbon to nitrogen ratio for cow manure was found to be 26.57 and this ratio can be considered appropriate for the anaerobic bacteria as stated in the literature review. It was found that the total solid content of cow manure was 9.7-13 but from the table above the total solid content of the cow manure was slight higher due to a lower moisture content and higher organic content present in the cow manure [5]. Various studies reported that the volatile solid of cow manure was 83.0 and the result obtained during the experiment was almost similar at 84.6 [6].

The chemical oxygen demand of the dairy manure was also investigated and it was found to be 78,125 mg/l. However, other studies found that the COD of cow manure was 129,400 mg/l, 38230 mg/l and 165,000 mg/l [5, 6 & 8]. These different values confirmed that the COD depends on the solid content present in the cow manure.

The cow manure has pH of 6.79, as it is slightly acid by nature.

4.2 Biogas production

The performance of the experimental digester was monitored for 34 days. Initial the anaerobic reactor was fed with 540 kg of substrate. The volume of the biogas produced was measured four to five times a week through the water displacement method using a measuring cylinder of 2000 ml. The samples were also removed from the digester twice a week from the digester and were analysed for moisture content, volatile solid, pH and chemical oxygen demand according as per the standard method [4]

The graph above shows the rate of biogas production throughout the experimental period of 34 days. The degradation of the organic waste by the methanogenesis bacteria started as from the first day of the set – up of the anaerobic reactor. The biogas production was monitored four to five times per week and the volumetric biogas production for the experimental period.

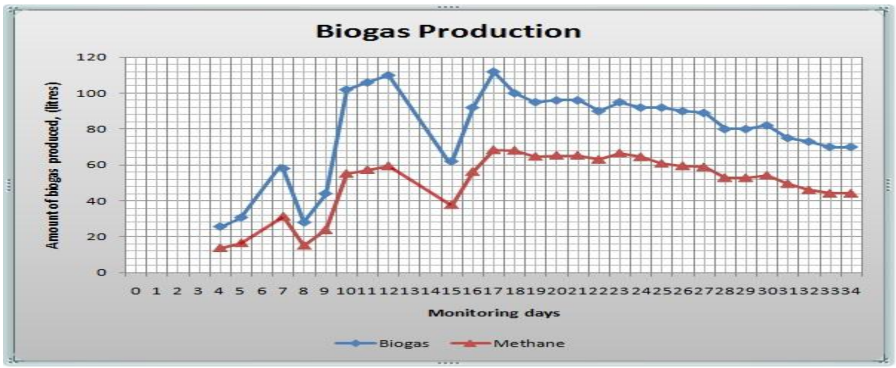

Figure 5.0: Biogas production through out the project.

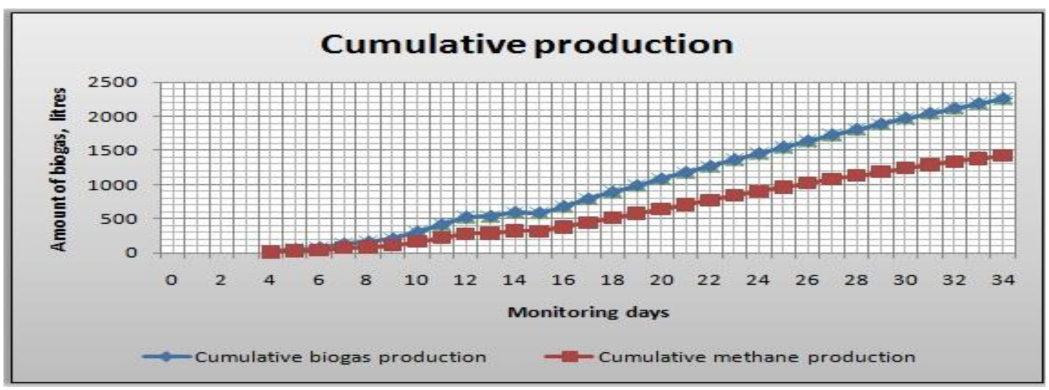

Figure 6.0: Cumulative production of biogas and methane.

The graphs indicate the biogas production and cumulative biogas production for the 34 days. The reactor was operated in batch mode for 34 days from the start up process. On the fourth day the first volume of biogas production was noted. As from day 6, the volume of biogas produced showed a decreasing trend due to the abrupt decrease in the pH. After the biogas production continues to increase daily and it reaches its maximum percentage on day 14. This occurred due to the fact that the digester was left on purpose for two days so as biogas would build up and have enough pressure for it to have a constant flame during ignition. On day 14, 38 minutes of burning of the biogas was recorded and still 62 litres of biogas remaining in the digester was measured.

As from day 16, the biogas production rate fell indicating exhausting of readily accessible substrate for biogas production as some of the organic substrate in the reactor was already converted to biogas by the methanogenesis bacteria. After that gradual decrease but constant of biogas production was recorded. The second graph indicates the trend of accumulative biogas production for the 34 days retention time. The total amount of methane noted at the end of the 34 days was 2179 L.

4.3 pH and volatile fatty acids variation

pH is one of the most useful parameter that indicates process stability and proper activities of methanogens in the anaerobic reactor. The accepted pH range for optimal growth of methanogens for anaerobic digestion is between 6.5 and 8.5. The pH of the experimental reactor was carefully monitored every two days for a period of 23 days.

At the start of the process, the composition of the substrate was slightly acidic as the pH in the reactor was below seven during the first 6 days. This was due to the formation of volatile fatty acid and this indicates that the digestion process had undergone the hydrolysis stage and reached the acidogenesis stage. To provide a stable medium for optimal activity of methanogenic bacteria, the digester was mixed well thoroughly thrice a day for days 7 and 8. On day 8 the pH of the reactor was 6.7 and compared to day 6 there was a significant increase in the amount of methane collected. Keeping in mind everyday, the digester was to be manually mixed at least twice a day. The increase in pH and biogas yield, indicate that the methanogenesis phase was taking place inside the reactor. After the pH was more or less constant through out the whole process; indicating a rather stabilized process as shown in figure 7.0.

The significance study showed that VFA is generally a good parameter for predicting process instability. In mesophilic conditions, the production of VFA decreased from 522.35 mg/L within 25 days of retention time to 243 mg/L. After 25 days VFA is increased by 24%; which can be explained due to the increase in pH at that period of time. This also explains the increase in alkalinity within the same period of retention days. Below shows the different graphs of pH and alkalinity trend through out the process.

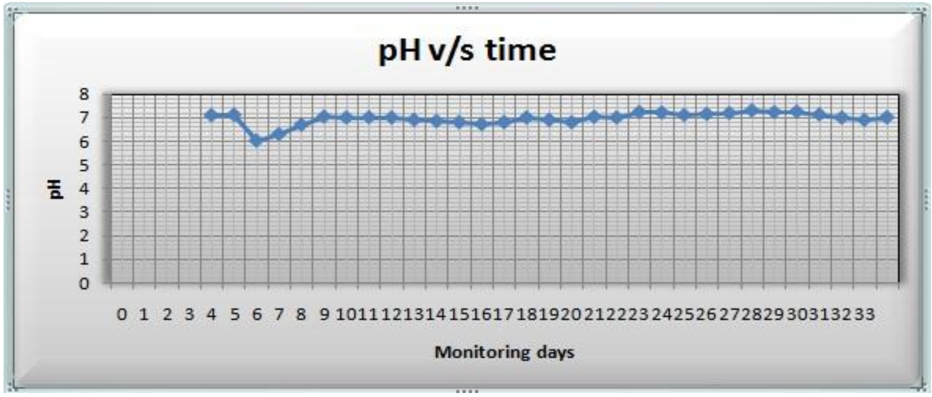

Figure 7.0: Graph of pH variation with time.

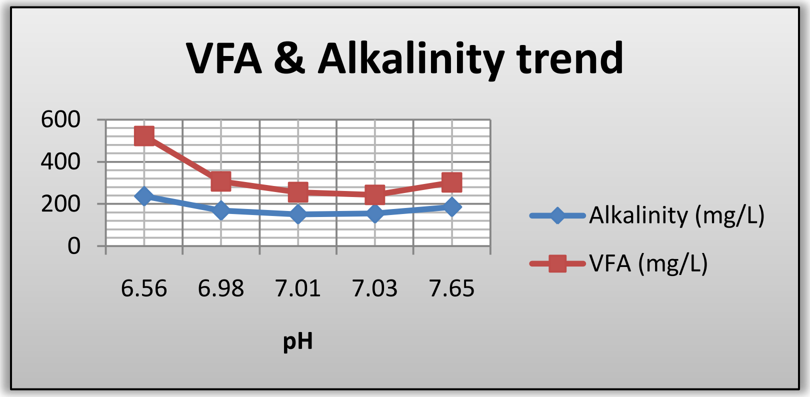

Figure 8.0: Graph of VFA and Alkalinity against pH.

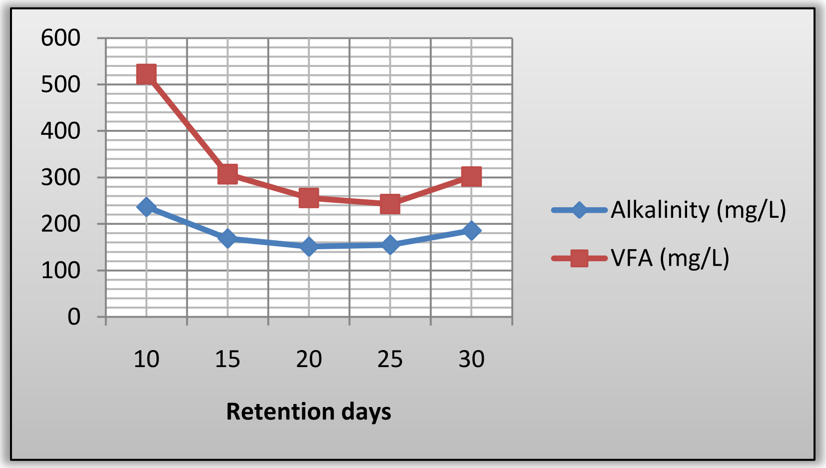

Figure 9.0: Graph of VFA and Alkalinity against retention days.

4.4 Chemical Oxygen Demand.

The chemical oxygen demand was used to measure the degree of decomposition of organic material present in the digester for the experimental period of 23 days. Chemical oxygen demand is a general measure of the amount of soluble organic compounds, which give an indication of the amount of soluble carbon compound that can be converted to methane during the process of anaerobic digestion.

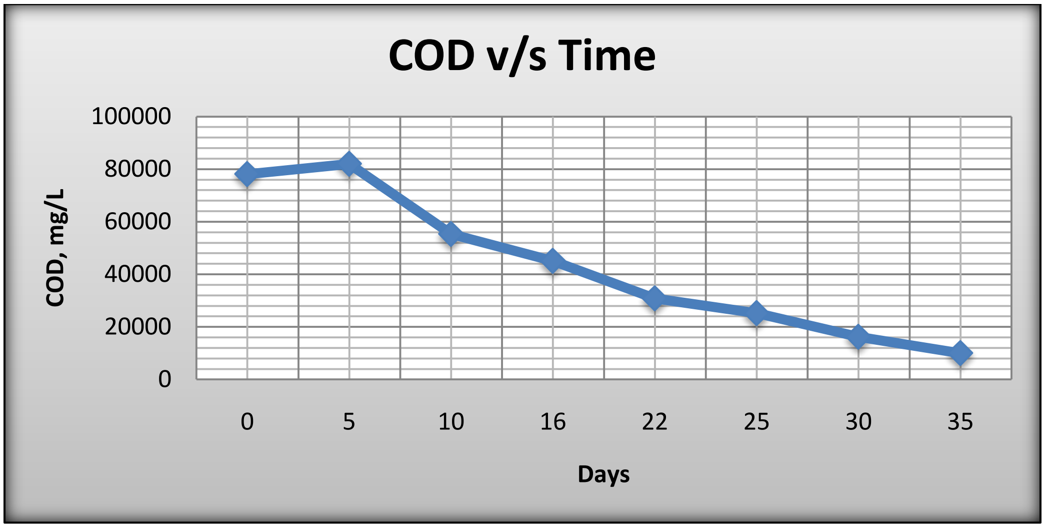

Figure 10.0: COD variation with time.

The graph depicts the variation of COD for the experimental period of 35 days. At the beginning of the experiment the COD content of the organic substrate was 78,125 mg/L and a significant decrease was observed during the start - up of the process. On day 5 the value of COD decreased to 64,500 mg/l and this result indicates that 82.56% of the COD content was removed during the anaerobic reaction. The significant removal of the chemically oxidizable organic compound was due to an increase in the conversion of organic matter into biogas production. The COD of the organic substrate was found to decrease significantly by same percentage of around 80-85 % from day 5 to day 12. There was a larger fall in COD concentration after 16 days of anaerobic digestion. It could mean that there was a higher microbial activity during that period.

From day 22 till day 35, a constant decrease in the COD concentration is observed. On day 35 the COD was recorded to be 9986 mg/L.

4.5 Total solids and volatile solids.

During the process of anaerobic digestion, volatile solids of the organic material in the reactor are degraded to a certain extent and converted to biogas. Volatile solid is an important parameter for measuring the biodegradation of organic substrate, which indirectly indicates the metabolic status of the microbial groups in the anaerobic digester [9]. The percentage of solid destroyed during anaerobic digestion is a measurement of system performance and the removal efficiency of the organic matter during the process.

The degradation of the organic matter for the experimental period of 23 days is illustrated in the graph of percentage volatile solids and total solids against retention time as shown below.

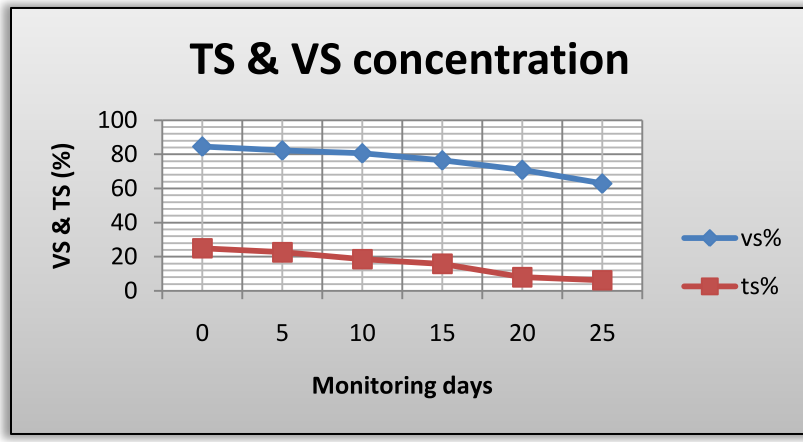

Figure 11: solid concentration variation with time.

It can be observed that volatile solids concentration decreases gradually as the retention time approaches. The total solids reduction and volatile solids destruction are 83.97% and 64.14 % respectively.

4.6 Biogas combustion

A premixed cooking stove model and Bunsen burner were used to burn the biogas and heat water in a beaker. A blue flame can be observed from the figures below.

Figure 5.8 (a): Bunsen burner

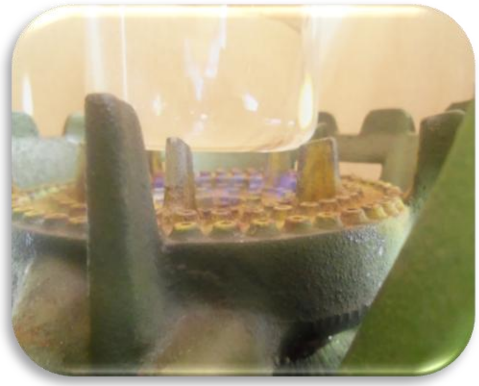

Figure 5.8(b): Cooking stove

On Day 13 and day 14, the biogas was left to build up enough pressure in the digester so as on day 15, it was decided to burn the biogas. This building of pressure was done so as the biogas travel easily in the gas pipes thus giving a nice blue flame.

First, the Bunsen burner was used to combust the biogas. The flame heated the beaker of water for 8 minutes giving a water temperature difference of 29°C. Then the gas pipe was connected to the cooking stove which same beaker of water for 30 minutes giving a temperature difference of 57°C. Still 62 litres of biogas were collected until no more could be obtained.

Based on these values, efficiency of the Bunsen burner and cooking stove were found to be 88.26% and 46.26%.

Table 4.0: Temperature change with time.

Specifications	LPG	Biogas	
		Bunsen burner	Stove
Initial temperature (°C)	24	29	29
Final temperature (°C)	94	58	86
Temp. difference	70	29	57
Time taken (mins)	17	8	30

5.0 ECONOMIC ANALYSIS

The economic analysis of the AD project was performed by extrapolating methods, allowing the total capital investment to be found as summarised in the following tables.

Table 5.0: Summary of cost investment

Specification	Cost, Rs
Estimation of total capital investment	
Purchased equipment cost	10,325
Total direct cost	19, 101.25
Total indirect cost	3216.00
Fixed capital investment	22, 317.25
Working capital	2479.70
Total capital investment	24796.95

6.0 CONCLUSION

Anaerobic digestion (AD) is a proven technique and technology to treat solid waste to produce methane gas which generates a clean and green energy. AD will offer Mauritius the opportunity to take the lead in sustainable waste and energy management which will contribute in the concept of Maurice Ile Durable (MID) and will help to substitute fossil fuels by renewable resources.

From this investigation it is concluded that source sorted organic fraction of municipal solid wastes can be anaerobic ally digested, producing a biogas containing 60.5% CH4 at a daily rate of approximately 0.158 L/kgVS. The rate of biogas production observed in the pilot scale digester declined with increasing influent volatile solids concentration and this decline was due to the limited ability of the digester to thoroughly mix the contents and thus avoid the production of scum layer. The mixing capability of the pilot scale digester far exceeded the mixing ability of commonly designed sludge digesters, indicating that new developments in digester mixing are needed for successful digestion of animal wastes.

In this study, pilot scale anaerobic digestion of cow dung was conducted. A 1m3 anaerobic reactor was designed and operated under semi-continuous mode during first 10 days and for the remaining days on batch mode. An attempt to optimize the process was done by constructing an Archimedes's screw type mixer together with a three-bladed propeller attached to the end of the mixing unit. The following conclusions can be drawn from this study

An effective start-up of the anaerobic digestion with inoculum and substrate acclimatization was done successfully. A constant temperature from mesophilic condition was observed per day reaching a condition of room temperature which was found satisfactory. A volatile solid reduction of 59.39% was obtained during the process and the pH was more or less stable lying in the range 6 to 8.

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SOLAR AND WIND ENERGY

Feasibility of using Solar Energy as a source of renewable Energy in Mauritius under collaboration of DIREKT.

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Abstract :

With limited indigenous conventional energy resources, Mauritius imports over 80% of its energy supply from foreign countries, mostly from the Middle East. Developing independent renewable energy resources is thus of priority concern for the Mauritian government. Mauritius, being a tropical island surrounded by the Indian Ocean has enormous potential to develop various renewable energies, such as solar, biomass, wind power and geothermal energy. In order to reduce external dependency of fuel the Mauritian Government introduced attractive policies and invited investors of the homeland and abroad to invest in renewable energy technologies. Thus, the aim of this study was to determine the feasibility of implementing solar photovoltaic panels at institutional and organizational level and determine its economical feasibility. The study also consisted of determining the extent to which Mauritians are ready to accept such technologies. A research was thus carried out in collaboration with DIREKT and was found that Mauritians are eager to accept and invest in the solar photovoltaic technology provided that they are given sufficient information on how the system works. Moreover, the economic evaluation for the implementation of the photovoltaic technology revealed that the payback period for such technologies will be around 4.3 years which is very much acceptable.

Keywords: Solar, photovoltaic

1.0 Introduction

Mauritius is a tropical country that has a very good solar regime with an average annual solar radiation of around 6 $kWh/m^2/day$. With emerging awareness about protection of the environment during the twenty-first century, the Government of Mauritius is focusing on broadening its energy supply, improving energy efficiency and adapting its energy infrastructure through modernization in order to meet the challenges ahead. To achieve this, Mauritians needs to adapt to a rapid shift in the practices of a low carbon, efficient and environmentally benign system of energy supply. As a result, the Government together with the Ministry of Renewable Energy and Public utilities have drafted a Long Term Energy Strategic plan based on practices of Renewable energy and has given it the name of Maurice Ile Durable vision. The Government also has a long-term vision of transforming Mauritius into a sustainable Island. One important element towards the achievement of this vision is to increase the country's renewable energy usage and thereby reducing dependence on fossil fuels. Democratization of energy production is determined to be the way forward. In line with the government's vision on renewable energy, the University of Mauritius has been working as a partner with DIREKT team to promote renewable energy infrastructure locally. The DIREKT (Small Developing Island Renewable Energy Knowledge and Technology Transfer Network) is a teamwork scheme that involves the participation and collaboration of various universities from Germany, Fiji, Mauritius, Barbados and Trinidad & Tobago. The aim of the DIREKT project is to reinforce the science and technology competency in the domain of renewable energy through technology transfer, information exchange and networking, targeting ACP (Africa, Caribbean, Pacific) Small Island developing states. A step in this direction is to transfer citizens the ability and motivation to produce electricity via small-scale distributed generation (SSDG), i.e. wind and photovoltaic.

1.1 Primary Energy Requirement In Mauritius

The total primary energy requirement of Mauritius is around 16, 328 GWh per year. In 2010, the non renewable fuels imported (petroleum products and coal) accounted for 81.2% of the energy demand. The remaining 18.8% were supplied by locally available renewable resources. The local renewable energy supply comes from bagasse (90.1%), hydro electricity (3.5%), solar thermal (3.1%) fuel wood

(2.9%) and wind energy (0.4%) (Ministry of renewable energy & public utilities, 2009).

1.2 Targets for Renewable Energy over period 2010-2025

On the basis of the Long term Energy Strategic plan set by the Government of Mauritius and the Ministry of RE and Public Utilities, it is expected that by 2015 the local renewable energy supply will amount to 24 % and by 2025 it will increase to 35 %.

1.3 Solar Energy Practices In Mauritius

Mauritius receives between 8 and 10 hours of sunshine daily and the average annual solar radiation is 6 kWh/m^2. To promote the development of solar energy, the Government issued tenders for the supply and installation of 125 units of photovoltaic systems for street lighting and lighting of Government offices as a pilot project in early 1998.

However, this form of energy is not sufficiently tapped, though the potential is very high. But, one of the means actually used to take advantage of this source of energy is through the use of solar water heaters. Due to the abundance of the solar energy resource in Mauritius, some 35,000 solar water-heating units have been installed all over Mauritius, which represents an 8% penetration of the household market. Solar water heating is the most common form of solar energy conversion, used in Mauritius.

With the setting up of the MID Fund in July 2008, the solar water heater loan scheme controlled by the Development Bank of Mauritius has been increased to Rs 10,000 so as to double the number of solar water for domestic use by end 2011. The outcome of this new scheme has been above expectations with some 49 thousand applications received by the Bank. Based on the constructive experience, the Government is now planning another scheme to encourage wider use of solar energy in terms of photovoltaic in household and other sectors of the economy.

The Government of Mauritius has also anticipated the production of 300 kW of electricity via solar photovoltaic to displace the diesel fuelled Mauritian generation. To lessen the impacts from new road and power line construction, the project will be constructed near the existing diesel generation plant. This project is expected to reduce greenhouse gas emissions by 470 metric tonnes per year. It is also projected to reduce around 16,000 metric tonnes of CO_2 over a period of 35-year which is expected to be the life- time of the project.

Moreover, the Government of Mauritius and the Central Electricity Board, with the help of the UNDP have set out a grid code which has been designed for small-scale distributed generators in order to allow the integration of small-scale renewable energies in the power system of Mauritius mainly through the use of photovoltaic panels and wind turbines.

2.0 Methodology

This research tries to find out the extent to which private and public sectors have implemented or are ready to invest on renewable energy technologies in Mauritius and what are the views of stakeholders to implement these technologies in the future. To measure the effectiveness, both quantitative and qualitative data have been used. All organizations and Institutions throughout Mauritius which are in some ways or the other involved in renewable energy were identified.

Data were collected using the Questionnaire based survey approach over a period of two months. Questionnaires were sent to the targeted groups by post, electronic mails, faxes and some were also delivered in person. The informal personal interview that is face-to-face approach was also used to some of the target groups due to the nature and content of the questionnaire. Prior meeting was arranged with the directors, managers and employees via the phone and emails one week before. Each face-to-face interview lasted for approximately 15 minutes. The face-to-face method provided an opportunity to probing (i.e. asking for addition information) if the answers given by the respondents were incomplete or ambiguous. Furthermore, it provides rich and descriptive data. Some filled questionnaires were returned by post while others forwarded by emails.

3.0 RESULTS AND DISCUSSIONS

3.1 Interest in renewable energy sectors

To determine the feasibility of using Solar Energy as a source of renewable Energy in Mauritius, a survey form was sent to stakeholders, governmental organizations, non- governmental organizations, private sectors and tertiary institutions involved in Renewable energy. The response obtained is as shown below

Field of Interest	% Interested
Biofuels	16
Biomass	24
Biogas	24
Wind power	48
Hydropower	16
Geothermal	12
Solar thermal	52
Photovoltaic	56
Hydrogen fuel cell	8
Hybrid system	40
Ocean energy	12

Table 1: Types of renewable energy organizations in Mauritius are interested in

It can be found that most organization are very much interested in Photovoltaic (56 %) followed by solar thermal energy (52 %), Wind Power (48 %), Hybrid systems (40%), Biomass (24 %), Biogas (24 %), Bio-fuel (16 %), Hydropower(16 %), Geothermal (12 %), Ocean Energy (12 %) and Hydrogen fuel cells (8 %). It must be noted that in the surveys, most organizations specified a hybrid system of wind / photovoltaic and solar thermal/ Photovoltaic. The objective of this question was to determine the interest and in turn the most appropriate renewable energy technologies to be applied in Mauritius in the coming future. Using this definition the sample surveyed reveals that stakeholders and organizations are mostly interested in Solar Photovoltaic technologies.

3.2 Market oriented service expected from Tertiary Institution

To be able to implement such practices, the same group of people were asked about their interest in terms of services they want to get from tertiary institutions.It was found that the types of market oriented services that the organizations prefer to have from tertiary institutions included among others; trainings to put RE practices into practice, providing information related to funding grants by international organizations for RE projects and partnership with private firms in consultancy. Moreover, many organizations are very much interested in getting training in construction and installation of RE devices mainly in the field of wind and solar energy and to get international and regional market surveys. Concern among targeted group were also diverted towards carrying out feasibility studies and to have complete assessment of sites in terms of RE sources up to implementation of project, including installation, testing and commissioning. The sample results show that the organizations are very much willing to be well informed and guided on the RE technologies to the extent of installation and commissioning.

4.0 Economics Of Photovoltaic Panels

Based on the results obtained regarding the interest in Renewable energy in Mauritius, It was found that respondents are much more willing to adopt the photovoltaic system as a source of producing electricity than any other type of renewable energies. Furthermore, with the motivating scheme provided by the government for citizens to produce electricity via small-scale distributed generation, most organization, stakeholders and businesses are willing to converge towards photovoltaic panels rather than wind turbines because of two main reasons; firstly due to the better aesthetic of PV and secondly sunshine insolation is much higher in all parts of Mauritius as compared to wind resource. So taking this into consideration, the economics of the installation and commissioning of solar photovoltaic was performed.

4.1 Sunshine availability in Mauritius

Data on amount of sunshine in Mauritius was collected by the meteorological station showed that there is a very good potential for exploiting solar energy in Mauritius. Sunshine is available in abundance all year round in Mauritius, be it summer or winter. This is shown in the table below in terms of hours of sunshine that yields the amount of insolation per m² per day:

MONTH	SUNSHINE		Insolation KW/m²/day
	Daily hrs per day	Mean Monthly	
January	7.0	216.3	6.80
February	6.6	186.1	6.48
March	6.7	209.4	6.08
April	6.0	179.1	5.07
May	6.3	193.9	4.45
June	6.1	182.8	4.17
July	6.1	187.6	4.30
August	6.1	187.7	4.99
September	6.3	189.5	6.01
October	6.8	210.1	6.89
November	7.3	219.8	7.47
December	7.0	216.8	7.10

Table 2 : Yearly Sunshine Data in Mauritius

4.2 Costing for Solar Panel

For the costing, quotations were taken from different solar companies in Mauritius and the Solar Electricity's Company quotation was selected since it was at a lower price. The quotation was as follows for various delivery capacities for a grid tied inverter all in Mauritian rupees (1 Euro = 40 MUR):

	1000W/ Hr	2000W/ Hr	3000W/ Hr	4000W/ Hr	5000 W/Hr	6000W/ Hr
Solar Panel (monocrystalline)	103,941	197,992	280,946	323,927	448,967	519,882
Inverter	33,020	52,960	80,840	92,682	117,714	142,948
Wiring +Installation Fee	41,300	44,700	51,257	52,956	63,754	76,300
Total excluding VAT	178,261	295,652	413,043	469,565	630,435	739,130
+ Vat (15 %)	26,739	44,348	61,957	70,435	94,565	110,870
Total	**205,000**	**340,000**	**475,000**	**540,000**	**725,000**	**850,000**
Units saved monthly	***120***	***240***	***360***	***480***		

The Independ Power producer(IPP) was taken as example for the costing. It has been found that the IPPs produce around 10 MW of electricity per year which amounts to 1141.55 W/ hr. Thus from the available quotation, we can opt for the 2000 W/Hr solar panel since taking the 1000 W/hr will deliver less than the actual demand. Thus the installation and production cost for 10 MW/year of electricity will cost 340, 000 Mauritian rupees (MUR) amounting to 8500 euro (1 euro = 40 Mauritian rupees). However, this cost excludes the profit when sold to grid. In Mauritius, the units of electricity are sold according to the amount of units consumed. This is shown in the table below:

Table 3 : Price of Units of Electricity in Mauritius (Source: CEB Utility Bill)

Unit(KW/hr)	Price (Rs)	Price (Euro)
First 25	2.87	0.07
Next 25	3.98	0.1
Next 25	4.31	0.11
Next 25	4.95	0.12
Next 100	5.59	0.14
Next 50	6.38	0.16
Next 50	7.18	0.18
Remaining	7.97	0.2

Since 1 unit of electricity means 1 KWh, thus IPPs produces 10,000 units. Using the above table, the selling price for the 10,000 units amounts to 78, 948 Mauritian rupees (1974 euro) (Calculations in Appendix 4.

With a production of 10,000 units per year at a selling price of 78,948 rupees the payback period is found to be 4.3 years (Calculations in appendix 4) as shown in the graph below:

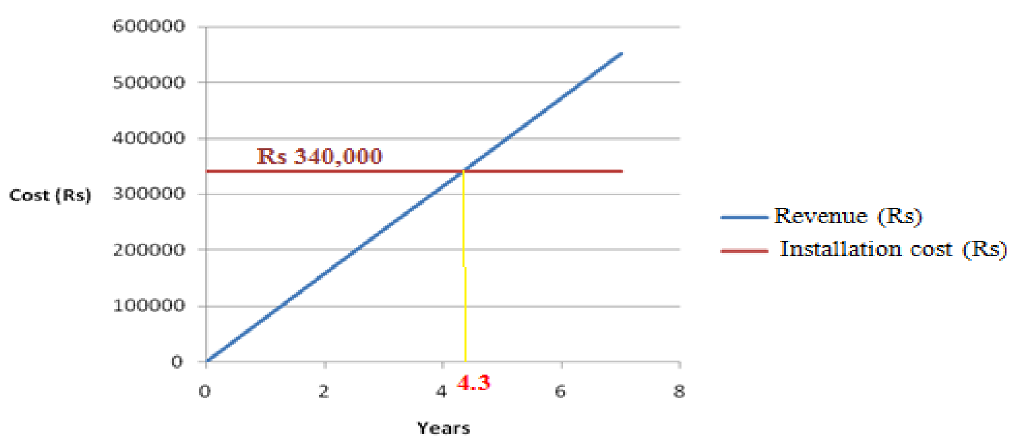

Figure 1: Payback period for the installation of PV panel to produce 10 MW of electricity/year

However, it must be noted that the payback period will be slightly higher as this quotation is based on the price of watt produced per hour and on the assumption that everyday there is availability of sunshine.

5.0 Conclusion

It has been found that a high number of tertiary institutions are actually running most of the market oriented issues. Nevertheless, these form part of a module only, thus the required in-depth knowledge may not be achieved by the targeted group. Thus, these institutions can make further provision in running these issues as a whole course in itself.

The surveys revealed that the renewable energy that is most in use in Mauritius is the solar energy, followed by wind, a hybrid of wind and solar technologies, hydro and biomass. But, the implementation of all the renewable energy sources at a time is not feasible for a small island like Mauritius. We should explore each and every aspect of the Renewable energy sources before embarking on them. However, the type of renewable energy which is most known to the Mauritian population and which is most ready to be accepted at household as well as at business and Organization level is the solar energy through the use of photovoltaic panels.

Based on another survey carried out by Doolaree (2010), the findings tallied with this study revealing that among all the renewable energy sources, 45 % of the respondents firmly believed that Mauritius should invest in solar while 21% suggested to invest in wind energy. Thus PV is expected to be the most prosperous RE in the long term due to the presence of sunlight everywhere. Moreover, with the introduction of net metering and awareness campaign, the use of PV will certainly be improved and well accepted at all levels.

The main reason behind this shift in the mindset might be probably due the interesting incentive schemes launched out in 2009 by the Government in collaboration with the Central Electricity Board, with the help of the UNDP.

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A method for mapping monthly solar irradiation over complex topography areas: Reunion Island's case study

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Abstract:

The aim of this study is to build a high-resolution mapping model for Reunion, a mountainous island with highly complex terrain. The dataset used here, which consists of solar irradiation, is not available on a regular weather station network over the island. This network is relatively dense and includes quality monitoring stations, providing then enough information to tackle the problem of climate data interpolation over complex terrain. A model for mapping the monthly means of such variable is presented. It combines Partial Least Squares (PLS) regression with kriging interpolation of residuals. For all the variables, a same set of nine predictors including altitude, geographical and topographic features is selected for PLS regression. The regression model gives statistically good estimates of the monthly solar irradiation. Accuracy gets significantly much higher for the mapping solar irradiation built with regression+kriging than for the mapping built with regression only.

Keywords: solar irradiation; spatial distribution; Partial Least Squares regression; kriging

1. INTRODUCTION

The last decade has seen the development of many high-resolution spatially distributed climate data for use in various fields. Many long-term time-mean meteorological gridded datasets have then been developed [1, 2, 3, 4, 5, 6]. Moreover, several authors have pointed out that high-resolution mapping (<1 km) is often required to take into account high topographic variability [7, 8]. Thus, geostatistical mapping based only on statistical interpolation of observational data is not sufficiently accurate to estimate spatial climate patterns as explained by topographic variables in complex terrain [9].

Reunion (a French oversea department) is a small island located in the southwest Indian Ocean (55°E-21°S) and 800 km off the east coast of Madagascar. It is a hotspot volcano with three circuses (Mafate, Salazie, Cilaos). Moreover, the observation network in this mountainous and complex terrain is irregularly spatially distributed. In order to capture meteorological spatial variability, the setting up of a high-resolution regular grid (<1 km) is needed in regard to the small size (2512 km^2) of the island and its topographical context. In addition, Reunion has been recognized as vulnerable to climate change. High-resolution gridded climate data should be used then as a complementary tool for assessing energy resource and meeting insular requirement and policy for renewable energy.

This paper addresses the issue of improving the spatial coverage of monthly solar irradiation over Reunion, which is a mountainous small island with very complex terrain (Fig. 1a). A multivariate approach is used here to include elevation and additional topographic and geographic parameters, which are expected to reflect the effects of local topography and weather patterns on the global solar radiation. The dataset consists of ground-based observations from Météo-France network. This network, which is a relatively dense network of quality monitoring stations, provides enough information to tackle the problem of solar data interpolation over complex terrain, and in this regard, makes Reunion a privileged area. Few islands, especially in the tropics, are as well documented. The main objective of this study was to compute a regression law using a specific set of predictors. Some of them are linked to orographic pattern (height, slope), others to the tropical marine environment and weather (the distance between the record stations and the sea, temperature inversion altitude, latitude, longitude). For each month, a regression law was built for the whole island. Finally, a residual kriging was applied to improve the mapping. In this work, same application of this regression method has been to solar irradiation. The into account the slope aspect and orientation which is assumed to be important solar irradiation [10]; (3) to compute the distance to the sea with real coastlines from a Digital Elevation Model (DEM); (4) to compute a regression equation with Partial Least Squares (PLS) procedure in order to handle collinearities among the predictors and set up the model to have the best correlation between the predictors and the predictand.

In Section 2, we describe Météo-France station data and the DEM used to generate high-resolution gridded maps of monthly global solar irradiation for Reunion. In Section 3, we present the mapping methodology based on PLS regression and residual kriging interpolation. Section 4 focuses on the obtained results and discusses the efficiency of the model to produce suitable high spatial resolution solar radiation dataset for Reunion. In last instance, some conclusions are highlighted.

2. DATA

The original dataset consists of daily time series of solar irradiation over a period of 10 years, for a total of 40 individual Météo-France meteorological record stations (Table 1). These stations did not make regular measurements over time, and quality check control and homogenization process were required. These two procedures were performed by the French Meteorological Service (Météo-France, 2000). The stations are irregularly spatially distributed over the island (Fig.1b) and about 80% of them being situated below 1000 m.

In this study, we propose to interpolate the station data on a regular grid with higher resolution. The spatial interpolation algorithm is based on regression and employs a DEM provided by the French National Geographical Institute (IGN) to describe the relief of Reunion. We used the IGN-BD ALTI® 250 m product on a regular grid of 250 m resolution. This product is a matrix of size 267x160 (42720 pixels). Elevations measured in-situ at each record station and elevations predicted by the DEM for the same locations can vary substantially with the model's resolution [11]. For each of the 40 individual record stations, we then compared the nearest pixel elevation as given by the model to the corresponding measurement point.

3. METHODOLOGY

In this paper, the daily station observations were used to produce monthly grids. The daily time series of the climate variables provided by Météo-France were thus transformed into monthly averages prior to the gridding process. Daily solar irradiation data records collected from 40 stations were averaged by month over the period 1998-2008 (Table 1).

The methodology in this study is a two-stage process of multiple regression of the monthly climate variable (which may be normalized first) with an extended set of predictors, followed by interpolation of the model residuals on a grid.

3.1 Regression

An exploratory analysis shows that the meteorological elements to be modeled over the study domain (Fig. 1b) exhibit dependencies on geographic features, especially topography. The summary statistics associated with the monthly station solar irradiation are presented in Table 2. This parameter fluctuates significantly over the year. There is a noticeable contrast between the summer and winter monthly means. As mentioned previously, this feature is mainly due to large-scale seasonal tropical patterns like the ITCZ and the trade winds [12, 13] and the associated trade-wind inversion. As far as solar irradiation is concerned, a minimum value of $971 \times 1e^{-4}$ J/m² was observed in July at Petite France (1200 m asl.) over the northwest inland side of the island and also in June at Le Baril station (115 m asl.) in the south of the island. A maximum solar irradiation of $2536 \times 1e^{-4}$ J/m² was observed in November there again at Bellecombe station. The preceding analysis shows different features from one place to another in the spatial patterns, thus revealing the complexity of the effects of mountainous orography as well as of tropical weather at meso-scales.

As shown in Fig. 2, solar irradiation is not well linearly distributed as compared to temperature and it is difficult to extract any linear pattern. The solar irradiation spatial distribution seems to be additionally influenced, throughout the year, by the meteorological conditions over the island like the trade winds and the wind and temperature inversion. In a tropical marine boundary layer, the low-level temperature inversion is generally located at the top of this layer, typically at an altitude of 1000 m to 2000 m, and corresponds to the large-scale pattern of the Hadley-Walker cell circulation [14]. Result in Fig. 2 thus shows that simple parameter dependence such as elevation cannot explain the observed variability of the solar irradiation, justifying then the extension of the predictor set as follows.

Nine predictors are used in this study namely: altitude, minimum distance of the station to the coastline, four altitude threshold criteria as defined by Douville [15], slope, latitude and longitude. These predictors are commonly used for mapping climate variables [16, 11, 17, 4, 18, 19, 20].

For the regression model, we combine Principal Component Regression (PCR) and Multi Linear Regression (MLR) approaches to capture the maximum variance of the predictor set and to maximize the correlation between the predictor set and the predictand. Thus, to establish a relationship between the monthly mean of the selected solar irradiation parameter and the predictor set, we have chosen to perform a PLS Regression (PLS-R) which would be a more suitable approach for mapping solar irradiation at Reunion. PLS was developed in the 1960's by Herman Wold in the science field of econometry [21]. PLS-R is used to describe the relationship between multiple response variables and predictors through latent variables [16, 22, 23]. It seeks to extract a set of mutually orthogonal components from independent variables that maximize the predictive power for one or more dependent variables. Moreover, PLS is a particularly useful method when predictors are cross-correlated [24, 25, 26]. In order to achieve the most accurate predictive equations, we have used a cross-validation procedure to identify the most appropriate dimension for the regression models [16]. For more details, readers can refer to reviews from Höskuldsson [27] and Wold et al. [28].

3.2 Residual Kriging

In this study, solar irradiation is related to some elevation and terrain morphology derived parameters by PLS regression analysis to create gridded dataset of the climate variables. Over a highly mountainous and complex terrain like Reunion Island, solar irradiation highly depend on the local meteorological conditions caused by the relief. As mentioned previously, this effect cannot be fully explained only by linear regression. The idea here is to extract additional information as contained in the part left unexplained by the PLS model with ordinary kriging of the regression residuals over a regular grid [29, 30]. PLS residuals refer to the difference between predicted values from the PLS model and the observed values at all measurement sites. In this case, the final maps of the monthly means for each climate variable are derived by adding the interpolated residuals to the initial regression-based field.

4. RESULTS

The quality of the PLS regression model was tested using a leave-one-out cross-validation (LOOCV) procedure. For each month, a model was fitted to all stations minus the first one, and the climate variable estimate for this station was computed. It should be noted that the PLS model was run twice. In the first run, all predictors (nine) defined in the last Section were considered in modeling; while in the second run, after finding the estimated number of significant components that minimizes the Predictive Residual Sum of Squares (PRESS) (e.g., [28]), only these components were considered in the modeling procedure. The LOOCV procedure was repeated by successively dropping each station, one at a time. Predicted values for all stations were then compared to the observed ones. For that purpose, two classical criteria were used here: Root Mean Square Error (RMSE), and average Skill (SK; [31]).

Fig. 3, which shows the results of the LOOCV procedure for monthly solar irradiation, indicates that the model achieves satisfactory predictive performance on average, except for certain respects. Even if the average skill is very high (SK ~ 80%) and the statistical error is low, the scattering of points about the line of best fit increases. Moreover, Fig. 4 reveals that the model overestimates low solar irradiation values. The model fairly overestimates the observations by 10% at values less than 1500 J/cm². On average, the model was run with two PLS components. Based on these two components, percent variance captured by the predictors is 54%, explaining 18% of the variation in solar irradiation during June and July. For the other months, proportion of explained variance is higher (from 61% for the predictors to 31% for the predictand).

In this work, fit quality of the PLS regression model was assessed in cross-validation mode. To calculate skill scores of the model in prediction mode, it is usually necessary to apply the model to a testing dataset different from the training dataset used to compute the model. In our case, such an approach would have some drastic limitations as: (1) the sample size is small with sparse data over the island so that subdividing the sample data into training and test sets would not provide sufficient sample size to assess the statistical significance of regression; (2) the spatial patterns solar irradiation over the island are so complex that the regression equation would strongly depend on the way the data set is partitioned into training and test sets. It is important to have both a training dataset and a separate spatially well-distributed dataset if we want these datasets to be representative of the prevailing patterns of solar irradiation over the island. In this work, the performance of the model in prediction mode was thus tested in the following way: (1) define a regression model based on a subset of observations from the available meteorological stations; (2) apply this model to predict values at the remaining meteorological stations considered as an independent test dataset. At Step (1), observations were randomly excluded from the original dataset using Monte Carlo (MC) simulations. Each MC simulation consisted first in generating a random number of stations to be extracted, and second in randomly extracting the number of stations from the available stations. The size of the extracted sample was limited arbitrarily in such a way that it did not exceed 20% of the available stations at the most. At Step (2), predicted values for the remaining stations were compared to the corresponding observed ones. In this work, Step (1) was repeated

5000 times. Prediction error statistics information for the entire year is retrieved from the preceding procedure, and results are summarized in Table 3. Note that the model performance is slightly different over the year. Good skill is also obtained but the model appears to be less efficient at predicting solar irradiation in May to August, especially in May to July when the lowest scores are found (SK < 55%).

One possible way to improve the predictive performance of the model for solar irradiation in May to August is to explore and fit the spatial residual error. Modeling and taking into account the residual error in regression is a well-known technique in mapping, named as residual kriging. Several studies have been conducted to map solar irradiation [32], using residual kriging. Fig. 4 shows that adding kriged residuals to the PLS regression estimates leads to significant improvement in predicting solar irradiation especially during the winter season. Fig. 5 displays the result of mapping processing presented here for each month of the year. We can see the impact of both the altitude and the topography of the terrain through the year.

5. CONCLUSION

In this study, a multivariate prediction model, using only topographic and geographic parameters as predictors, was defined to estimate the spatial distribution of monthly maximum and minimum solar irradiation over Reunion, a mountainous island with highly complex terrain. The weather prevailing over the island is dominated by both synoptic tropical weather (ITCZ, trade winds) and orographic effect. Such a configuration leads to a seasonal contrast throughout the year with roughly a windward-leeward regime along a southeast-northwest axis on the island. In addition, the presence of the circuses and the volcano, and the marine conditions make the spatial weather pattern over Reunion more complex. The predictor set in the regression model was built up using geomorphological information (elevation, slope, geographic location) available at the stations, along with the distance of these stations to nearest sea as computed with a DEM model and some altitude threshold criteria. A model based on Partial Least Squares regression was chosen so as to deal with correlated predictors and maximize the correlation between the independent variables (predictors) and the dependent variables (predictands). Combination of the DEM model and information from stations to define the predictor set, together with PLS regression produced good results. Good skill was also obtained for the solar irradiation. Residual kriging significantly improved the skill for solar irradiation prediction during austral winter. Thus, this model is found to be relevant for high resolution mapping of solar irradiation over a complex terrain like that of Reunion.

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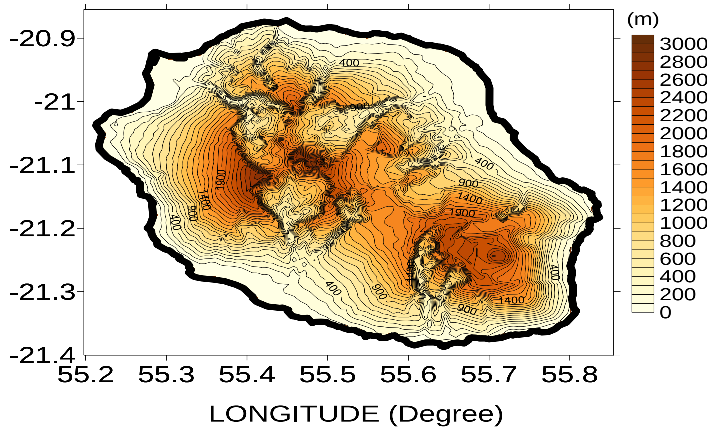
Table 1 Features of the solar irradiation observational network.

	Solar radiation
No. of sites in data set	40
Mean duration of records (year)	10
Minimum elevation (m)	5
Mean elevation (m)	549
Median elevation (m)	379
Maximum elevation (m)	2245
standard deviation (m)	576
1st quartile (m)	119
3rd quartile (m)	806

Table 2 Climatological characteristics of solar irradiation over Reunion Island.

($1e^{-4}$ J/m²)	Min.	Mean	Median	Max.	St. Dev.	1st Quartile	3rd Quar
Year	971	1665	1629	2536	333	1403	193
Summer (November to April)	1101	1816	1794	2536	301	1577	131
Winter(April to October)	971	1514	1452	2484	294	1315	169

(a)



(b)

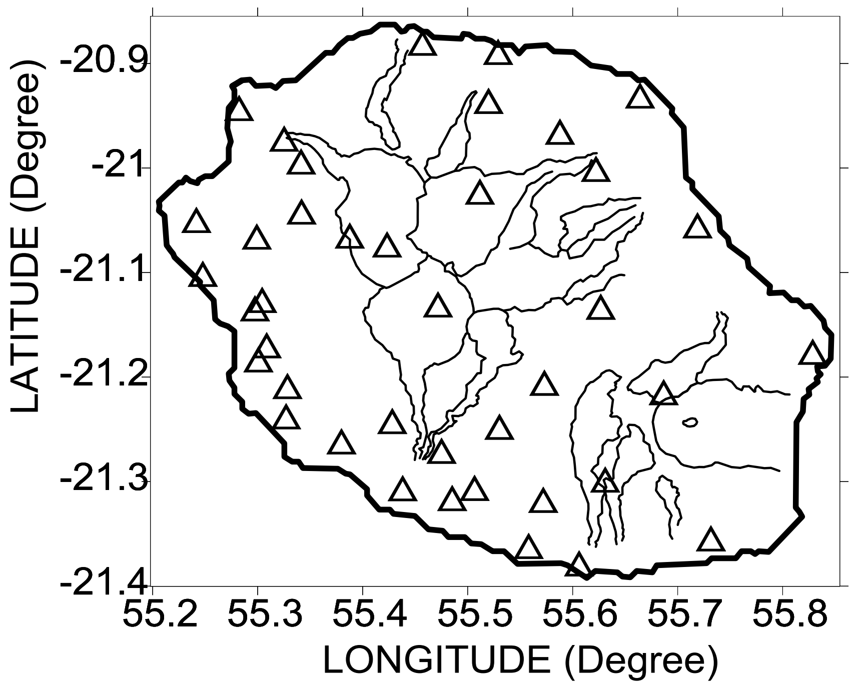


Fig.6 (a) 250-m DEM topographic data for Reunion; (b) Solar radiation observing station network over Reunion provided by Météo-France.

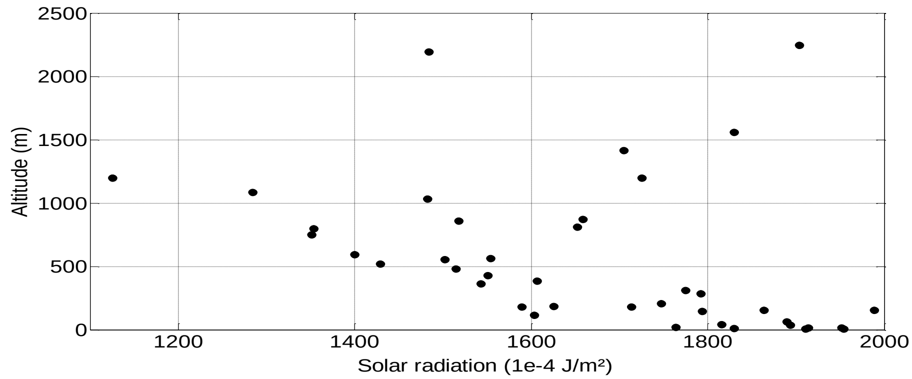


Fig.2 Solar radiation averages from Météo-France recording stations at different altitudes over Reunion.

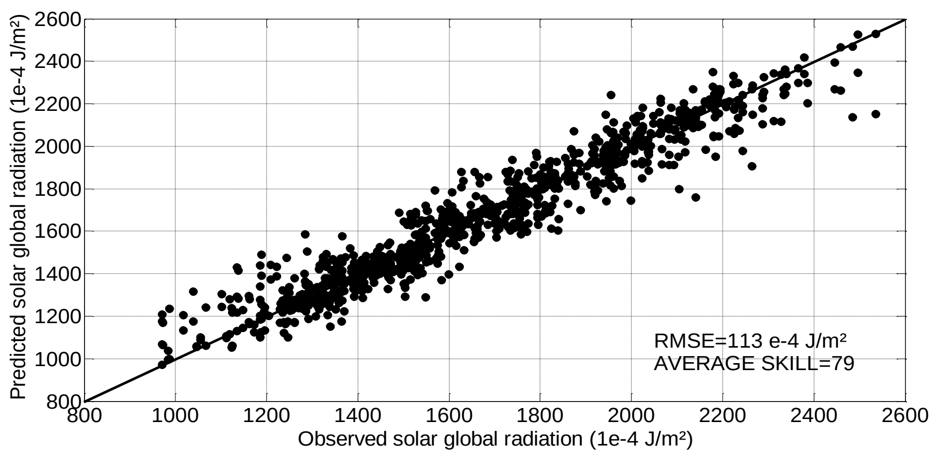


Fig. 3 Observed versus predicted values of solar irradiation.

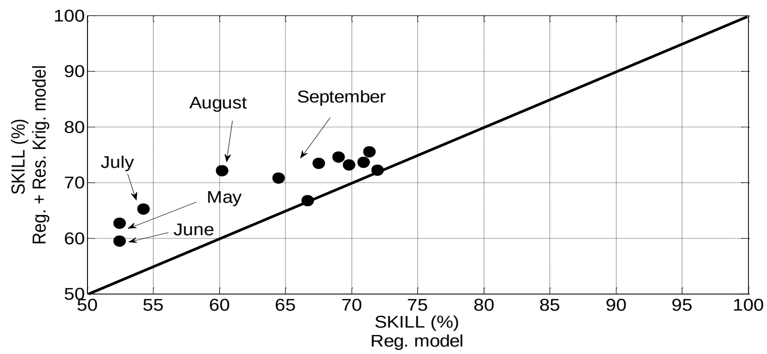


Fig.4 Comparison of the predictive skills of the purely regression model and the regression+kriging model, for solar irradiation.

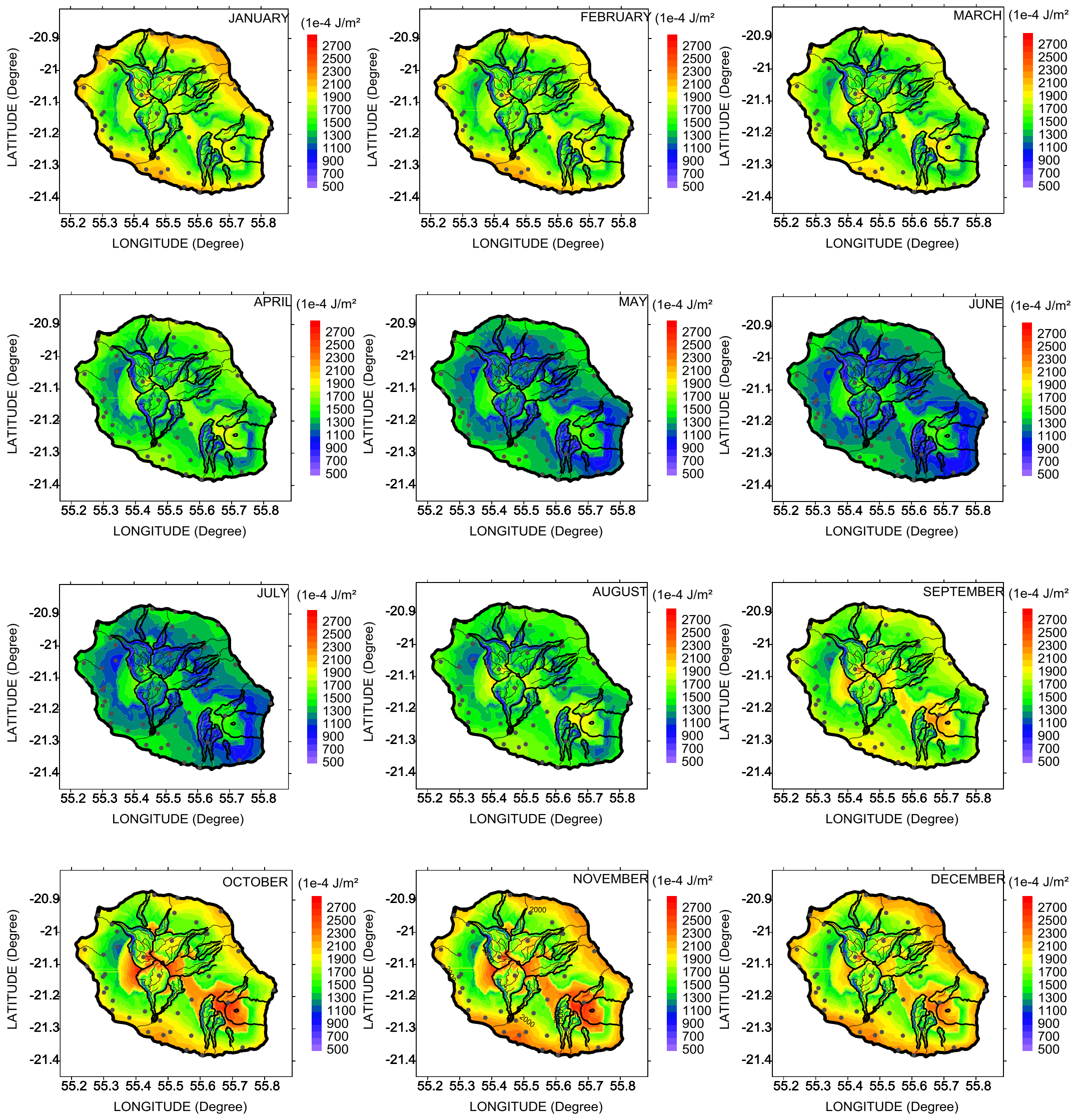


Fig.5 Monthly mean solar irradiation mapping of La Réunion. Station locations are displayed with grey dots.

Optimization of a Standalone Renewable Energy System: For a Small Load Requirement.

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Abstract:

Optimization of Standalone Renewable Energy (RE) system looks at the process of the selection of the best RE resources, components and sizing the system accordingly to get the most efficient and cost effective solution.

Design and optimization of the RE power system to cater for a USP car park lights was carried out using HOMER and compared to manual calculations. Resource analysis showed that on average the site received 3.8 kWh m^{-2} day^{-1} of solar energy with 1387 full sun hours annually. Monthly average wind speed of 3.88 m s^{-1} at 10 m above ground level extrapolated to 15 m (the hub height of the wind turbine) resulted in an average wind speed of 4 m s^{-1} with power density of 70 W m^{-2}. With this wind resource, a Whisper 100 wind turbine would be in operation for approximately 50% of the time in the year. The complementary nature of solar and wind resources showed good potential for a solar-wind hybrid system. In this work three possible systems; a PV system, a wind power system, and a hybrid power system (PV-wind) were analyzed. It was found that a hybrid system is the best and cost effective option as it is able to provide reliable power by minimizing the need for battery storage compared to a single RE power system.

The optimum system comprised of 0.270 kW_p PV combined with a 900 W Whisper wind turbine with total battery storage capacity of 440 Ah at 12 V. Manual calculation were found to be similar to that of HOMER simulations.

Keywords: HOMER, Hybrid systems, optimization, resource, Whisper 100

1. INTRODUCTION

Depleting fuel reserves and the rising global awareness has caused many to look for alternative methods of energy generation to provide for the increasing energy demand [1]. These alternative sources are in the form of renewable energy which is available in many forms which are either derived directly from the sun (PV), or indirectly (wind, biomass, etc).

Pacific Island Countries (PIC's) have huge renewable energy (RE) potentials which need to be tapped to meet their energy needs. Currently in the PIC's imported petroleum is the primary source of commercial energy of which a large proportion is used in transportation [2]. Fiji's annual energy consumption was estimated to be around 835 MWh in 2010 with approximately 292 MWh being generated form use of diesel alone [3]. This energy however reaches approximately 70 % of the people only and rest are left to cater for their own needs since the local utility, Fiji Electricity Authority, grid does not cover the smaller islands and many of the rural settlements. Small diesel generator sets and kerosene lamps are usually used to meet the energy needs in these isolated areas which are expensive looking at the current fuel prices [4]. Renewable energy resources such as solar and wind are abundantly available in the PIC's and with proven technology one could easily setup a sensible system to harness either of the energies for electricity needs or better still use a combination of the system by hybridizing solar and wind to provide a more reliable source of power [5]. Many studies have been done to determine optimal hybrid system configurations for small loads requirement. Fortunato et al. [6] reported that hybrid systems are now proven technologies to cater for electric loads in remote locations.

Thus it is important that research be carried out in the PIC's to study PV and wind resource distribution and design suitable systems to meet the load requirements of remote population. The current study entails the study of PV and wind resource estimation at the University of the South Pacific (USP) Laucala to validate the affordability, reliability and appropriateness of using RE to harness cheap and clean energy.

2. METHODOLOGY

The installed standalone Renewable Hybrid (RH) system (Fig 1) consisted of a PV panel and wind turbine together with a battery backup and an inverter for AC conversion.

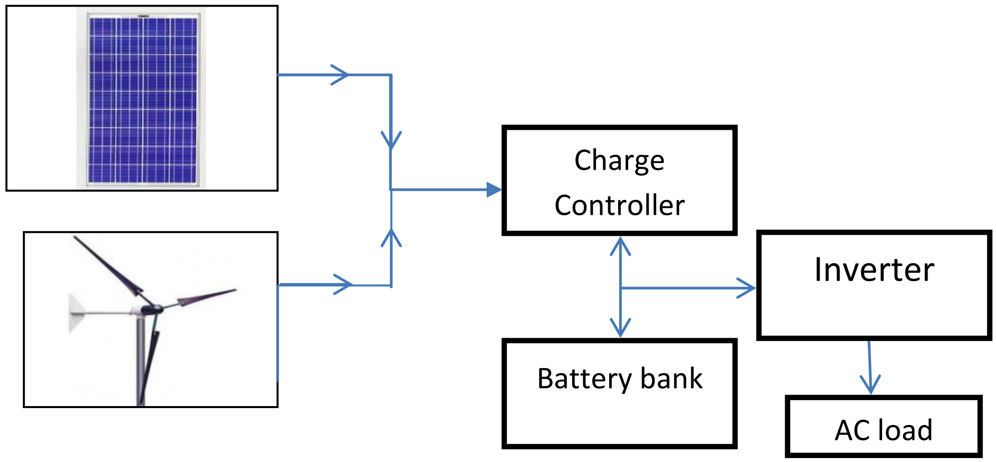


Fig 1: Schematic showing PV-Wind hybrid with storage

The current from the PV panel and the wind turbine was passed through the controller to charge the battery bank. The state of charge (SOC) of the battery was constantly monitored by the controller which effectively stopped charging the battery once maximum SOC was reached. The current to the load was then supplied by the battery when needed. The essential components of the system (Table 1) comprised of a wind turbine, PV panel, battery and an inverter.

Table 1: Essentials of a hybrid system

Equipment	Cost (FJ$)
Whisper 100 wind turbine	8000
135 W Co energy panel	1200
Haze 12 V 110 Ah battery	1000
200 W inverter	500

Renewable hybrid system sizing and optimization was divided into four parts; i) system load was decided and categorized according to voltage requirements, ii) wind and solar resources were estimated at the site to explore the viability of such a system, iii) system design was carried out using manual and HOMER calculations, and iv) estimated output form the two methods were compared and analyzed.

2.1 Load characterization and Calculation

The proposed RH system was designed to cater for street lights to be used in a car park at the USP Laucala campus. A total of 18 AC lights consisted of 12 X 9 W CFL lamps and 6 X 3 W LED lamps were the required load. The design of the system was based on the usage of the lamps. All lamps were expected to be switched on between 6 pm to 6 am daily. Hence, the load extracted current from the battery bank, however wind turbine was assumed to continuously replenish the charge in the battery bank during operation and PV module and wind turbine to charge the battery bank during the day. Thus the daily energy consumption (Eq 1) was calculated by multiplying the total power rating of light (P_{light}) with the number of hours of use (H_L).

$$\text{Daily energy consumption (kWh)} = \frac{P_{light} \times H_L}{1000} \quad (1)$$

Because of the long distance transmission required and high losses expected from using DC supply only AC system was considered. The daily energy consumption was calculated by assuming the inverter efficiency was 90 % and further corrected by taking into account cabling and battery losses of 12.5 %. The corrected DC energy demand was then used to carry out the manual system sizing.

2.2 Wind and solar Resource

The present study utilized wind/solar resource data obtained from a nearby monitoring site at the USP campus. A complete set of wind and PV resource data were available for 2007 to carry out the analysis and assessment. To separate short-term from long term fluctuations average monthly wind speeds were calculated. The wind and solar data were measured at 10 m and 3m above ground level respectively.

2.3 Manual System Sizing

The manual system sizing was carried out using monthly energy demand (E_{ML}) which was obtained by multiplying the corrected DC energy demand by the number of days in the month. The monthly energy demand was calculated to determine the energy contribution by the individual components of wind and PV system. This was made possible by using the wind resource and wind power curve of the chosen wind turbine to determine the average monthly energy of the wind system (E_W). The wind speed was extrapolated to the hub height using the power law (Eq 1). The data were analyzed to establish the fraction of the time the turbine would be producing some power.

$$V = V_0 \left[\frac{H}{H_o}\right]^{\alpha} \quad (2)$$

Where, V is the speed at desired height, H and V_o is the known wind speed at H_o and a is the power law exponent. This and many other studies [7,8] have used a value of 1/7 for a. Vega [9] stated that in order to estimate AEP, site specific wind distribution is needed and where wind distribution is not present it can be estimated using Rayleigh distribution (Eq 3).

$$F(v) = 1 - e^{\left[\frac{-\pi}{4}\left(\frac{V}{v_a}\right)^2\right]}, v \leq V \quad (3)$$

Where $F(v)$ represents the time fraction or probability that the wind speed is smaller than or equal to a given wind speed, V, and v_a is the average wind speed.

Since wind power density is directly proportional to the cube of velocity, average power in wind was found by statistical analysis of wind; that is by finding the value of the average of wind speed cubed rather than averaging the wind speed than obtaining the cube [10]. The average of wind speed cubed (v_i^3) (Eq 4) can be obtained by multiplying the cube of wind speed with the fraction of hours that the wind speed will be experienced.

$$(v^3)_{avg} = \sum v_i^3 \times \text{probabilty } (v = v_i) \quad (4)$$

To determine the probability that ($v=v_i$) Rayleigh probability distribution (Eq 5) was used. The probability of each wind speed was calculated using the sum of the product of power output (kW) from the power curve of the wind turbine, frequency of each bin and hours in the particular month.

$$p(v) = \frac{\pi}{2}\left[\frac{V}{v_a^2}\right] e^{\left[\frac{-\pi}{4}\left(\frac{V}{v_a}\right)^2\right]} \quad (5)$$

Thus the energy demand to be met by the PV system (E_{PV}) was calculated by subtracting the monthly power generated (E_W) from E_{ML} (Eq 6).

$$E_{PV}\ (\text{kWh}) = E_{ML} - E_W \quad (6)$$

The PV system size was then estimated using Eq 6.

2.3.1 PV Array Sizing

Solar data for a horizontal surface were available from local measurements, however in order to maximize the power production the panel must be tilted at an optimum angle. The optimum tilt for this study was used as 20^0 [2]. The number of modules in a series string (Eq 7) the DC bus voltage (12 V) was added to the diode drop voltage (1 V) and divided from the module working voltage; obtained from the I-V curve of the selected PV panel.

$$\text{Module in Series string} = \frac{\text{DC bus voltage + diode drop voltage}}{\text{module working voltage}} \quad (7)$$

To calculate the number of modules in parallel the gross mean daily output which was determined by multiplying the working current (I_P) by the mean daily radiation of the design month at optimum tilt allowing for 10 % to cater for wiring and mismatch. Thus for each month the gross mean daily output was calculated which was then divided from the annual mean daily load for the deficit month to calculate the number of strings in a parallel combination. The PV monthly array output was determined by multiplying the gross mean daily output with the number of modules in a parallel string with the number of days in the month (Eq 8)

$$\text{PV monthly array output (kWh)} = \text{gross mean daily o/p} \times \text{modules in parallel} \times \frac{\text{days}}{\text{month}} \quad (8)$$

2.3.2 Battery sizing

The battery capacity (Eq 9) was determined keeping in mind that the battery had to cater for load at night as well as for days of no power generation from the renewables. Ball and Riser [11] stated that deep cycle batteries have a depth of discharge (DOD) of 80 % which was considered to determine the battery capacity of the hybrid system.

$$\text{Battery Capacity (Ah)} = \frac{\text{Daily load (Wh)}}{\text{system voltage (V)} \times \text{DOD}} \quad (9)$$

2.3.3 HOMER

In order to determine if the above system was optimum the simulation program Hybrid Optimization Model for Electric Renewable (HOMER) was used. HOMER has been reported as the most widely used simulation model in many case studies and designs [12]. For proper optimization of the system HOMER needs to be provided with different energy resources, economical and technical constraints, storage requirements as well as component type, capital and replacement cost, and operation and maintenance cost [4]. Methods outlined in the HOMER user guide [13] were executed to adequately design and optimize the system [13]. Solar and wind resource data from 1st January to 31st December, 2007 were used to carry out simulation in HOMER.

3. RESULTS AND DISCUSSION

From Eq 1 the daily energy consumption was calculated to be 1.6 kWh for AC loads. Thus DC corrected daily energy consumption is estimated to be 1.92 kWh. Table 2 shows the monthly energy (DC) required for each month. On average each month the system is required to produce at least 58 kWh to meet the demand. Annually the system has to meet a total load demand of 702 kWh.

Table 2: Monthly Energy Consumption

Month	Energy consumption
January	59.52
February	53.76
March	59.52
April	57.60
May	59.52
June	57.60
July	59.52
August	59.52
September	57.60
October	59.52
November	57.60
December	59.52

Since the peak load to be catered for is 0.126 kW AC, a 0.2 kW inverter was sufficient to convert DC into AC power.

3.1 Resource Assessment

Resource analysis showed that on average the site received 3.8 kWh m^{-2} day^{-1} on a horizontal surface which translates into 1387 h of full sun in a year producing approximately 1.4 MWh m^{-2} of global solar radiation yearly. Shaahid and Elhadidy [14] stated that daily solar radiation averaging between 3.61 – 7.96 kWh m^{-2} indicates a potential site for harnessing solar energy. The study site had similar daily averages; hence it is categorized as a good solar potential site. The solar resource (Fig 2) shows that solar radiation decreases from a max of 5.5 h day^{-1} in January to a min of 2.75 h day^{-1} in July then gradually increases to 4.41 h day^{-1} in December. When studied together the wind and solar resource show a somewhat complementary nature making the solar-wind hybrid system a viable option for the study site.

The time series plot (Fig 2) shows that wind resource fluctuates throughout the year. Starting from January the wind speed decrease to a minimum of 2.6 ms^{-1} (the lowest wind speed in the year) after which the wind speed peaks in August at 5.2 m s^{-1} and gradually decreases till December.

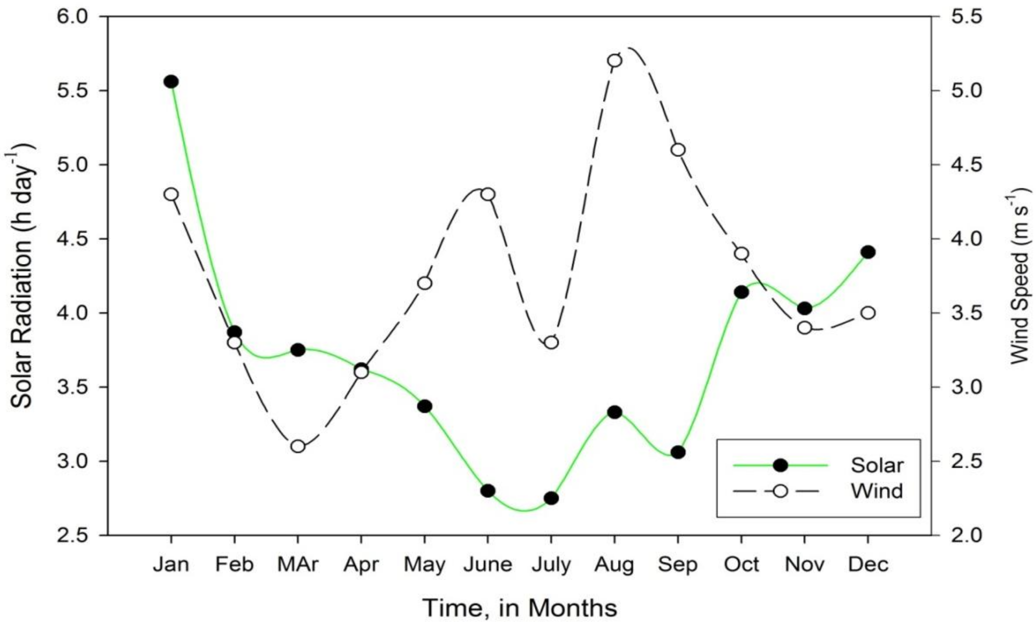


Fig 2: Solar and wind resource distribution at the study site

Annually, the site receives monthly mean wind speeds of 3.88 m s^{-1} at 10 m above ground level which extrapolated to 15 m (Table 3) (the hub height of the wind turbine) gives 4 m s^{-1} with a power density of 70 W m^{-2}. With this wind resource and assuming Rayleigh distribution, a Whisper 100 wind turbine would be in operation for approximately 4767 hours (50.4 %) in a year.

Table 3: Extrapolated wind speeds at hub height, 15 m

Month	Wind speed (ms-1)	Hours of wind turbine operation
January	4.56	479.5
February	3.50	319.5
March	2.76	214.5
April	3.28	305.3
May	3.92	408.2
June	4.56	465.9
July	3.50	357.3
August	5.51	549.1
September	4.87	491.3
October	4.13	436.0
November	3.60	362.1
December	3.71	378.6

3.2 Monthly wind power Output

Monthly energy output (Table 4) of a Whisper 100 wind turbine was determined as stated in section 2.3. Statistical analysis predicted an Annual energy production (AEP) of 635 kWh for the wind turbine which just falls short of the 702 kWh needed to meet the demand. from February (Table 4) to May, July, November and December the wind turbine is not able to meet the required demand. This means that either two Whisper 100 wind turbines must be used or the wind system must be coupled together with a PV system to meet the required demand. Using Two Whisper 100 wind turbine makes the system very expensive due to the cost of the wind turbine (Table 1) and will also generate more than required energy thus the option of coupling it together with a PV system is considered.

Table 4: Average Monthly output of Whisper 100 wind turbine

Month	Energy output (kWh)	Surplus
January	66.17	6.65
February	24.38	-29.38
March	16.73	-42.79
April	38.45	-19.15
May	42.15	-17.37
June	67.45	9.85
July	52.54	-6.98
August	69.69	10.17
September	79.51	21.91
October	70.59	11.07
November	57.06	-0.54
December	50.60	-8.92
AEP	635.32	

3.3 PV array Sizing

Using steps outlined in section 2.3.1 the PV array was sized. The system voltage was chosen to be 12 V since a 200 W 12-240 V inverter was chosen to convert DC voltage to AC voltage. The number of panels in a series string was calculated to be 1 since the module working voltage obtained from the I-V curve of the 135 W panel is 15 V. Wenham et al. [15] stated that conversion of radiation form a horizontal surface to a tilted surface is computationally extensive and better left to available PV programs thus for this study RETScreen was used to convert the horizontal radiation for the month of March (largest deficit) to the optimum tilt angle in order to carry out the calculation for the gross mean daily output. For the month of March the average daily solar radiation on a tilt of 20^0 was found to be 3.76 kWh m^{-2} day^{-1} which multiplied with the I_P of 7.0 A yielded a gross mean daily output of 24 kWh. Note that the PV array needs to cater for a load of 42.79 kWh, thus dividing the load by the available array output. It requires two panels in parallel to meet the requirement.

With 2 X 135 W panels, the PV array was predicted to produce an annual energy production (AEP) of 312 kWh determined by with the number of hours of full sun in the year multiplying (corrected by allowing 10 % for dirt losses and mismatch). If the PV alone was to meet the load demand than the number of panels in a parallel string increases as the DC bus voltage does not change. Thus the load to be catered by the PV array would be 59.52 kWh which requires three panels.

3.4 Battery Sizing

The battery bank has to cater for the load at night as well as to cater for 1 day of no generation by renewables for a hybrid system. Thus the battery needs to cater for a total load of 3840 Wh. The battery bank capacity was calculated to be 417 Ah. Since the chosen battery is 110 Ah, hence four batteries were needed to meet the capacity making the total storage capacity 440 Ah.

For a PV only system it was determined that the site has to cater for at least 4 days of no sun. Thus total load delivered was 5760 Wh yielding a battery bank capacity of 800 Ah. This meant that a total of 8 X 110 Ah batteries. Hence, large battery storage for a small load requirement that was not critical. This was grossly over-sized, hence PV only system was not considered any further. Based on this PV-wind hybrid combination was considered.

3.5 HOMER Simulation and Optimization

After resource assessment and manual system sizing HOMER was used to carry out the hybrid design. Input parameters for HOMER (Fig 3) shows equipment and resources to consider for the hybrid design.

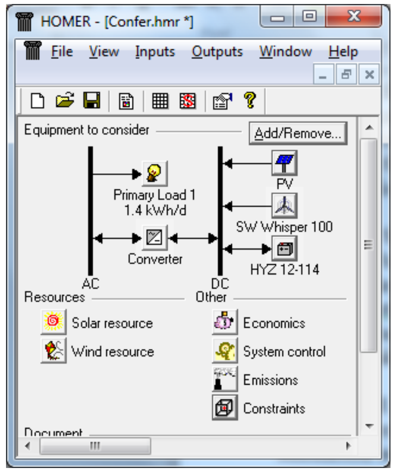
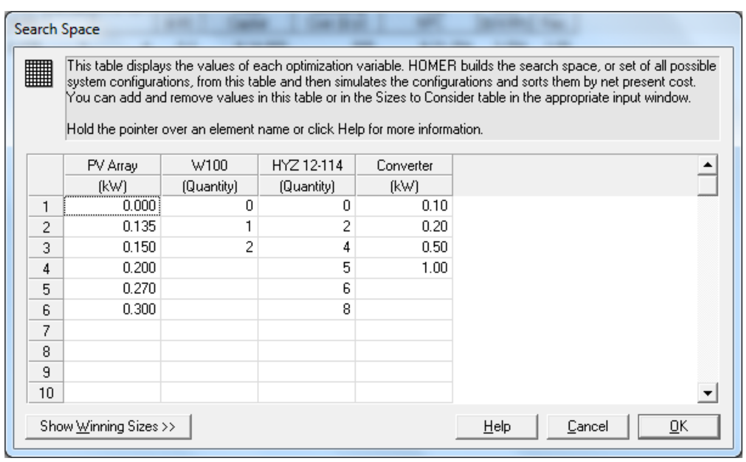


Fig 3: HOMER inputs.

The search space (Fig 4) shows a number of possible combinations for HOMER to consider. Using the list of possible combinations HOMER carried out simulations to derive the most favorable system to cater for the load. With the current search space HOMER executed 432 different combinations to obtain the optimal system to meet the demand. The optimal system was then decided bearing in mind the capital cost and the cost of energy.



	PV Array (kW)	W100 (Quantity)	HYZ 12-114 (Quantity)	Converter (kW)
1	0.000	0	0	0.10
2	0.135	1	2	0.20
3	0.150	2	4	0.50
4	0.200		5	1.00
5	0.270		6	
6	0.300		8	
7				
8				
9				
10				

Fig 4: HOMER search space.

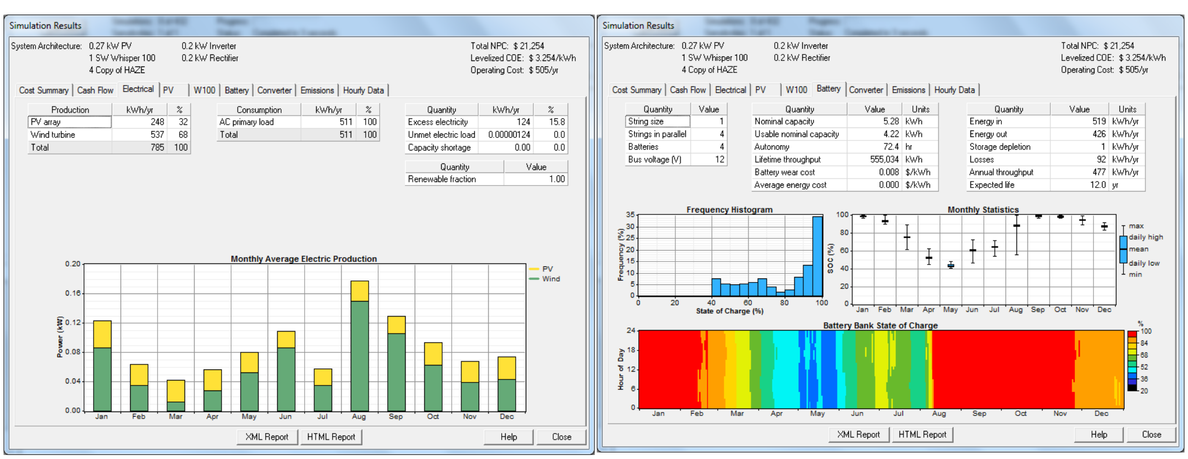
HOMER predicted the two most probable systems (Table 5) that it considered to meet the energy demand with the lowest cost of energy and capital cost.

Table 5: HOMER optimal system

Option	PV (kW)	W100	HYZ 12-114	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction
1	0.27	1	4	0.2	$14,800	505	$21,254	3.254	1
2		1	8	0.2	$16,400	625	$24,390	3.737	1

Option 1 was chosen based on the cost of energy and capital cost. HOMER (Fig 5a) predicted that the PV array would meet 32 % of the load while the wind turbine would meet 68 % of the load for option 1. The overall system capital cost was calculated to be $14 800 with a cost of energy of $3.25 per kWh. The system is predicted to meet the energy demand with no capacity shortage. Overall, the battery SOC (Fig 5b) reached a minimum of 40 % in May which is still over the 20 % allowable limit [11].

The annual energy production from the hybrid system was expected to be 785 kWh which is greater than the annual energy demand calculated earlier. From the monthly average production graph (Fig 5a) most of the months the wind contribution is more than the PV contribution. However, during the months of March and April PV is the major contributor. During these months the wind speeds are quite low and is considered to be the "calm" period for the wind turbine.



(a) (b)

Fig 5: HOMER simulations output

The battery SOC when studied for option 2 showed that the SOC dips below the 20 % limit thus not only making option 2 expensive but unreliable as well. After carrying out manual calculations and simulations using HOMER it can be seen that the optimal system to cater for the load demand is a hybrid consisting of a single Whisper 100 wind turbine coupled together with a 0.27 kW_p PV array and 440 Ah of battery storage. The wind turbine or the PV only system is capital expensive (Table 5) compared to the hybrid combination and requires more storage capacity; once again making the hybrid system seemed more feasible.

3.6 Comparison

Once an optimized system had been attained from HOMER it was compared with the manual sizing to see if the two were similar. Parameters of interest were the number of wind turbine, PV array size and battery bank size and the AEP. Table 6 summarizes the parameters of interest from each method.

Table 6: Results summary

				AEP (kWh)		
Output	PV	Wind Turbine	Batteries	wind	PV	Overall
HOMER	0.27	1	4	537	248	785
Manual	0.27	1	4	635	312	947

The configuration of the hybrid system from both methods (HOMER and manual) is comparable with slight difference in AEP. It should be borne in mind that for manual calculation the AEP is predicted by average values whereby HOMER used daily data analysis to predict the AEP. Since AEP is more than the demand for both calculations, it is safe to assume that the system configuration meets the requirements.

4. CONCLUSIONS

Site specific solar and wind resource assessment of solar and wind was carried out in order design a solar-wind hybrid system to power street lights around a USP car-park with a total daily load requirement of 1.6 kWh AC. The study utilized the solar wind data (from 1st January to 31st December, 2007) collected by the School of Engineering and Physics metrological data bank.

From the time series plot the seasonal variation of the two resources revealed a complementary nature existed between solar and wind at the site making it a potential site for generating electricity by hybridizing the two. With annual average solar radiation of 3.8 kWh m^{-2} $day^{-1}$the site is predicted to receive 1387 h of full sun annually. Hence, 2 X 135 Co-energy PV module is expected to produce approximately 300 kWh annually. Statistical analysis of wind speed at the site showed an annual average of 3.88 m s^{-1} at a height of 10 m and Whisper 100 will be in operation for more than 50 % of the time indicating good potential for wind. The Whisper 100 is predicted on average to produce approximately 800 kWh annually.

System design was carried out using two different methods and compared. Both (manual and HOMER) yielded an optimal and feasible combination of a single Whisper 100 wind turbine together with a 0.27 kW_P PV array with a battery storage capacity of 440 Ah. Since the design criteria from both the methods were same the above configuration was accepted to be the optimal one that is adequate to meet the required load. Battery simulation done using HOMER showed that for the optimal system the battery SOC would remain above the critical level of 20 %.

Hence, for remote areas in Fiji Wind-PV hybrid systems should be considered to produce affordable reliable and clean energy. Further monitoring of RE resources around the Fiji islands is crucial for future design of adequate renewable systems since wind and solar resources are site specific.

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Assessment of the Most Sustainable Renewable Energy Configuration System in Mauritius and Rodrigues

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Abstract :

The Maurice Ile Durable (MID) initiative was launched by the Government of Mauritius in year 2009 to transform the country into a sustainable island. The wind sector is experiencing a sustained growth and many wind farm projects have been announced by the private sector under the Clean Development Mechanism (CDM) and sales of carbon credits namely the 18 MW wind farm project at Plaine des Roches and the 22 MW Wind Farm at Britannia. As land resource in Mauritius and Rodrigues is not unlimited and only a few sites have the necessary characteristics for exploiting wind potential. Therefore, it is essential for policy decision makers to consider the possibility of using other local renewable energy resource as part of the energy mix (including wind energy) for electricity production in Mauritius and not to concentrate solely on wind energy.

In that context, this study was initiated to assess the renewable energy configuration system in Mauritius and Rodrigues including wind energy using a simulation optimization model. An economic assessment was carried out for different configuration of renewable energy system including wind energy for Mauritius and the island of Rodrigues using a simulation tool namely HOMER software. Two case studies were proposed for Mauritius and Rodrigues to include renewable energy sources such as the use of bio-fuel, renewable biomass, mini hydro plant and solar energy using PV Grid tied systems.

Keywords: Renewable energy, Homer software, Mauritius, Rodrigues

1. INTRODUCTION

Exploiting renewable sources of energy for power generation is today the priority of the Government of Mauritius to reduce the high dependency on fossil fuels. The emissions of Carbon Dioxide (main GHG emitter) was about 3256 thousand tons in year 2007 and has slightly decreased by 3.5 % to 3075 thousand tons in year 2009. [1]

Mauritius presently obtains around 17.5% of its energy needs from renewable sources (mainly from bagasse which is a by-product of sugar cane, wind and Hydro representing only 4.8 %). [1]. Some 2,577 GWh (222 ktoe) of electricity was generated in 2009 in Mauritius and the peak demand for electricity in Mauritius continued to increase every year and have reached 388.6 MW in 2009. [1]

In 1980's, a United Nations Department of Technical Co-Operation for Development (UNDTCD) funded project entitled 'Wind Energy Resource Assessment for Mauritius' was conducted to identify the most potential sites for wind power generation in Mauritius. Only a few sites were recommended by the study and since Mauritius is a small country where land is an important resource, it would be wiser for the Government or the private sector to explore and invest on other economically sustainable renewable energy sources other than wind energy. Therefore, there is a need to assess the cost and environment benefits of having other renewable energy source together with Wind energy such as bio-fuel or synthetic gas-fuel, PV solar energy or other types of renewable sources.

In recent years, a feasibility study of wind farming in Mauritius has been conducted in 2002 by C. Palanichamy and the wind potential has been estimated to be 60-65 MW taking into consideration wind speed data obtained, the CEB grid capacity and the available land resources. [2]

Table 1: Total installed capacity for Electricity production 2008 and 2009. [1]

Year	Effective Capacity (MW)	Peak Power Demand (MW)		Electricity Generated from Wind	Electricity Generated from Thermal	Total Electricity
		Mauritius	Rodrigues			
2008	612.2	378.1	6.0	0.4	2,448.8	2,557.2
2009	656.3	388.6	5.6	1.5	2,453.5	2,577/4

The proposal of an assessment of the most economical and sustainable mixed Renewable Wind energy Configuration System in Mauritius and Rodrigues using a simulation optimization model will enable future investors or policy decision makers to understand the important parameters to achieve a mixed sustainable renewable power generating system in Mauritius while decreasing at the same time our dependency on fossil fuel.

2. OBJECTIVES

The main objective of this report is to use HOMER Simulation and optimization tool to economically assess the different combinations of Wind energy with other renewable energy resources at namely;

a) The existing wind farm at Grenade and Trefles region in Rodrigues;
b) The two proposed wind farm in Mauritius namely the 22 MW Wind Park at Britannia and the 18 MW Wind farm at Plaine des Roches.

Different combinations of Wind energy with other renewable energy resources will be proposed and analyzed for the above projects to see which mixed renewable system configuration would have been the most cost effective and at the same time which will be the most environmentally sustainable system. An optimization model will be formulated for this project using the HOMER free software. The HOMER simulation tool a computer model developed by the U.S. National Renewable Energy Laboratory

(NREL) and is used to simulate and compare different design system based on its technical and economical aspects.

3. PROPOSED CONFIGURATION SYSTEM FOR MAURITIUS AND RODRIGUES

The proposed system configuration system for Mauritius will include the proposed Wind Farm at Plaine des Roches and Britannia, proposed two mini hydro plants at Midlands Dam (350 kW each) and Bagatelle Dam, PV grid tied power generating unit (430 kW) and the Gas to energy project (3 MW) at Mare Chicose land fill site.

The proposed wind farm at Plaine des Roches will consist of 18 wind turbines of model Vergnet GEV HP 1 MW aero generator each rated 1 MW. The promoter Aerowatts (Mauritius) ltd through the Clean Development Mechanism (CDM) involving reduction of greenhouses gases has actually finance the 18 MW wind farm project at Plaine des Roches over 7 years using 210,000 carbon credits contract sold to the Swedish Government represented by the Swedish Energy Agency. [3]

Similarly, the proposed renewable system configuration for Rodrigues will include the existing wind farm at Grenade and the possibility of considering biomass resource (1 MW) and a PV grid tied system (1 MW), mini hydro plant (350 kW) and generators running on coconut oil instead of diesel.

4. MODELING USING HOMER SIMULATION TOOL

4.1 Methodology

The simulation results for each proposed hybrid wind configuration can be easily evaluated by HOMER simulation tool and can be discussed in terms of economic sensitivity of hybridization and the economic and environmental benefits. HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis.

In the simulation process, the performance of a selected design configuration is determined each hour of the year including its technical feasibility and life-cycle cost. In the optimization process, simulation of different system configurations is carried out to find the most appropriate system configuration that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, HOMER software performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. [4]

When proposing a hybrid configuration and simulating its technical and economical behavior using HOMER, many important criterions that can impact on the proposed system need to be input into the simulation tool. Examples of such input that need to be identified are namely;

a) Daily power load requirement,

A baseline load profile data for Mauritius is created using one typical daily load profile 24 hours average (Month is March 2008) obtained from the sole distributor of electricity in Mauritius i.e. the Central Electricity Board (CEB). [5]

Information on daily baseline load profile for Rodrigues is could only be obtained from CEB for year 2003. The maximum peak for 2003 was 3.8 MW whereas the maximum peak demand for Rodrigues Island in year 2008 was obtained to be 5.97 MW. [5] Similarly, a baseline load profile data for Rodrigues Island can be created using the above information and a typical daily load profile 24 hours average for Rodrigues (data November 2003 scaled to November year 2008) and HOMER Software will scaled the data for the rest of the year.

b) Wind data input

The user needs to input wind data for the proposed system since wind power is an integral part of the proposed hybrid system. HOMER application will use this wind data to calculate the output of the wind turbine in each time step specified. For Mauritius the wind dataset will be computed using data received from the Mauritius Meteorological Services Institute services. [6]

c) Wind Turbine data

Since different wind turbine will be used in Rodrigues and Mauritius, the wind turbine data for each sites namely at Grenade in Rodrigues, Plaine des Roches and Britannia need to be input in HOMER individually. For the island of Rodrigues, the wind turbine type assessed will be the four new 275 kW Wind turbine Vergnet GEV MP 275 which was commissioned in 2009 and 2010. Similarly, for the island of Mauritius, the wind turbine type to be used at the proposed project Plaine des Roches and Britannia is the model Vergnet aero generator each rated 1 MW.

d) Temperature

The effect of temperature on the efficiency of PV system is also taken into consideration. The output of the PV system is dependent on temperature. The PV cell temperature is the temperature of the surface of the PV array and during the day the cell temperature can exceed the ambient temperature. [40]

e) Grid data

The user has to input grid information data such as the cost of buying power from the grid, emission data of the grid and other advanced economic information such as interconnectivity charges and standby charge of the grid.

f) Solar data resource

The user needs to input the solar data resource information for both Mauritius and Rodrigues to calculate the output of the PV array if included in the hybrid system configuration. The solar radiation data for Mauritius is calculated using the Photovoltaic Geographical Information System (PVGIS) website designed by the European Commission whereby solar data for the region of Mauritius can be found.

The solar PVGIS radiation estimates for long-term monthly average for Mauritius is obtained by entering the longitude and latitude data (20°20'40", 57°31'27"). Similarly the data for Rodrigues is obtained by entering the longitude and latitude data (19°42', 62.25).

g) PV data

The user needs to input data for PV power system that will be used. Other parameters such as the lifetime (years) of the PV system, the de-rating factor and ground reflectance etc need to be input together with its associated costs. A proposed system of 430 kW PV grid tied system is proposed for Mauritius and a 1 MW grid tied system is proposed for Rodrigues.

h) Biomass data

For Rodrigues Island, the user has to input biomass resource data for a proposed 1 MW BIONERR gasification unit. About 8 450 Tons of wood is required annually i.e. 23.08 tons/day. HOMER will use this information to calculate the amount of biogas produced from the 1 MW proposed unit for each hour of the year.

The average cost of fuel is estimated by ARER [54] to be 60 USD/ton. The gasification ratio is 3.5 kg of wood is necessary to produce 1 kg of biogas according to ARER report [54]. The LHV of biogas produced comes mainly from hydrogen gas, CO and CH_4 is 10.4 MJ/m3.

The LHV of bagasse in Mauritius is estimated to be 17.9 MJ/kg.

i) Current Power plant Capacity data

The user needs to input data on the type of generator to be used. The size of the generator and the capital cost need to be input together with the type of fuel. Diesel fuel and coconut oil fuel will be investigated here.

j) Economics data and any constraints.

Other important parameters such as investment costs on different technologies, technical features, maintenance requirements and lifespan of equipment and the cost of energy produced by different energy configuration will also be computed. Economics parameters that will be considered in this project are namely;

- Annual Real interest rate (%)
- Project life time (years)
- System Fixed capital cost

The project lifetime is also set to 25 years and the system fixed capital cost and system fixed operation and maintenance cost is set to zero. Calculated annual interest rate is calculated to be 1.85 % taking into consideration present inflation rate of Mauritius which is 6.8 %.

A total of 500 MW is allowed to be purchased from the Grid for Mauritius at a purchase price of 0.11 USD/kWh. This figure of 500 MW represents the contribution of electricity production from the CEB and two IPPs Belle VUE Ltd and FUEL Ltd to meet the daily load requirement. This is due to the complexity of estimating the capital cost price and operating cost of fuel running of both bagasse and coal due to lack of cost data.

5. RESULTS & DISCUSSION

For the above mentioned case studies, simulation have been carried out by HOMER simulation tool, the latter simulating the operation of the different proposed system by making energy balance calculations for each of the 8,760 hours in a year. HOMER then performed energy balance calculations for each system configuration that is proposed and have considered whether a configuration is feasible. After simulating all of the possible system configurations, HOMER have displayed a list of configurations, sorted by net present cost (NPC).

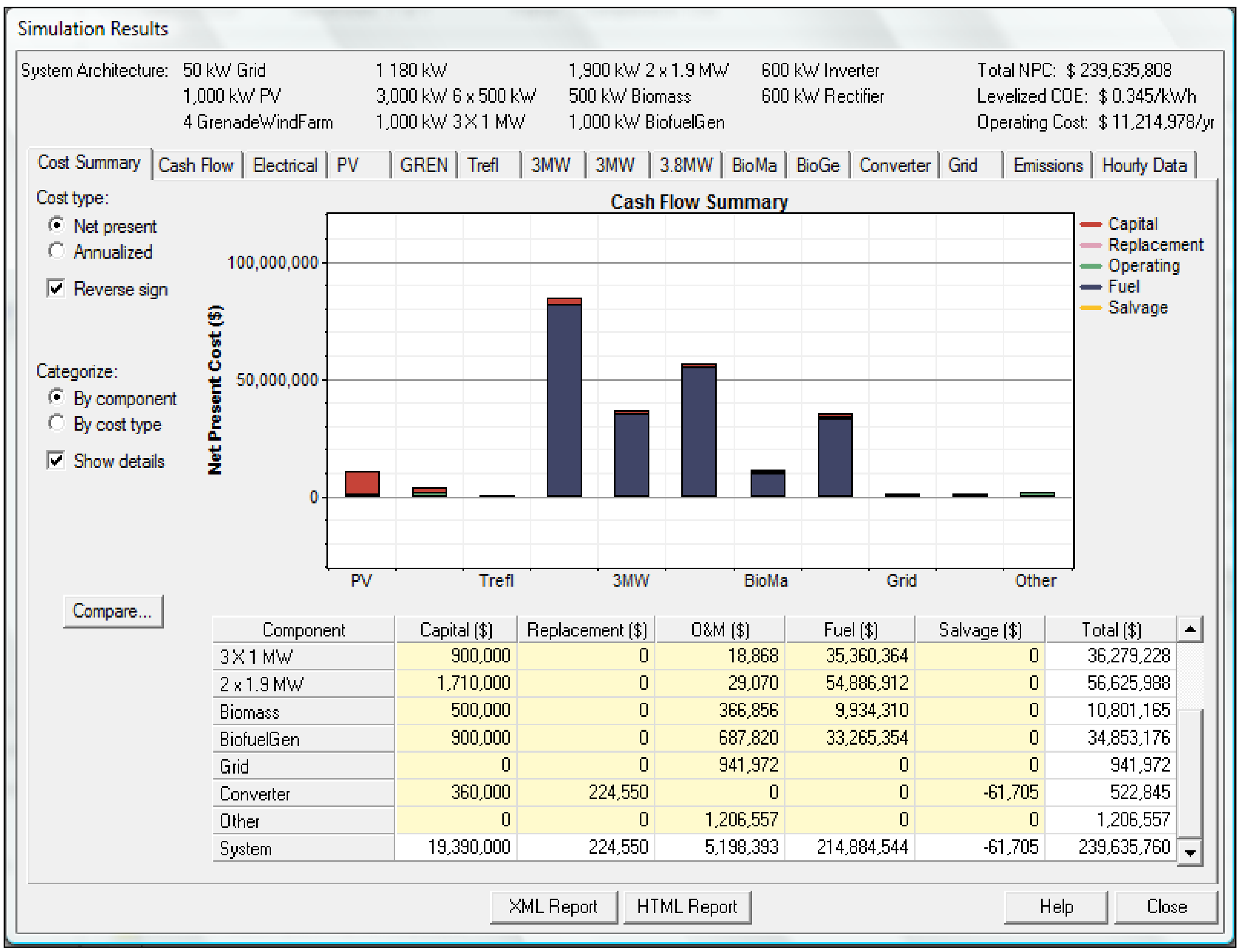
5.1 Rodrigues results & discussion

The renewable energy system configuration that has the lowest Net Present Cost (LCOE of 0.345 USD/kWh, cost of electricity generation) of 239.6 Million USD for Rodrigues Island has the following renewable energy resource component namely;

- Renewable Biomass resource running a 500 kW gasification unit
- 1 MW PV array is considered economically feasible by HOMER
- Mini Hydro power station at Grenade is not considered feasible (Least NPC cost)
- Bio-fuel renewable resource (coconut oil) running a 1 MW generator unit

- A 1000 kW PV grid tied system array
- Trefles and Grenade Wind Farm are considered economically feasible.
- The total installed power capacity for the existing 6 X 500 kW MAN diesel generator to be reduced to 1 MW installed capacity
- The total installed power capacity for the existing 2 X 1.9 MW diesel generator to be reduced to 1.9 MW installed capacity

The annualized cost amounts to 12.2 Million USD and it is interesting to note that the fuel component account for most of this annualized cost, 10.94 Million USD.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
3X1 MW	900,000	0	18,868	35,360,364	0	36,279,228
2 x 1.9 MW	1,710,000	0	29,070	54,886,912	0	56,625,988
Biomass	500,000	0	366,856	9,934,310	0	10,801,165
BiofuelGen	900,000	0	687,820	33,265,354	0	34,853,176
Grid	0	0	941,972	0	0	941,972
Converter	360,000	224,550	0	0	-61,705	522,845
Other	0	0	1,206,557	0	0	1,206,557
System	19,390,000	224,550	5,198,393	214,884,544	-61,705	239,635,760

Fig.1 Cost summary for the least NPC system configuration for Rodrigues

For the island of Rodrigues, the PV array component that has the least cost benefit is the 1 MW PV array system and for the Biomass generator, a 500 kW unit is the most appropriate one (category winner) and a 1 MW unit coconut oil generator is the best option in term of cost. The existing 6 x 500 kW MAN diesel installed capacity remain 3 MW whereas the 3 x 1 MW MAN diesel generators can operate as only 1 MW power capacity. Moreover, the 2 x 1.9 MW diesel generators can also reduce to a 1.9 MW capacity i.e. using one generator set instead of two.

This is economically possible by adding 1 MW generating running of renewable fuel oil such as coconut oil. Reduction of the import of diesel in Rodrigues by coconut oil (CNO) is economically feasible and sustainable and can serve as a successful case study for Mauritius. About 2870 tons of CNO fuel will be required for the 1 MW generators running of bio-fuel. The question is whether the 2870 tons of CNO fuel can be 100 % available is Rodrigues is further investigated here. The coastal strip of Rodrigues could easily be planted with coconut trees. If all the coastal area is planted with coconut trees, 180 hectare of plantation can be achieved and using an estimate of 1 hectare of land containing about 200 coconut trees, around 36,000 coconut trees can be harvested.

Walter L. Bradley et al mentioned in a study entitled "Cocos Nucifera: An Abundant Renewable Source of Energy" that Palm oil and coconut oil have extremely high yield. About 0.1 liter of coconut oil can be extracted from a coconut or about 2.7 Kilo-liter of coconut oil per hectare can be obtained using standard extraction techniques. [7] Around 500 tons of coconut oil can be obtained locally and the rest of the 2370 tons of CNO have to be imported from Agalega or purchased internationally. **Thus although a 1 MW bio-fuel generator is the most economically feasible system configuration, the constraint of availability of CNO oil should be carefully addressed.**

In a latest study conducted in the year 2007 by the Reunion Island Regional Energy Agency (ARER) for Rodrigues with regards to the potential of exploiting renewable energy resources in the island, a 1MW biomass unit has been recommended by ARER. [8] **However HOMER simulation tool have shown that only a 500 kW biomass system is sufficient for the input electricity demand curve for Rodrigues.**

With regards to the electricity production for the least NPC cost configuration system as shown in Figure 86, Trefles 180 kW wind farm and 1.1 MW wind farm at Grenade, the biomass unit 500 kW, the 1 MW PV array and the bio-fuel generator 1 MW will contribute to 47 % of the total electricity production. The 1 MW PV array proposed system and the 500 kW biomass gasifier will account to 5 % and 7 % respectively of the power generating capacity whereas the Bio-fuel generator of 1 MW using coconut oil will have the greatest share of electricity production from renewable energy resource if implemented (24 %).

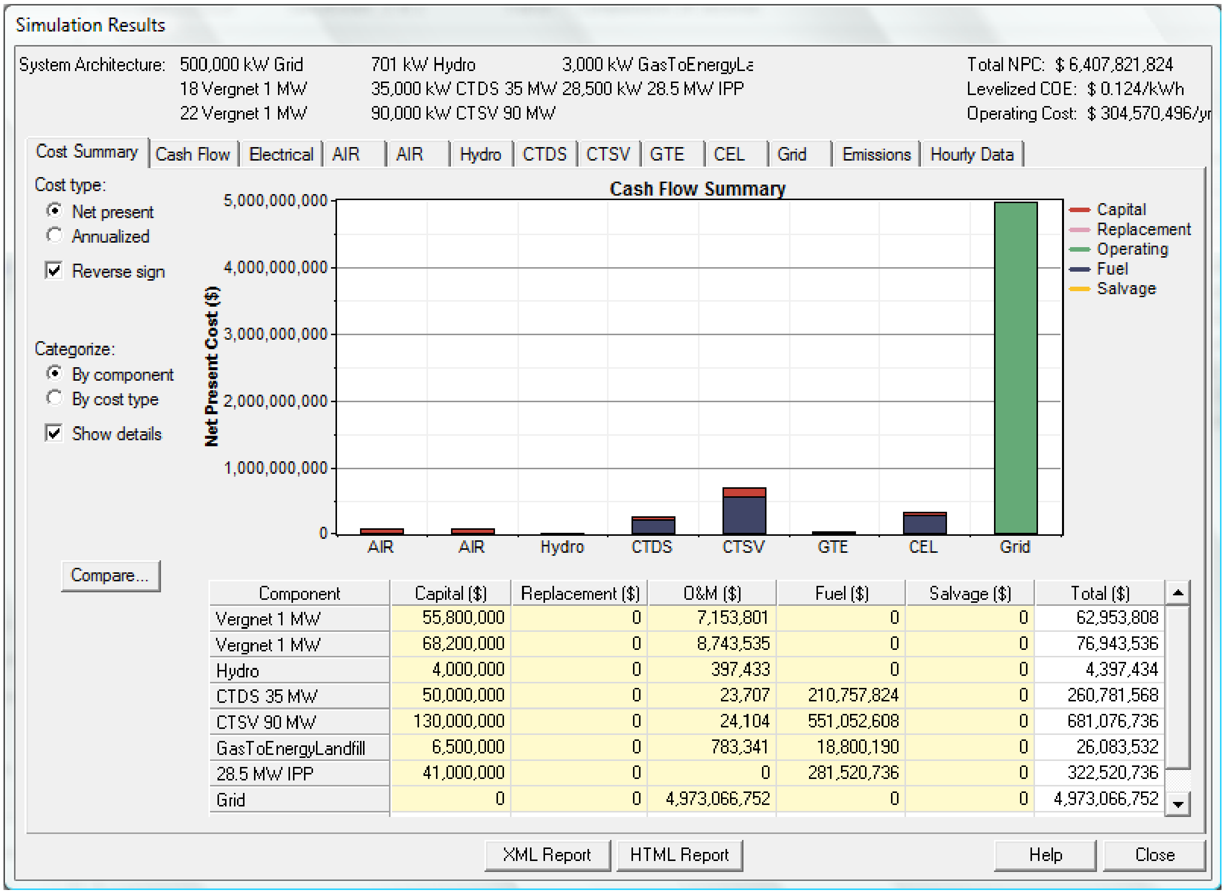
Although the potential of hydro power exist at Grenade, it is still not considered as economically feasible by HOMER simulation tool to install a 350 kW mini hydro power station.

5.2 Mauritius results & discussion

The renewable energy system configuration that has the lowest Net Present Cost of 6.45 Billion USD (COE of 0.124 USD/kWh, cost of electricity generation) has the following component namely;

- Mini Hydro station at Bagatelle and Midland Dam with total installed capacity of around 700 kW.
- 3 MW Gas To Energy system at Mare Chicose Land Fill site
- No PV grid tied system array is considered economically feasible by HOMER
- The 18 MW Wind Farm at Plaine Des Roches and the 22 MW Wind farm at Britannia is economically feasible.

With regards to the economics of the most feasible hybrid system configuration, the annualized cost amounts to 335 Million USD



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Vergnet 1 MW	55,800,000	0	7,153,801	0	0	62,953,808
Vergnet 1 MW	68,200,000	0	8,743,535	0	0	76,943,536
Hydro	4,000,000	0	397,433	0	0	4,397,434
CTDS 35 MW	50,000,000	0	23,707	210,757,824	0	260,781,568
CTSV 90 MW	130,000,000	0	24,104	551,052,608	0	681,076,736
GasToEnergyLandfill	6,500,000	0	783,341	18,800,190	0	26,083,532
28.5 MW IPP	41,000,000	0	0	281,520,736	0	322,520,736
Grid	0	0	4,973,066,752	0	0	4,973,066,752

Fig.2 Cost summary for the least NPC system configuration for Mauritius

With regards to the electricity production for the least NPC cost configuration, the 18 MW and 22 MW wind farm at Plaine des Roches and Britannia, the Gas to Electricity 3 MW, the two mini hydro power stations (total installed capacity of 700 kW) and the bio-fuel generator 1 MW will contribute to 5.1 % of the total electricity production. The potential of two mini hydro power stations (total installed capacity of 701 kW) at the existing Midlands Dam and at the future Bagatelle Dam has been considered economically feasible by HOMER simulation.

Moreover, based on the actual solar resource available energy and the price of PV technology, neither a 430 kW nor a 1 MW PV array is considered feasible by HOMER simulation tool. The price of PV technology is still on the high side requiring an investment of around 4.3 Million USD for a 430 kW PV system.

The 3 MW Gas to Energy proposed unit at Mare Chicose landfill station has been considered feasible by HOMER simulation tool requiring a total initial investment capital of 6.5 Million USD. When implemented the Gas To energy unit will provide electricity to around 20,000 households.

If we compare the LCOE cost to produce 1 kWh of electricity for Rodrigues and Mauritius, the LCOE cost for Rodrigues is 0.345/kWh and is higher than the LCOE cost for Mauritius which is 0.124/kWh. The LCOE value for Mauritius calculated by HOMER is closer to was is actually paid by the consumer in Mauritius (around 0.103/kWh for the first 25 kWh for residential purpose and gradually increasing)

A sensitivity analysis is also performed by HOMER simulation tool for the least NPC hybrid configuration system for Mauritius. The main reason to perform a sensitivity analysis for Mauritius the cost price of PV technology is expected to decrease in the coming years. A multiplier factor of 0.4, 0.3 and 0.2 will be applied to see at what falling price the PV technology will be integrated in the least NPC cost configuration system. Sensitivity analysis results have shown that if the present price of PV technology should fall by 80 % to become economically feasible. Moreover, if the local authorities of Mauritius can decrease the present inflation rate of 6.8 %, the least NPC cost would decrease from 6.4 Billion USD to 4.25 Billion USD.

6. CONCLUSION

From the above simulation results by HOMER simulation tool and sensitivity analysis for Rodrigues Island, it can be concluded that the most economically feasible hybrid configuration will include a 500 kW biomass BIONEER gasification unit, a PV array system, no mini hydro power plant and a decrease in the use of diesel generator by replacing the latter with bio-fuel generator such as coconut oil (CNO).

A proposal for a mini Hydro power station at site Grenade is not considered feasible by HOMER simulation tool and this may arise from a very high initial investment of around 1.8 Million USD for a 350 kW unit.

The LCOE cost for Rodrigues system configuration is found to be high compare to that of Mauritius and this is due to high fuel cost coupled with high initial investment cost required and Operational & Maintenance costs involved especially that most of the electricity is generated from Diesel fuel.

From the above simulation results and analysis for Mauritius Island, it can also concluded that the most economically feasible hybrid configuration will include the 18 MW wind farm at Plaine Des Roches, the 22 MW Wind farm at Britannia, a 3 MW Gas to Energy power station at Mare Chicose landfill site, two mini hydro power station at the existing Midlands Dam and at the future Bagatelle Dam.

Therefore, exploiting renewable energy resources such as hydro and wind should be further encouraged by the Government of Mauritius in order to achieve the objectives set under the Maurice Ile Durable initiative for a sustainable island by 2020. However, no PV power generating plant is considered feasible by the HOMER optimization tool.

But although a renewable energy resource is not considered economically feasible, this does not mean that it should never be implemented.

Under the Maurice Ile Durable initiative, a 430 PV power generating unit has been built by a private firm to power its new eco-building headquarter.

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A Comprehensive Study of Wind and Solar Potential for Gau Island, Fiji

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Abstract:

In Vadravadra village, Gau Island electricity is provided by a 15 kW diesel generator 4 hours every evening and fuel usage is approximately 3200 litres/yr. Problem faced by villagers is the constant rise of diesel fuel price which is even more after the addition of transportation cost (from main land to remote island) resulting in villagers currently paying approximately $2.80/litre. This paper attempts to determine energy produced (kWh) from wind and solar for electricity generation at the site as well as the cost of energy (COE).

The first section presents the energy supply and demand for the village. The second section gives the wind and solar resource characteristics for the site. The annual average wind speed for the site is 6.2 m/s and the average insolation is 5.50 kWh/m2/day. The third section presents wind energy potential and size of stand-alone solar system. Using a 15 kW wind turbine with 0.25 as the overall power coefficient, the estimated annual wind energy yield is 33700 kWh. With 5 days storage, stand-alone solar system has a size of 84 batteries and 308-125 W PV modules. The next section presents optimum hybrid configuration for the site using HOMER and finally some conclusions are drawn.

Keywords: Small Wind energy, Solar energy, hybrid system, battery storage, cost of energy

1. INTRODUCTION

Fiji is one of the island countries in the South Pacific region. It has approximately 330 islands of which about one third is inhabited. The total population of Fiji is about 840000 [1]. The mainlands of Fiji (Viti Levu and Vanua Levu) have grid connected electricity. However, small islands are powered by diesel generators through the rural electrification program. Biodiesel and biofuel are slowly being integrated into existing diesel generator sets. One island (Koro island) to date is getting electricity from biofuel. Now, since diesel costs are constantly increasing, small remote islands are looking for alternative sources for electricity production. Currently, in Fiji there is not a working stand-alone wind/solar hybrid system. However, plans are underway to revive the Nabouwalu wind/solar/diesel hybrid system in Vanua Levu which successfully worked for 3 years and then the renewable component stopped producing due to lack of maintenance [2].

Gau Island is situated on the East of Viti Levu (one of the main islands), Fig. 1a. Vadravadra village, belonging to the district of Sawaieke is located in the island of Gau within the Lomaiviti province as shown in Fig. 1b. The location of Vadravadra village is at latitude of 18°06'S and a longitude of 179°20.6'E. The main means of transportation to the island is through a monthly boat service and a weekly flight schedule on Wednesdays. There is no electrical grid available on the island. Electricity is supplied by a 15 kW diesel generator for only 4 hours every evening.

1.1 Current energy supply and demand at the village

Vadravadra village of 44 households with a population of 174 individuals. The village currently has an 18.5 kVA (15 kW) DG set that was installed in 1999 assisted by the Government of Fiji under the Rural Electrification (RE) programme of the Department of Energy (DOE). This generator operates 4 hours every evening and the fuel consumption is approximately 2.2 liters/hour. Hence, in a month (30 days) the fuel consumption is 264 liters which results in 3168 liters of fuel consumed per year with a yearly fuel cost $8870.

Fig. 1a Map of Fiji Islands

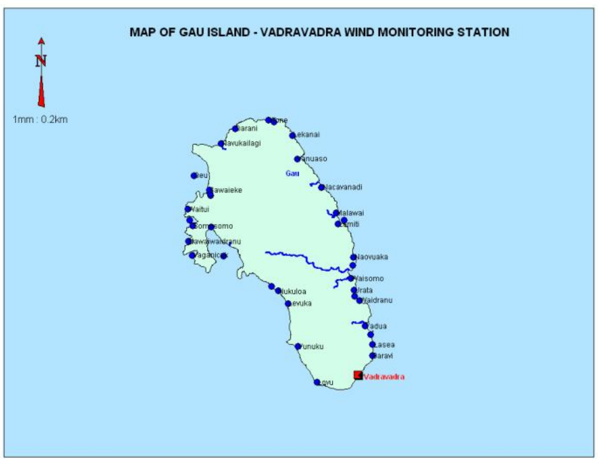

Fig. 1b Map of Gau Island showing Vadravadra village marked in red.

Table 1 show the current load which is used if electricity is assumed to be produced for 24 hours. If the electricity is supplied for 24 hours, current electricity consumption per capita correspond to approximately 150 kWh/year. The electricity usage for the village had been collated by Fiji Department of Energy (FDOE). Fig. 2 shows the daily variation in load when using Table 1.

Table 1 Electrical load at Vadravadra site

load	**power (kW)**	**hours used***	**energy (kWh)**	**Time***
light	2.03	6	12.18	6-10pm and 4-6am
Fridge	2	24	48	24 hours
TV	0.466	6	2.796	4-9pm
Washing Machine	0.4	1	0.4	10-11am
Radio	1.541	5	7.705	6-9am and 2-4pm
Mixer	1	1	1	3-4pm
Daily total			**72**	
Annual consumption			**26310**	

* values are assumed

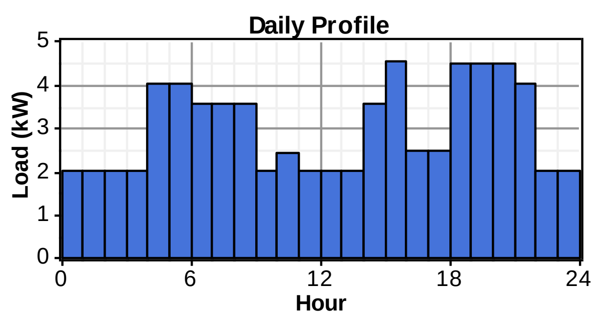

Fig. 2 Daily load profile at Vadravadra site

1.2 Problem at Gau Island

Currently for Vadravadra village electricity is not produced from renewable source. People have to purchase diesel fuel from main land, transport it to the island and then use it in their generators for electricity to be provided 4 hours in the evenings every day. Recently, the price of diesel fuel has been rising and it varies between $2.30-$2.80/liter. The total price of diesel fuel in a month would be approximately $740 if the $2.80/liter is taken as the diesel fuel cost. This is a huge cost compared to the amount of income that they get monthly. Like any ordinary village, villagers sell cash crops for example, copra. For most households copra is the second most income earning crop with pandanus leaves (mat selling) being the most. Copra is sold through the cooperative present within the village which is further transported and sold in Savusavu. The villagers are beginning to plant dalo to be sold in Suva.

News came in local newspaper that Gau Secondary School does not have electricity at school consequently boarding students have to use kerosene lamps to study [3]. This shows the energy security issues in remote islands in Fiji. People are desperate on remote islands to get electricity just to cover their basic need which is education and health.

2. WIND AND SOLAR RESOURCE CHARACTERISTIC

2.1 Wind Characteristic

For Vadravadra site the wind speed and direction data have been analyzed for 3 consecutive years (2003 - 2005) which was recorded by FDOE at a height of 27m on 137 m Delainasinu hill. Wind characteristics such as monthly variation in wind speed, diurnal variation in wind speed, the wind speed frequency and duration curves and turbulence intensity curves will help wind developers make better decision in installing a wind turbine at a particular site.

From the analysis of the three years of wind data, the annual average wind speed for the site is 6.2 m/s and the average turbulence intensity is 0.174. The wind speed frequency for the site is shown in Fig. 3. This curve will be used to estimate the wind energy output from the site by using the selected wind turbines' power curve.

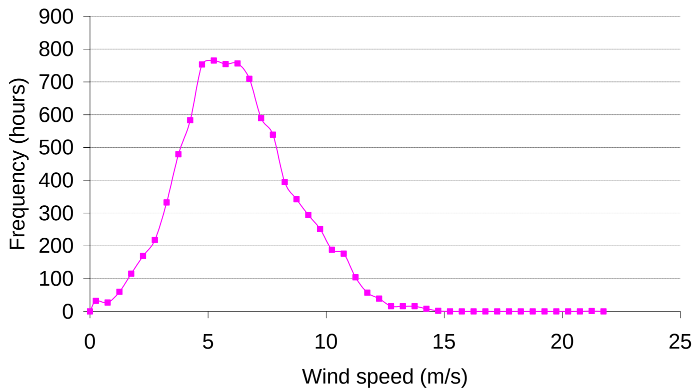

Fig. 3 Wind speed frequency curve for Vadravadra village

From Fig. 3 it is observed that majority (75 %) of the time wind speed is between 3.5 m/s and 8.5 m/s. This graph can be used while choosing an appropriate wind turbine by looking at its cut-in(v_c), rated (v_r) and furling (v_f) wind speed. It would not be desirable to have large v_r *and* v_c compared to the wind speed characteristics for the site since this would decrease the capacity factor for wind turbine. $v_c = 3.5\, m/s$ and $v_r = 8-10\, m/s$ can be chosen for the site.

In Fig. 4 the highest wind speed of 8.50 m/s is in June and the lowest wind speed is recorded in March of 4.60 m/s. This graph can be used to plan for monthly wind energy production and determine months where there would be a backup power needed and for months where there will be excess energy generated.

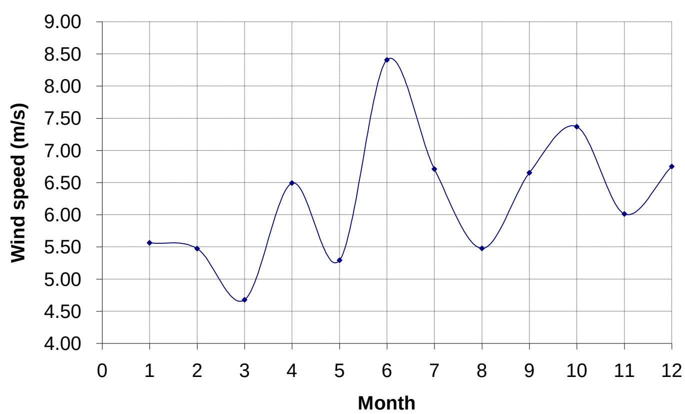

Fig 4 Monthly wind speed variation at Vadravadra village

From the daily variation in wind speed, Fig. 5, it is seen that during day time the wind speed is less while during the night time wind speed increases. There is a peak in wind speed during the mid-day but when compared to late at night this wind speed is less. High wind speeds around mid night would mean more wind energy production.

However, the load requirement for villagers at mid night is not that much, so the excess wind energy production can be stored in a battery bank or in some other kind of storage.

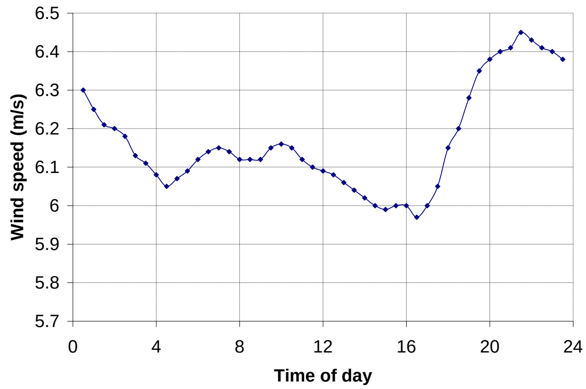

Fig 5 Diurnal variation in wind speed

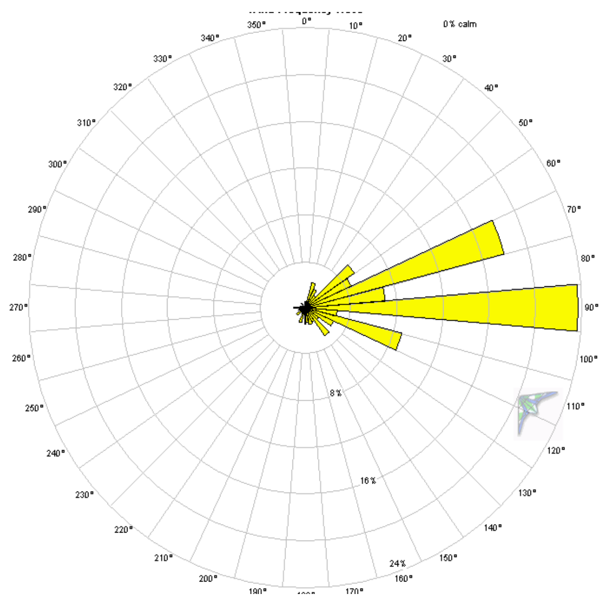

Fig. 6 Wind rose for Vadravadra village

From the wind rose for Vadravadra site (Fig. 6), the prevalent wind is from the East. This knowledge would help wind planners in the installation of the wind turbine at the site by orienting an upwind wind turbine in the correct direction to reduce the fatigue and other loads on the wind turbine and its blades.

2.2 Solar Resource

Since the solar insolation data is not recorded for Vadravadra site, the data has been obtained from NASA website [4] by entering the latitude and longitude of the site.

The 22-year average solar radiation data per square meter per day for Vadravadra site for a solar panel tilted at 18° pointing the equator is 5.50 kWh/m^2/day. The monthly variation in solar radiation data is shown in Fig. 7. Comparison of Fig. 7 to Fig. 4 shows that when the solar radiation data is less during the middle of the year, the wind speed values are high this time and when wind speed is low (during beginning of the year) the solar radiation is high. This means that solar and wind speed data complement each other. Hence, for an energy planner it would be wise to set up a Solar PV/Wind Hybrid system to fully exploit the renewable energy resource.

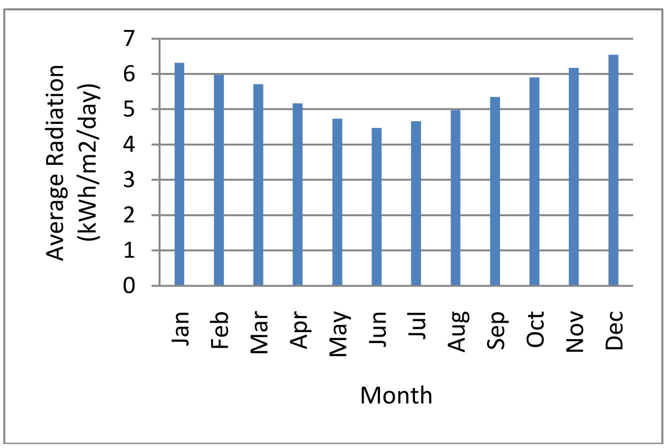

Fig. 7 Monthly variation in solar radiation

3. WIND AND SOLAR ENERGY POTENTIAL

3.1 Selecting Wind turbine

Not just any wind turbine should be installed at the proposed site. The wind speed characteristic for the site should match the wind speed specifications of the wind turbine. This means that cut-in and rated wind speed $(v_c \text{ and } v_r)$ of the wind turbine should not be very high. Also the chosen wind turbine should be able to meet the electrical demand for the site as well as cater for 10 % increase in energy demand.

Considering the wind speed characteristics at the site, the electrical demand (~26000 kWh/year) and the fact that once electricity is provided for 24 hours electrical demand will increase, Hannevind 15 kW, 3 bladed wind turbine is chosen for the site. The specifications of this wind turbine are: $v_c = 2.5 m/s; v_r = 9 m/s$; diameter of blades = 10 m; permanent magnet generator and a self supporting lattice tower is recommended with height options of 21/27/33m. This wind turbine is chosen because it has low cut-in wind speed, low rated wind speed, and has 10 m diameter of wind blades. The diameter of wind turbine blades is directly proportional to the electrical power output (P_e) from wind turbine because P_e output from any wind turbine is given by [5,6]

$$P_e = \frac{1}{2} C_{op} \rho A v^3 , \qquad (1)$$

Where

C_{op} is the overall power coefficient of the wind turbine which takes into account the aerodynamic efficiency, mechanical efficiency and electrical efficiency.
ρ is the density of air (1.2 kg/m^3)
A is the area of the turbine blades
v is the wind speed

From Eq. (1) it is also noted that wind speed plays a major role in the wind turbines P_e output. If the wind speed doubles then the output power from wind turbine will increase by 8 times. The power output curve is shown in Fig. 8.

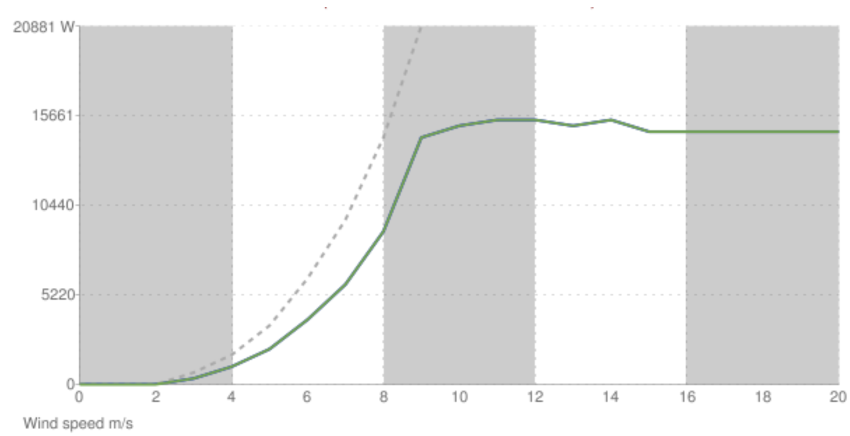

Fig 8 Hannevind 15 kW wind turbine power output based on manufacturer's data

The efficiency of the 15 kW wind turbine is shown in Fig. 9 [7]. In view of efficiency variation of Hannevind 15 kW wind turbine with respect to wind speed the turbine has high efficiency (more than 30 %) from 3-10m/s. From Fig. 3, it is noted that most of the time wind speed is between 3-10 m/s which implies that there would be high wind energy yield during this range of wind speed.

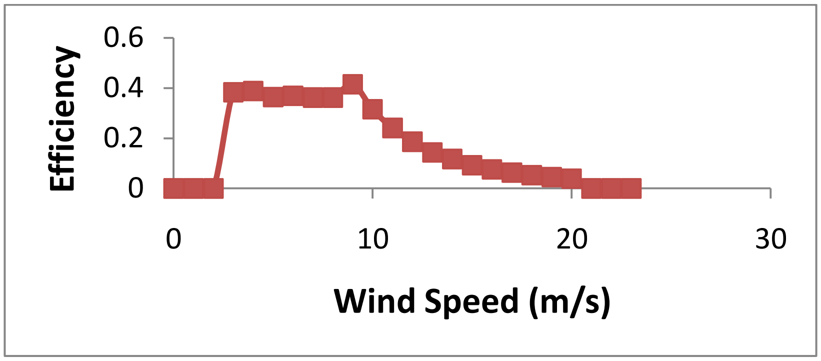

Fig. 9 Efficiency variation of Hannevind 15 kW wind turbine

3.2 Estimated wind energy output

The annual energy (E_{ann}) yield was calculated using Eq. (2).

$$E_{ann} = \sum_{i=v_c}^{v_r} P_{e_i} t_i \qquad (2)$$

Where

i is the wind speed

P_{e_i} is the electrical power from wind turbine at a particular wind speed i

T_i is the number of hours in a year for which wind speed is i

When the overall power coefficient of the 15 kW wind turbine is taken as 0.25, the estimated annual wind energy yield is 33700 kWh. However, considering manufactures power curve, the annual energy output from the wind turbine is estimated to be 42900 kWh. Using error analysis annual mean energy yield from Hannevind 15 kW for Vadravadra site can be $38300\ kWh \pm 20\%$. Considering Fig. 10, energy output more than 1000 kWh is mostly for wind speed between 5-11 m/s.

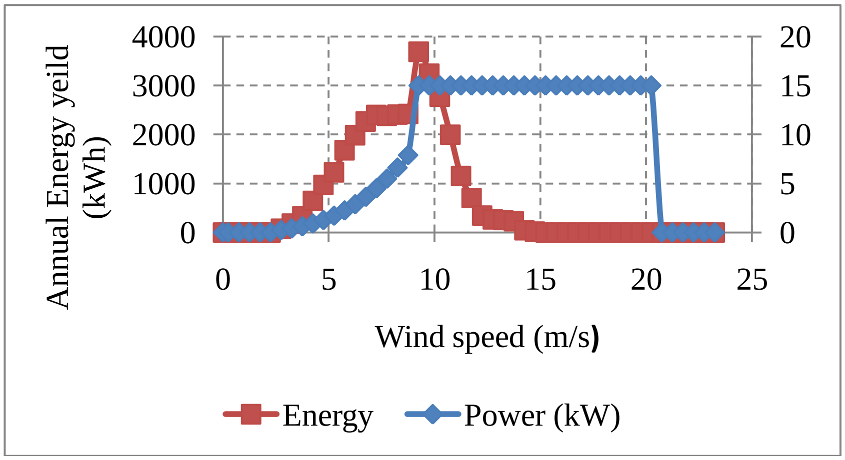

Fig. 10 Energy yield and power output at C_{op} = 0.25

3.3 Sizing stand-alone solar system

The annual average number of consecutive "no sun day" for the site is calculated to be 5.2 days. However, Table 2 [4] also shows that in August there are 9 "no sun days". To calculate the battery storage size maximum number of 'no sun days" should be taken so as to not to undersize the system. However, during design tradeoff is between supplying electricity continuously (100 % of the time) and cost.

A stand-alone system will have the components shown in Fig. 11. To size the system one needs to work backs from the ac load and try to determine the size of battery bank and the size of solar panels. The number of batteries and PV modules needed in a stand-alone system is determined during sizing. In sizing the stand-alone solar system for Vadravadra site the following will be used:

The ac load for the village is 72 kWh/day. 5 days of storage with Surrette 12 V battery of capacity 600 Ah. The coulomb efficiency is taken as 80 %. The system voltage will be 24 V. 12 V, 125 W solar module which has a rated current of 7.2 A is considered. Efficiency of inverter is taken as 90 %. According to Fig. 7, June has the lowest solar insolation of 4.47 kWh/m^2/day and hence the use of 4.47 hours of full sun.

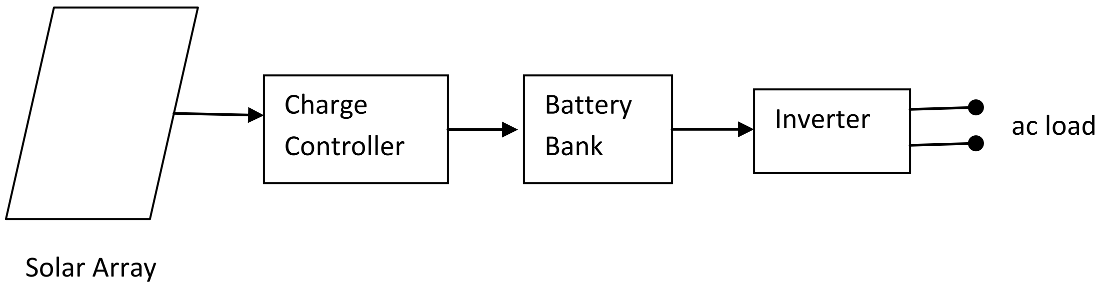

Fig. 11 Stand-alone solar system

Table 2 Average no-sun days for different months

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No-sun day	4.2	3.46	5.28	6.84	3.36	4.98	4.41	8.98	6.17	4.92	4.78	5

Step 1: Total daily ac load

72 kWh/day + (20% × 72) = 86.4 kWh/day = 86400 Wh/day

20 % is taken to cater to unexpected rise in energy demand during the day.

Step 2: dc load input to inverter

$$\frac{86400\,Wh}{0.9} = 96000\,Wh\ d.c.$$

Step 3: battery storage capacity

$$Battery\ storage\,capacity\ (Wh) = \frac{total\ daily\ load\ demand \times No.of\ \ no\,sun\,days}{\eta_{Coulomb}}$$

$$= \frac{96000\,(5)}{0.80} = 600000\,Wh$$

Step 4: calculating the size of battery

(i) Since the system voltage is 24 V, 2 batteries will be in series.
(ii) Battery Ah for storage

$$Ah \;\; for \;\; battery = \frac{600000 \, Wh}{24 \, V} = 25000 \;\; Ah$$

Number of parallel strings is

$$\# \, of \;\; parallel \;\; strings = \frac{25000 \;\; Ah}{600 \;\; Ah} = 42 \;\; parallel \;\; strings$$

Altogether there are 2 batteries in series with 42 parallel strings = 84 batteries in total.

[8] gave the following formulas to have storage capacity which provided electricity 99 % of the time and 95 % of the time.

$$Storage \; days \; (99\%) \approx 24.0 - 4.73(Peaksunhours) + 0.3(Peaksunhours)^2 \qquad (3)$$

$$Storage \; days \; (95\%) \approx 9.43 - 1.9(Peaksunhours) + 0.11(Peaksunhours)^2 \qquad (4)$$

From Eq. (3) 9 storage days is calculated and Eq. (4) calculates 3.1 storage days.

With 9 days storage the number of batteries comes to 150 which would increase the cost of the system and with 3 days storage the number of batteries comes to 50 batteries.

Step 5: PV sizing

Number of PV modules in series is

$$\# \, of \;\; PV \;\; modules \;\; in \;\; series = \frac{System \;\; voltage}{V_{PV \, module}}$$

$$= \frac{24 \, V}{12 \, V} = 2 \; modules \;\; in \;\; series$$

Since a.c. load is 86400 Wh/day and d.c. load for input to inverter is 96000 Wh/day, the ampere-hours (Ah) needed at the inverter is

$$Ah\ needed\ @\ inverter = \frac{96000\,Wh}{24\,V} = 4000\ Ah/day\ @\ 24\,V$$

One string has 2 modules, therefore, Ah to inverter is

$$7.2\ A \times 4.47 hrs\ \ full\ \ sun \times 0.90 \times 0.90 = 26.1\ Ah/day$$

Hence, the number of parallel strings is

$$\#\ of\ \ parallel\ \ strings = \frac{4000\ Ah}{26.1\ Ah} = 153.3 = 154\, parallel\ \ strings$$

Therefore the PV array will have 2 modules in series with 154 parallel strings gives a total of 308 PV modules. Since one module is 125 W, the rated power of the whole array of the PV modules would be 38.5 kW. Having this huge number of PV modules will increase the cost the system. Hence, the next section is analyzing the possibility of wind/solar hybrid system.

4. STAND-ALONE WIND/SOLAR HYBRID CONFIGURATION

Since there no grid connection to the island and to make the system reliable and efficient a wind/solar/diesel hybrid configuration has be analyzed using HOMER software. Wind and solar data had been available during the write up of this paper and these data have been used for running the software. The daily load for the site was taken as shown in Fig. 2. This had been used for weekdays and in weekends. The hybrid components that were considered in HOMER were wind turbine, solar panel, battery, diesel generator and converter. Hannevind 15 kW wind turbine has been considered and power curve was taken from the manufacturer's data. A diesel generator was considered for the simulation to make the whole hybrid system more reliable. 2 batteries were taken in series and the bus voltage was taken as 12 V. 2 types of load were considered during HOMER simulations: (i) current load and (ii) 20 % increase in load. Furthermore, for each load 3 different kind of stand-alone hybrid system were considered (i) Wind/Solar/Diesel Generator, (ii) Wind/Diesel Generator and (iii) Wind/solar. All hybrid system had battery as the storage system.

The cost of the different equipment is as shown in Table 3. The operation and maintenance cost is taken as 3 % of the capital cost and the replacement cost is taken as the capital cost. The project lifetime was taken as 20 years with interest rate of 10 % and the diesel fuel cost is taken as $3.00/liter. Table 4 is summarizing the outcome of the optimized results in HOMER and Fig. 12 shows the monthly energy yield from wind and solar when the electrical load for the site is 71 kWh/day.

Table 3 Cost input in HOMER

Technology	Capital cost (F$)	Replacement costs (F$)	O&M costs (F$)	Expected lifetime	Efficiency
wind turbine	$6000-6500/kW	$6000-6500/kW	3 %	20 years	
Solar Panel (BP solar 165 W)	$1510/unit or ($9200/kW)	$1510/unit	3 %	20 years	Derating factor 80 %
Diesel generator	$1500/kW	$1200/kW	$0.05/hr O&M and $3.00/L Fuel	Model determines	
Converter	$1500/kW	$1500/kW	$100/yr	15 years	90 %
Surrette Batteries (6 V, 460 Ah)	$1300/unit	$1300/unit	$50/yr	Model determines	
Yearly O&M			$1000		
Fixed capital cost (transportation, road making and foundation, etc.)	$100000				

Table 4 Summaries the simulations run in HOMER

	Electrical Load					
Hybrid System Components	Case 1: 71 kWh/day [8.5 kW peak]			Case 2: 85 kWh/day (20 % increase in load [10 kW peak]		
	Wind+solar+gen	Wind+gen	Wind+solar	Wind+solar+gen	Wind+gen	Wind+solar
Wind Turbine						
Size (kW)	15	15	15	15	15	15
Annual production (kWh/yr)	46399	46399	50188	46399	46399	50188
CF (%)	35.3	35.3	38.2	35.3	35.3	38.2
Levelised cost ($/kWh)	0.286	0.286	0.267	0.286	0.286	0.267
PV						
Size (kW)	1	-	10	1	-	10
Annual production (kWh/yr)	1588	-	15878	1588	-	15878
CF (%)	18.1	-	18.1	18.1	-	18.1
Levelised cost ($/kWh)	0.857	-	0.865	0.857	-	0.865
Renewable	0.90	0.89	1.00	0.86	0.84	1.00

Fraction						
Diesel Generator						
Size (kW)	5	5	-	5	5	-
Annual Production (kWh/yr)	5491	5818	-	8104	8538	-
Hours of operation (/yr)	1703	1669	-	2202	2248	-
No. of starts (/yr)	408	458	-	659	700	-
Lifetime	8.81	8.99	-	6.81	6.67	-
CF	12.5	13.3	-	18.5	19.5	-
Fuel consumption (L/yr)	2054	2122	-	2907	3034	-
Specific fuel (L/kWh)	0.374	0.365	-	0.359	0.355	-
Efficiency (%)	27.2	27.9	-	28.3	28.6	-
Marginal generation cost ($/kWh)	0.750	0.750	-	0.750	0.75	-
TOTAL ANNUAL PRODUCTION	53478	52217	66067 (Figure 13)	56091	54937	66067
Battery						
Number	10	10	60	10	10	100

Expected life	4.61	4.75	8	5.03	5.24	8
Converter (Inverter and Rectifier)						
Size (kW)	5	5	10	5	5	10
Emission						
CO2 (kg/yr)	5409	5588	0	7655	7989	0
Excess electricity (%)	49	47.5	57.3	42.3	40.9	47.9
Total NPC ($)	348780	337967	542876	371535	362645	649685
Levelised COE ($/kWh)	1.581	1.532	2.308	1.403	1.370	2.302
O&M (/year)	14281	14091	18495	16954	16990	24533

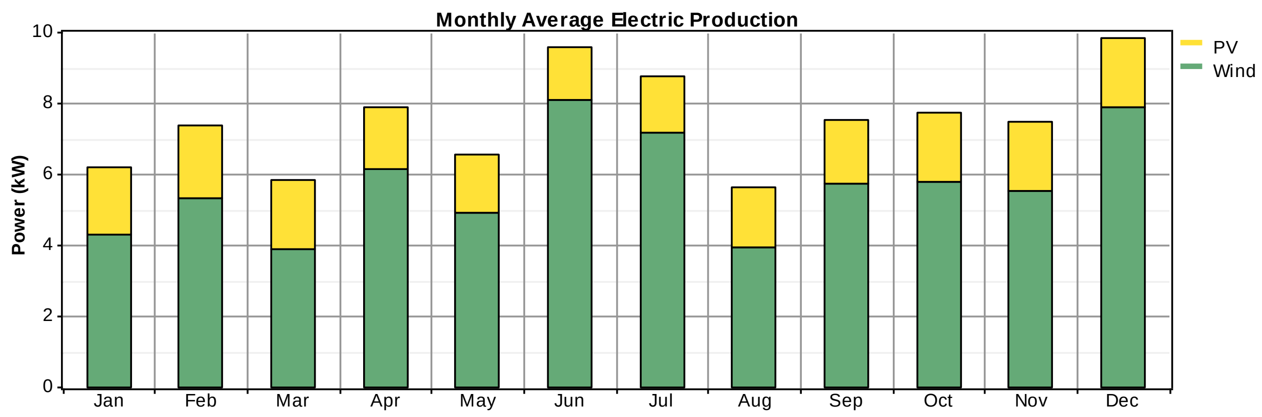

Fig. 12 Monthly average electric production

For each of the different scenarios in Table 4, the diesel fuel consumed per year is less than what is actually being used at the village. This would imply that the burden on diesel fuel would be less. Considering Table 4, the cost of energy (COE) for wind/solar hybrid system is the highest ($2.308/kWh for case 1 load and $2.302/kWh for case 2 load) due to the high number of batteries needed, large converter size and more number of PV modules. Hence, the option of just solar/wind hybrid is not very financially viable. For the two cases of electric load, wind/diesel generator gives the lowest COE of $1.532/kWh for case 1 and $1.370/kWh for case 2 with 10 batteries and 5 kW converters for both cases. Wind/solar/diesel generator hybrid system is not very different from the wind/diesel system since the % electricity from PV is less compared to wind.

In addition, comparing the cost of energy generation from each of the 3 sources (wind, PV and diesel generator) wind has the lowest cost of energy $0.286/kWh whereas PV has $0.857/kWh and diesel generator has $0.750/kWh.

5. CONCLUSIONS

Vadravadra village in Gau island is situated at a remote island not connected to any grid electricity with electricity provided by 15 kW diesel generator 4 hours every evening. Due to the rising fuel cost and the irregular supply of fuel to the island, the villagers are looking for alternative source of electricity. From the study it is found that the site has abundance of wind and solar resource. HOMER simulation results shows that wind/diesel hybrid configuration is the optimum for the site with cost of energy ranging from $1.37-1.53/kWh with increase in electrical load. Now, with the preliminary wind and solar resource survey done, the Fiji Department of Energy is looking for funds to implement this hybrid system to benefit the villagers on Gau Island in terms of education, health and also reduce the carbon footprint.

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TECHNOLOGY TRANSFER AND INTERNATIONAL COOPERATION

Mapping of Organizations Involved In Energy Research Activities in the Pacific Island Region, their Research Projects, Budget and Research Gaps.

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Abstract:

This Study was carried out within the framework of the Pacific Europe Network for Science and Technology (PACE-Net), a European Commission (EC)-funded project. The PACE-Net project seeks to improve regional and bi-regional collaboration and cooperation activities in science and technology (S&T) research within the Pacific and between Europe and the Pacific (ACP and OCT). Its global aim is to develop networks between Pacific and European stakeholders from research entities, universities, industries, policy-makers, programme managers and civil society in order to facilitate and establish balanced and multidisciplinary partnerships in priority areas of mutually beneficial research. Energy is one the theme on which the survey study was carried on. The presentation will be on renewable research in comparison to other research themes in the Pacific. Furthermore the renewable energy research institutions, their projects and the total cost of research in the Pacific is discussed. It is seen that only 4% of the total research in the Pacific is on energy and most of its collaboration happens nationally. The percentage of energy research projects is also compared with the pacific goals in energy and the funding/research/collaboration gap is discussed. The results are further divided on ACP[1], OCT[2] and regional organisations[3] in Pacific for specific data.

Keywords: ACP, OCT, Regional Organisations, Research Institutions, Pacific Goals

1 *Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Samoa and Vanuatu.*
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1. INTRODUCTION

This study was carried out within the framework of the Pacific Europe Network for Science and Technology (PACE-Net), a European Commission (EC)-funded project.

The PACE-Net project seeks to improve regional and bi-regional collaboration and cooperation activities in science and technology (S&T) research within the Pacific and between Europe and the Pacific. Its global aim is to develop networks between Pacific and European stakeholders from research entities, universities, industries, policy-makers, programme managers and civil society in order to facilitate and establish balanced and multidisciplinary partnerships in priority areas of mutually beneficial research. To this end, PACE-Net pursues the following three objectives: [1]

- To reinforce existing S&T dialogues and networks and promote regional integration for those networks by seeking to increase the cooperation between research organisations and universities in the region;
- To identify S&T international cooperation activities and programmes in the Pacific region by setting up a dialogue that will bring relevant S&T experts and stakeholders from the Pacific and Europe together to establish the priority areas for EC's funding instrument, the 7th Framework Programme for Research and Technological Development (FP 7) and beyond; and
- To strengthen the coordination of S&T cooperation and the complementarities with activities and programmes carried out by other European instruments; in particular, synergies with the European Development Fund (EDF) shall be found.

The Pacific Islands Energy Policy was established in the 2004 Regional Energy Meeting in Papua New Guinea, to come with renewable energy technologies in the Pacific Island Countries [2]. However, the difficulties to take up renewable energy are weak institutional planning and management structures; a lack of clear renewable energy development policies; a lack of technical expertise and understanding of the renewable energy potential; a lack of successful demonstration projects; a lack of public and political confidence in renewable energy technology; and an over reliance on donor-funded projects[2]. There are many regional organization and local government ministries which are the key actors who take up this iniciative, for example, USP, SOPAC, SPREP, the Pacific Islands Energy for Sustainable Development (PIESD), EUEI (the European Union Energy Initiative for Poverty Eradication for Sustainable Development), the Renewable Energy and Energy Efficiency Partnership for Asia Pacific (REEEP), the GEF (the Global Environment Facility) and the UNDP [2].

2. METHODOLOGY

Various organisations (research institutions, academic organizations, private institutions, development agencies and ministries by desktop survey) in 19 targeted South Pacific Island Countries and Territories (PICTs)[3] as well as in Australia and New Zealand were contacted for this survey, and in total three questionnaires were designed. The first questionnaire targeted the South Pacific Islands organisations undertaking S&T research for the years 2008, 2009 and 2010, and the second targeted the New Zealand and Australian organisations undertaking S&T research in and with the South Pacific island region for the year 2008, 2009 and 2010. The questionnaire was designed for South Pacific islands' government ministries.

The first questionnaire targeted the research institutions, academic institutions, inter-governmental agencies and the private companies in the Pacific island region, the questionnaire was divided into two parts; Part 1 had questions that only the administrative or corporate section of the organisations was meant to answer, and Part 2 had questions specific to the researchers or research teams working in these organisations. These two parts, when addressed to the respondents, appear as two separate electronic word files or two separate hard copy documents.

The second questionnaire targeted the research organisations, academic institutions, inter-governmental agencies and private companies in Australia and New Zealand that undertake S&T research activities in the South Pacific island region and/or with the South Pacific island researchers.

[3] Includes 15 member countries of the Africa Caribbean Pacific (ACP) Group of the Pacific region (Cook Islands, Federate States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Solomon Islands, East Timor, Tonga, Tuvalu, Samoa and Vanuatu) and the four Overseas Countries and Territories (OCTs) in the Pacific region (French Polynesia, New Caledonia, Wallis and Futuna, Pitcairn)

3. ANALYSIS FOR RESEARCH IN PACIFIC

The Table presents the total number of organisations in the Pacific that were contacted to participate to the survey with Questionnaires 1 and 2 and the number of organisation participated in the survey. The percentage response came up to 40.1%.

Table 1 Organisations contacted for questionnaire 1 and 2.

Questionnaire (regardless of the part completed)*	Organisations contacted for questionnaire nº 1 and 2				
	ACP-based	OCT-based	Regional Organizations	Based in Australia and New Zealand	Total
Sent	47	43	6	28	123
Received	19	19	3	9	50
% response rate per region	40.4	44	50	32	40.1%
Overall % response rate					

From these survey responses majority of the research in the Pacific island region appears to be carried out by the public sector (74%); more precisely by the public universities (23%) and research institutions (26%), followed by governmental departments and ministries (25%) (see Fig. 6). In the OCT region, the majority of organisations undertaking research activities appear to be public research institutes (60%), while in ACP and in Australia and New Zealand these are primarily public education-provider institutes (respectively, 50 and 57%). The low survey sending and response rates in these countries do however mean this is a partial picture and more research is required.

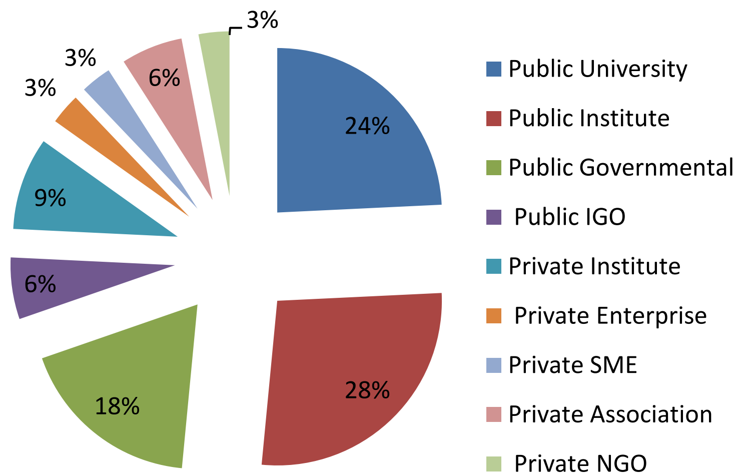

Fig. 1 Distribution of types of organisations in the Pacific ACP and OCT group, Australia, and New Zealand as well as regional organisations involved in S&T research for the Pacific Island Region

From the responses, the predominant area in which S&T research is undertaken in and for the Pacific Island region appears to be Biology and Medicine at 28%. Environment (including climate change) at 24% and Agriculture and Food Supply (at 17%) are also R&D sectors in which considerable numbers of research teams in the Pacific are working, while a few research teams appear to be working in the areas of Industry and Industrial Technology and Information and Communication Technology (5% and 6% respectively) and Energy (3%).

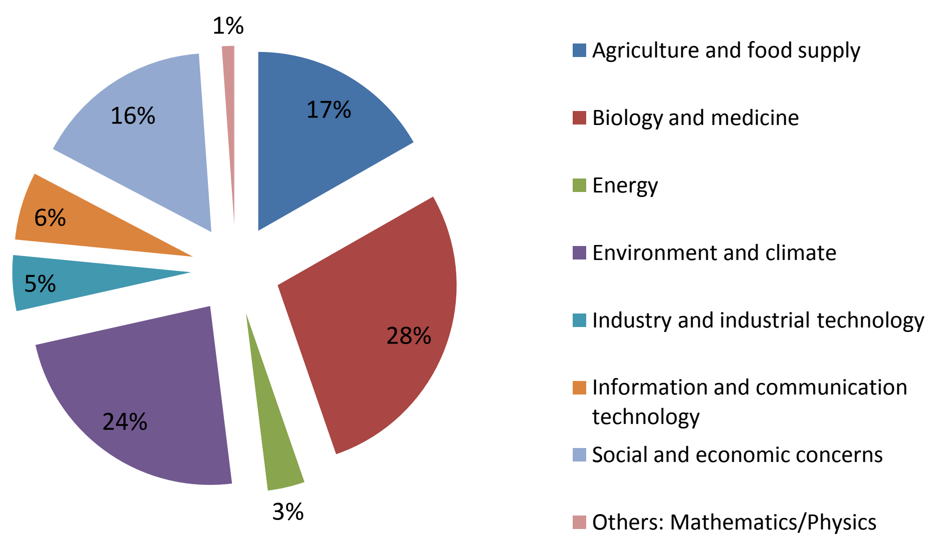

Fig 2 Distribution of Research and Development sector in which all Respondent Research Teams undertake S&T Research Activities

There four institutions in the ACP side that have research groups in Energy. They are the University of the South Pacific, Faculty of Science Technology and Environment Renewable Energy Group (USP), Scientific Research Organisation of Samoa (SROS), Ministry of Natural Resources and Environment Samoa (MERE) and Ministry of Environment and Climate Change Tonga (MECC). Institute of Research and Development does a project on renewable energy but does not have specific research team on energy.

3.1 Research Projects in the Pacific

Figure 3 shows that the predominant area in which S&T research is undertaken in and for the Pacific Island region is Environment including Climate Change (39%). Biology and Medicine (25%) and Agriculture and Food Supply (13%) are also R&D sectors in which a large proportion of research is undertaken. A few projects address the areas of Industry and Industrial Technology (7%), Social and Economic Concerns (7%) Energy (4%) and Information and Communication Technology (3%). It is worth noting that the results in Fig. 3 correspond to those obtained for the R&D sectors of research teams in Fig. 2.

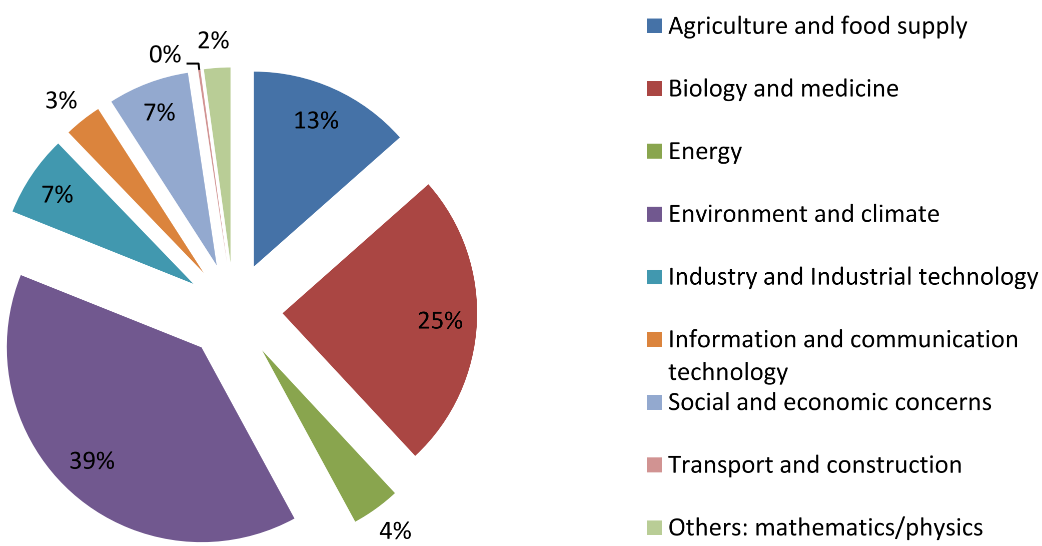

Fig. 3 Overall Distribution of Research and Development Sector of the Research Projects

3.2 Energy Projects

A total of 22 projects out of 524 were energy research projects. Based on the data ACP side has most number of projects (18) in comparison with OCT which has one research project, and Australia and New Zealand three projects. Among the renewable energy groups, the University of the South Pacific has the maximum number of projects (73%) followed by Ministry of Environment and Climate Change –Tonga (13%), Scientific Research organisation of Samoa (9%) and Ministry of Natural Resources and Environment – Samoa.

Table 2 Percentage of Collaborations with Research Organizations Located in Different Regions of the World or with Regional and International Organizations

Respondent research teams based in:	Percentage of Collaborations with Research Organizations Located in Different Regions of the World or with Regional and International Organizations:					
	ACP	OCT	Regional Organisations	Australia and New Zealand	Asian Countries	Europe	International organizations
USP	25%	0%	0%	6.3%	18.8%	0%	0%
SROS	0%	0%	0%	100%	0%	0%	0
MNRE	50%	0%	50%	0%	0%	0%	0%
MECC	14.3%	0%	14.3%	0%	14.3%	28.6%	28.6%

Table 2 demonstrates that the largest proportion of collaboration activities in relation to Pacific Island energy research is happening within the region. Surprisingly from the data, despite the geographical proximity of Pacific ACP and OCT there is no collaboration within these two areas. Similarly the collaboration between the Pacific ACP countries research institution and teams in Europe and Asia is very small. This gap is identified and there is a need to increase collaborative research activities between the regions.

Nonetheless the analysis shows the research in Pacific Islands Energy projects is funded from several sources, including institutional, private sector, civil sector bi-lateral and multilateral donors. This shows that the stakeholders from different sectors of the society more or less support Renewable Energy research in the Pacific Islands. It is also seen that Apart from Lacal and Regional Organisation, Europeean Countires, Asian Countries and International Organisaton funds projects in renewable energy research. It is also interesting to see that the USPs Faculty of Science Technology and Environment funds 64% of these projects.

Table 3 Funding Agencies with Research Organizations Located in Different Regions of the World or with Regional and International Organizations

Respondent research teams based in:	**Funding Agencies with Research Organizations Located in Different Regions of the World or with Regional and International Organizations:**						
	ACP	OCT	Regional Organisations	Australia and New Zealand	Asian Countries	Europe	International organizations
USP	88%	0%	0	0%	12%	14%	0%
SROS	50%	0%	50%	0%	0%	0%	0%
MNRE	33.3 %	0%	0%	0%	0%	33.3%	33.3%
MECC	14.3 %	0%	14.3%	0%	14.3%	28.6%	28.6%
Total							

Major research work is been carried out in Wind Energy, mostly on blade design, power control of wind hybrid system and frequency control techniques using fuzzy logic technique.

Aside from the concerns associated with biofuels stakeholder consultations also raised a range of specific needs regarding the energy sector, including the need for capacity-building on top of direct support for research projects themselves. Some related research projects are Ethanol production from selected Cassava varieties, Engine performance of coconut oil and coconut and bioethanol production projects. Less work is been carried out on solar and ocean energy, solar research are mostly on data collection and ocean projects are on turbine design and data collection. Hybrid renewable energy research, particularly solar/wind/diesel systems, have seen some success in the Pacific islands due to their high efficiency, reliability and comparatively low costs.

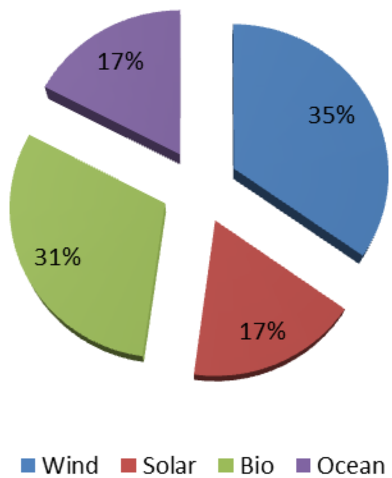

Fig. 4 Percentage of Renewable energy research projects in Pacific

4. CONCLUSION

Comparing the energy research teams with the research projects, it can be observed that energy research teams work on many projects. Which is four research teams doing a total of 22 projects. Most of the Projects in the Pacific receive public funding. There is a gap for private sectors such as the electric company of the respective island countries to fund some research projects and then take up the research data for infrastructure and capacity building. The collaboration gap also shows that there is a need of collaboration between the regions to boost up the research, especially the OCT and ACP side has the same climate conditions. Although survey responses are very good some of the ongoing research institutions did not respond, hence the data might change a bit due to this.

5. ACKNOWLEDGMENT

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A framework for technology cooperation for the successful deployment of renewable energy technologies in Pacific Island Countries and Territories

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Abstract:

Local market conditions should be taken in due account for the success of technology deployment. The organisational framework should favour the consolidation of the transfer, through the establishment of the appropriate mechanisms for capacity retention and private sector involvement (i.e. public-private partnerships with independent power producers, renewable energy service companies, etc.). Ultimately, local capacity of maintaining and operating the technologies that are going to be transferred is key.

Each country has different priorities and reasons for desiring an increased deployment of renewable energy technologies: the EU has a focus on climate change mitigation, the US has a focus on energy security, and sub-Saharan African countries generally have an energy access objective. Small Island Developing States in the Pacific have a clear focus on energy security at the regional level, while many of them also have an unfinished agenda for energy access.

Technology transfer and cooperation efforts in the region must address the barriers to the deployment of renewable energy technologies, to ensure long lasting provision of energy access and durable improvement of energy security. Pacific Energy Ministers have endorsed the Framework for Action on Energy Security in the Pacific (FAESP) and its associated implementation plan (IPESP) in April 2011. At the global level, the UN General Assembly declared 2012 as "International Year of Sustainable Energy for All".

This paper analyses the needs in terms of renewable energy technologies in Pacific Island Countries and Territories, their role in the context of the FAESP and IPESP, their possible contribution to increased energy access and identifies main barriers to their deployment. Once common barriers are identified, specific actions to address them will be highlighted in a framework that includes guidelines for policy development,

identifications of technology transfer needs, barriers to successful technology deployment and funding opportunities.

Keywords: Small Island Developing States, Renewable Energy, Technology Transfer, Technology Cooperation, Energy Policy

Outline

1. Introduction
2. Technology cooperation on renewable energy in the Pacific
3. Orgware: the institutional framework
4. Software: capacity needs
5. Hardware: technology needs
6. Towards a framework for technology cooperation on renewable energy in the Pacific

1. Introduction

The Pacific hosts some of the smallest and most remote countries in the world. Lack of scale and challenging logistics led to an energy sector almost entirely dependent on diesel fuel for power generation.

Larger countries in the region with hydro power resources largely benefit from the use of this reliable, affordable and environmentally friendly renewable energy source. As a matter of fact, the Pacific Island countries with the lowest price of electricity are the ones with the highest share of renewable energy in the mix, almost entirely produced by hydro power plants.

	Average residential electricity tariffs (US cents/kWh)	Average Commercial electricity tariffs (US cents/kWh)	Renewable energy share in electricity (%)
Fiji	16.1	23.8	50
Samoa	35.3	42.3	43
RMI	38.8	44.8	0.22
Palau	41.3	46	0
FSM	42.6	46	0.45
Cook Islands	48.5	54.9	0
Niue	49.7	48.5	2.6
Tonga	50	50	0
Solomon Islands	50.5	55.5	0
Vanuatu	72.1	50	-
Tuvalu	83	94.3	2.1

Figure 7 - Residential and commercial electricity rates for selected PICs and the share of renewable energy. In green the only two countries with relevant hydro power generation.

In most of the region there is an increasing focus on solar photovoltaic as a way to reduce dependency on diesel fuel for power generation. Although there is at least one donor funded solar PV system in each country (in many countries there are dozens of them), the resulting share in the electricity mix is, if not negligible, generally below 1%, as it can be noticed in the previous table.

A similar reduction of diesel consumption can be easily achieved with basic energy efficiency measures on the supply side, usually much cheaper[4], but also less visible.

At the regional level, Pacific Energy Ministers have endorsed the Framework for Action on Energy Security in the Pacific (FAESP) and its associated implementation plan (IPESP) in April 2011. These documents represent the guiding regional framework on energy matters in the Pacific.

As the name suggests, the main focus is on energy security. The driving force behind the preparation of this framework is the need to reduce the region's high vulnerability to rising and volatile oil prices.

The suggested means to reduce this vulnerability are:

- mainstreaming energy security into national planning and budgetary processes
- improving energy efficiency and conservation
- adopting financially viable renewable energy sources
- where appropriate, taking regional and subregional approaches to petroleum procurement

2. Technology cooperation on renewable energy in the Pacific

The FAESP emphasizes that technological solutions need to be "Cost-effective, technically proven and appropriate", while acknowledges the importance of capacity building for ensuring proper maintenance and use of these energy technologies. Most important, it is clearly stated that each country should invest in its human capital for energy, "to gain the skills needed for planning, management and implementation of national energy plans".

Lack of capacity at the country level is often the limiting factor to the identification of the most cost-effective solutions for the improvement of the energy security, for the development of realistic yet ambitious energy plans and, often, to access additional sources of funding for the energy sector. Numerous facilities exist, both from bilateral and multilateral donors, which could provide a good boost to the removal of barriers to

[4] For some specific recommendations, see: KEMA "Quantification of Energy Efficiency in the Utilities of the U.S. Affiliate States (excluding US Virgin Islands)"

the deployment of renewable energy in the Pacific[5]. Way too often these facilities are too complex to access for the national institutional actors, and many smaller Pacific Island Countries are unable to submit acceptable proposals. In many other circumstances, these grants are expected to be sufficient alone for the achievement of ambitious renewable energy targets. While grants are useful for technology demonstration and for building the capacity of local actors on specific renewable energy technologies, significant deployment requires larger investments. Lack of fiscal surplus prevents direct investments from the government, while the expensive diesel fuel baseline makes an excellent case for an economically viable loan, available from commercial and, most important, several development banks; the latter usually provide particularly favorable conditions and associated free technical assistance. However, some Pacific Island countries have reached the threshold after which they are not eligible for further loans from development banks; in these cases, the focus should be on how to mitigate the risk and reduce the interest rates applied by commercial banks, which usually consider the Pacific an high risk region for lending. Grant funding can, for instance, be used to mitigate the risk and reduce the interest rate on commercial loans.

The other way to scale up the deployment of renewable energy in the Pacific would be increasing private sector's participation. As of today, in many cases private sector involvement is often limited to small companies that provide technical services to grant funded projects. Although important, this is not sufficient to scale up the deployment of renewable energy in the region. There is a urgent need of addressing the "orgware": creating a level playing field for investors to bring in Foreign Direct Investments (FDI) into the Pacific Island Countries.

Capable policy makers are needed to create a stable policy framework for Independent Power Producers (IPPs) to invest in renewable energy deployment in the Pacific region. The baseline is a very high cost of power generation through diesel; however, although the potential for renewable energy technologies to provide more affordable electricity is there, is often largely unexploited.

According to the definition from IIASA, technology is the sum of hardware, software and orgware. While hardware in our case is simply the equipment that will produce electricity from renewable energy sources, and the software is constituted by the

[5] See Gualberti and Taibi "The role of climate financing for reaching universal access to modern energy services", EADI/DSA General Conference 2011 proceedings

knowledge required to design, operate and maintain this renewable energy systems, orgware is often the overlooked component in technology cooperation projects. Orgware is defined as the set of institutional settings and rules for the generation of technological knowledge and for the use of technologies.

This article argues that the main role for technology cooperation on renewable energy in the Pacific should be on the Orgware, to enable the creation of a strong and stable policy framework for the improvement of energy security in the Pacific, through increased deployment of renewable energy technologies.

This deployment should be started by accessing the available grant financing, scaled up through the access to soft-loans from development banks and completed by creating the conditions for the private sector to invest its own capital in the deployment of renewable energy in the Pacific.

As an integral part of this deployment, national capacity needs to be strengthened in all its dimensions, from the policy making, to the technical expertise on the technologies. Although in the short term this has been always addressed in past donor-funded projects, retention of this expertise has always proven to be difficult. Some solutions to this have been tried in different contexts[6], but not yet successfully proven in the Pacific. In the long term, investments in the educational sector of each country are needed to create the local energy experts of the future. This applies both to policy makers and technicians. As an example, energy experts trained at the University of the South Pacific in Fiji provide a critical mass of expertise for the energy sector of Fiji itself. Through regional organizations, this expertise often reaches out to the rest of the Pacific.

3. Orgware: the institutional framework

Enabling the *creation of knowledge on renewable energy technologies through national or regional training institutions* is the first change in that is needed for long term sustainability of the efforts toward a more energy secure Pacific.

Being able to produce knowledge on technology locally is the first step to enable a paradigm shift from assistance-based, ad-hoc, small renewable energy projects to self-sustaining, large scale deployment of renewable energy technologies. Trained policy makers can do better energy planning. Trained designers and technicians can lower the cost of renewable energy projects, allowing for more competitiveness and, ultimately,

[6] See, as an example, the training of grandmothers on solar technologies from the Barefoot College in India

more energy produce with the same amount of money. This will also radically lower the costs associated with lack of professional maintenance, which translates in poor efficiency and, ultimately, low reliability of energy supply.

To scale up the deployment of renewable energy, after the initial hand-holding through the "valley-of-the-death" between the early adoption of technologies and their full commercialization, *the private sector must be involved*.

After the initial risk has been taken by the government - if not with own money through some grants and, possibly, some loans to initiate the deployment at scale - having a stable and incentivizing playing field in place for the private sector to invest in renewable energy is essential. Although the scale in the Pacific might be generally too small for large investors to be interested, the high cost of producing power from diesel generators can alone provide for very profitable returns on investments for medium-sized investors. As many power utilities in the Pacific structure their tariff based on a fix amount per kWh for operational costs plus a changing amount linked to diesel price, a simple tender process where the winner is the company that bids for the lowest discount on the fuel price would transfer the risk connected with fuel price volatility from the government to the investor.

Another essential component of the institutional framework to be addressed is the *strengthening of the role of energy offices* in the government structures. Very often energy offices in the Pacific have very little personnel or simply one person, sometimes with no educational background in energy. Considering the relevance that energy expenses have in the budget of Pacific Island countries, an investment must be done to enable national energy offices to undertake a serious energy policy process, and political support must be given to these offices and the policies produced by them. Due to the same constraint on energy experts in the government structures of Pacific Island countries, there are still many opportunities for grant funding that remain unexplored or untapped. Simply hiring a person with some energy background capable of writing grant proposals would be easily covered by a small fraction of the grants this person would leverage.

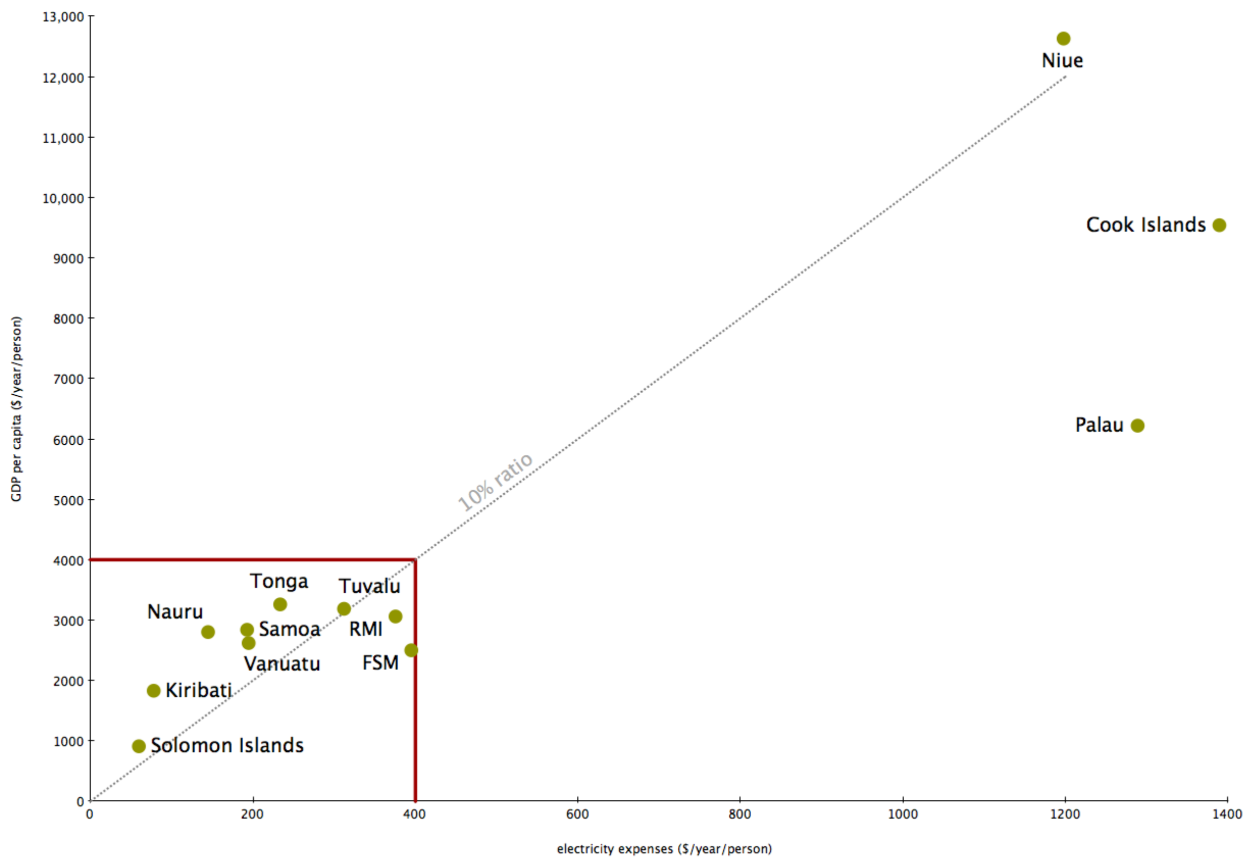

Figure 8 - Yearly expenses on electricity compared to GDP in selected Pacific Island countries (per capita values)

As in the short term it would be an increased cost incurred by the government, already by the end of the first year the investment will pay back: even a 1% saving in the multimillion yearly energy expenses due to a more effective energy office would repay many times the salaries of the additional staff. In the same fashion, if the policies put in place by energy offices are not reflected in the national budgeting process, it will not only limit the extent to which the policies can be actually implemented, but also make them not credible for the private sector and the lending institutions. Without an associated budget commitment, any policy will unlikely bring the results for what it has been designed.

4. Software: capacity needs

Having training programs set up in local training institutions and the energy offices properly staffed is only the first step, although the first and necessary one. The next step is how to create knowledge through this training institutions, how to educate policy makers and technicians on renewable energy matters. Technology cooperation efforts should use the existing institutional framework to address the capacity needs of each country. Training the trainers provides longer lasting results than repeating one off, ad hoc trainings for each technology cooperation project that takes place. The same applies to both training for the trainers and for the policy makers: trainings should build on the existing ones, in order to gradually increase the knowledge of the institutions, both the ones providing training and the ones directly involved in the energy policy process.

This is the approach taken by the North REP project[7] in the Federated States of Micronesia, where the training components are conveyed through the local college, in order to train their trainers and provide the training materials for the incorporation of solar PV into their electrical vocational courses.

Regarding the strengthening of policy makers' capacity of producing sound energy policies and regulations, this needs to be addressed under the software components of technology cooperation. As the orgware has to essentially provide energy offices with sufficient personnel and able to get the policy it produces implemented, the software component should support these offices in the adjustment of the country's body of rules and regulations. As it has been expressed by Pacific Island leaders in recent occasions[8], there is a need for Independent Power Producers (IPPs) to scale up renewable energy deployment in the Pacific. However, most Pacific Island Countries do not have regulations for IPPs to operate under the existing legal framework, and often the existing law prohibits to any entity except from the public power utility to produce electricity.

Another important issue, which energy offices must be put in condition to work on, is the transition from an electricity tariff based on a fix component and a variable component linked to diesel fuel price, to a tariff that incorporates the different cost structure associated with a significant share of renewable energy in the electricity generation mix.

[7] North REP stands for North Pacific ACP Renewable Energy and Energy Efficiency Project. It is funded by the European Union under the 10th EDF funding window and implemented by the Secretariat of the Pacific Community. North REP covers the Federated States of Micronesia, Palau and the Republic of the Marshall Islands.

[8] For instance, this was raised again by more than one government official during the Pacific Islands renewable energy workshop organized by IRENA in Sydney in October 2011.

Both of these issues have to be addressed under the software components of a technology cooperation framework, in order to have the necessary conditions for rapid, large scale deployment of renewable energy technologies in the Pacific.

5. Hardware: technology needs

In the Pacific there has commonly been a problem with operation and maintenance of renewable energy systems. While training on the topics reaches out to all the technicians involved into operating and maintaining renewable energy systems, to mitigate this problem in the short term technology cooperation should choose the hardware and the technology accordingly. Not necessarily the technology that, on paper, provides the lowest cost per unit of electricity produced is the best. Even less so the ones that minimizes the initial investment cost. Local capacity existing at the moment of the design of the renewable energy systems should be taken into account in the design, assuming that a poorly operated or non-maintained system will have a lower efficiency and a shorter lifetime. Taking into account these elements would favor technologies that require less maintenance and that are easier to operate. In addition, sometimes more expensive equipment will last longer in the harsh salty environment of most Pacific island countries. Replacing rusted or failed components, especially in remote outer island locations, requires sometimes many months, in some occasion more than one year[9]. To increase the emphasis on "spending more today, to spend less tomorrow", oversizing the components of a renewable energy system is often a good practice, especially when storage is involved.

To give a simple example, if you are providing power to a remote rural clinic, one of the great benefits is that you do not have to rely on people to come from the main island for administering vaccinations. However, if you undersize your battery bank, in case of an unusually long series of very cloudy days the system might run out of power. This is not unlikely, as during cloudy days artificial lighting will be also used during daytime, shortening even further the battery life. Failing to keep vaccinations cold will make them unusable, defeating the main purpose of electrifying the rural clinic.

In brief, technology cooperation on renewable energy in the Pacific has to be carefully addressing not only the orgware and software components, but also the hardware. Harsh environmental conditions, difficult – sometimes extremely difficult – logistics,

[9] In the Federated States of Micronesia some islands are only reached by one ship twice a year. It therefore takes up to six months to detect the failure of some component in these islands, and the replacement will be installed on the next trip of the ship, six months later.

and poor capacity to operate and maintain renewable energy systems require a careful selection of technology, components and design.

6. Towards a framework for technology cooperation on renewable energy in the Pacific

Based on the previous considerations, the following framework is presented, to identify goals, actors and concrete actions for the large scale deployment of renewable energy in the Pacific, through a concerted effort between international, regional and national actors, governments, training institutions and the private sector. For effective technology cooperation all these actors should be involved and all the conditions must be fulfilled, as overlooking one of the dimensions of technology cooperation might make the efforts in the other dimension more difficult and any result achieved not sustainable in the medium and long term.

	Orgware	Software	Hardware
Goals	Strengthening national and regional policy making and training institutions in the field of renewable energy Creating an enabling policy framework for private sector involvement in the deployment of renewable energy	Build the capacity of national policy makers on renewable energy planning and regulation Enable national training institutions to deliver quality vocational and graduate trainings in the field of renewable energy Building technical capacity in the private sector and public utilities for supporting the	Identification of the most appropriate technologies and technical requirements for RE systems in each Pacific Island Deployment of the most appropriate RE technologies on a large scale in the Pacific

		deployment of renewable energy (i.e. on installation and maintenance of RE systems)	
Participants	Regional and international organizations, donors, national governments, regional and national training institutions	Regional and international organizations, donors, national governments, regional and national training institutions, private sector, public utilities	Regional and international organizations, donors, development banks, commercial banks, private sector, public utilities
Scope of Activities	Creation of vocational and graduate courses in renewable energy in local training institutions Strengthening of the role of national energy offices Creation of policies and regulations for the promotion of renewable energy	Ad-hoc trainings for policy makers on energy planning Support to policy makers by regional and international organization on the development of national regulations on renewable energy Train the trainers courses to national training institutions and institutional support for the incorporation of renewable energy topics in their vocational and graduate courses Ad-hoc trainings for the private sector an public utilities for	Identification of the most appropriate technical requirements and existing standards for renewable energy technologies in the Pacific context and environmental conditions Use all the available funding sources to deploy renewable energy technologies on a large scale in the Pacific

		installation, operation and maintenance of renewable energy technologies	
Resources	Bilateral and multilateral donors, government own resources, training institutions own resources	Bilateral and multilateral donors, private sector	Bilateral and multilateral donors, concessional loans, commercial loans, public utilities own resources, private sector equity investment

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Study to achieve Government power generation target from Non Conventional Renewable Energy by year 2015

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Abstract:

Both electric energy consumption and maximum demand in Sri Lanka have shown growth rate of 6~8% per year for the last 10 years. Therefore the development of power generation and transmission systems has been an important factor for Sri Lanka. According to year 2010 statistics 53% of electric energy is supplied by Hydro power plants and the rest is supplied by the thermal power plants. Sri Lanka doesn't have any thermal fuel resources. But Sri Lanka has good wind and solar resource by its geography. The Government of Sri Lanka has taken a policy decision to move from the present two-energy resource (hydropower and oil) status to a multiple resource status [1]. The coal power is coming as the third electric power source, the first 300 MW coal power plant connected to the grid in last June 2011. The Non-Conventional Renewable Energy (NCRE) shall be the fourth energy resource. The wind studies done in Sri Lanka have concluded that Sri Lanka has huge wind potential. In this study only wind resource is considered to achieve the 10% target of Non Conventional Renewable Energy by 2015 mainly because of two reasons. The wind power generation is the available most economical energy option and the best tariff in Sri Lanka. The Central province has selected as the Candidate site for the study because it has best wind potential and the availability of measured wind data of the area. In this study Ambewela, Hare Park, Ratninda and Naula sites are identified as suitable locations for wind power extraction from Central Province, Sri Lanka. "The Swiss Wind Power Data Website" is used to do the calculations for wind turbine selection. This Software consists of Wind Profile calculator, Weibull distribution, Air density calculator and Power calculator. After detailed analysis of wind resources in the area the Gamesa G97 wind turbine for 2MW range and Leitwind LTW77 wind turbine for 1MW range are selected as most suitable for Central Province. The 21MW wind power plants (WPP) for

Ambewela, Hare Park & Ratninda sites and 4MW WPP for Naula are decided. 21MW WPP consist of ten numbers of 2MW turbines and one 1MW turbine. Further 4MW WPP consist of two 2MW turbines. In this study wind turbines are located in suitable grounds using 1:10,000 geographical maps for each site. NuwaraEliya, Badulla, Ukuwela and Naula 132/33kV Grid Substations are identified as suitable interconnection points for the above selected sites respectively.

Keywords: Sri Lanka, Non-Conventional Renewable Energy, Candidate site, Wind Turbine, Wind Power Plants, Interconnection Points

1. INTRODUCTION

Sri Lanka has huge wind resource. It has been proven by many local and foreign studies such as report on Wind and Solar Resource Atlas of Sri Lanka and Maldives prepared by National Renewable Energy Laboratory, USA, Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka prepared by local professionals [2]. Wind is recognized as the one leading renewable source that to generate electricity because wind is an infinite primary energy source and the low environmental impact, wind is known as a main clean source to generate electricity. Other than the affect the local sceneries and noise that generates by the blades of the rotor consequences of happening of permanent changes to the environment is very less, wind power is a relatively cheap source of renewable energy and hence it is the trendy source at present.

In order to integrate large amounts of wind power successfully, a number of issues need to be addressed. Among them, this paper discussed initial site screening process for wind power plants, selecting wind turbines and selecting the interconnection points only.

The site screening process mainly involves initial screening of wind resources and land suitability. The most essential factor in selecting a wind energy site is the wind resource itself. The wind resource in Sri Lanka mainly varies according to exposure to the monsoon winds. The southwest monsoon (SWM) is stronger and penetrates farther inland and to higher elevations than the northeast monsoon (NEM). An initial land suitability screening will eradicate sites where wind turbines either cannot or should not be installed. Factors that would eradicate a site from consideration include National parks, wildlife sanctuaries or other areas where development is prohibited, migration routes of migratory bird species, areas with high concentrations of rare or endangered birds, some military areas, culturally sensitive areas (historic, religious or archeological sites) and urban areas. In addition, sites will be subjected to an initial screening for transportation and transmission access.

There are lots of wind turbines developers in the world. The wind turbines differ in type, model, capacity …ect. The selection of wind turbine involves matching wind turbine parameters with the site conditions such as wind speed, frequency of each wind speed, wind direction, site conditions..ect.

Wind power as a generation source has specific characteristics, which include variability, geographical distribution and behavior in the power system. These raise challenges for the integration of large amounts of wind power into electricity grids and selecting the interconnection points in first challenge. When selecting interconnection points; available interconnection points (grid substations), capacities of the exiting grid substations, possibilities of having new grid substations, line routes and lengths should be considered. Then the selected interconnection points should be verified by system studies which are not covered in this paper.

Many areas in Sri Lanka shows good-to-excellent wind resources. These areas are concentrated largely in two major regions. The first is the northwestern coastal region from the Kalpitiya Peninsula north to Mannar Island and the Jaffna Peninsula. The second region is the central highlands in the interior of the country, largely in the Central Province but also in parts of Sabaragamuwa and Uva Provinces. Much of the highlands region is over 1500 m in elevation, and the best sites are those that are well exposed to the strong southwest monsoon winds. Other regions with notable areas of good wind resource include the exposed terrain in the southern part of the North Central Province and coastal areas in the southeastern part of the Southern Province [3].

2 METHODOLOGY AND RESULTS

2.1 Decide the wind capacity for study, Reasons for selecting wind as the resource

The following electricity generation targets are envisaged with coal and NCRE resources according to the Government of Sri Lanka policies.

Table 4 Electricity Generation Targets [1]

Year	Electrical Energy Supplied to the Grid as a Share of the Total			
	Conventional hydroelectric	**Maximum from oil**	**Coal**	**Minimum from NCRE**
2000	45%	54%	0%	1%
2005	36%	61%	0%	3%
2010	42%	31%	20%	7%
2015	28%	8%	54%	10%

The Long Term Transmission Development Plan 2008-2016 described the maximum demand for the year 2015 is 3500 MW. So the 10% of the system demand for the year 2015 is 350MW and 5% of the system demand for the year 2015 is 175MW. As per the report on Wind and Solar Resource Atlas of Sri Lanka and Maldives prepared by National Renewable Energy Laboratory, USA the wind potential of the provinces can be illustrated as Table 2.

Table 2 Wind Potential in Provinces

Province	Good-Excellent Potential	Moderate-Excellent Potential
Central	7,550	11,750
Eastern	150	1,350
North Central	300	4,100
North Western	1100	2,050
Northern	4,950	13,450
Sabaragamuwa	2,200	4,100
Southern	650	2,900
Uva	3850	11,650

The table 6 shows the most suitable provinces for wind power connection and their contribution to meet national targets.

Table 6 The contribution of wind capacity from the most suitable provinces

Province	Good-Excellent Potential MW	Wind Capacity (10% Demand	Wind Capacity (5% Demand)
Central	7,550	134	67
North Western	1100	20	10
Northern	4,950	88	44
Sabaragamuwa	2,200	39	20
Uva	3850	69	34
	19,650	350	175

The paper analyzes and discusses the challenges, procedure and power system improvements to absorb almost 67MW wind resource from Central Province. The 67MW satisfy the 5% NCRE target from wind from Central province. The main two reasons for selecting only wind resource to fill the 5% target of Non Conventional Renewable Energy by 2015 are wind power generation is the available most economical energy option and it have best tariff in Sri Lanka.

2.2 Central Province as the candidate site

In this paper Central Province is selected as the candidate site because the best wind potential is recorded in the Central province and there is the measured wind data in the area under "Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka" which is conducted by the Ceylon Electricity Board. In the Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka study, they have selected three wind data monitoring stations in the Central province; they are Rantinda, Hare Park and Ambewela. The detailed data analysis is given for the Ambewela site. So in this paper Ambewela wind data is consider common for all locations in the Central Province.

2.3 Sample Candidate Site Location - Ambewela

Wind mast in Ambewela is situated in the cattle farm of the National Livestock Development Board and evation is about 1800 m. The overall wind pattern in Ambewela follows the general monsoon wind climate in Sri Lanka, which is characterized by South West Monsoon (SWM) (May~September) and North East

Monsoon (NEM) (December~February) (Figure 3). The annual wind speed in Ambewela is 7.31m/s at the measuring height of 40m.

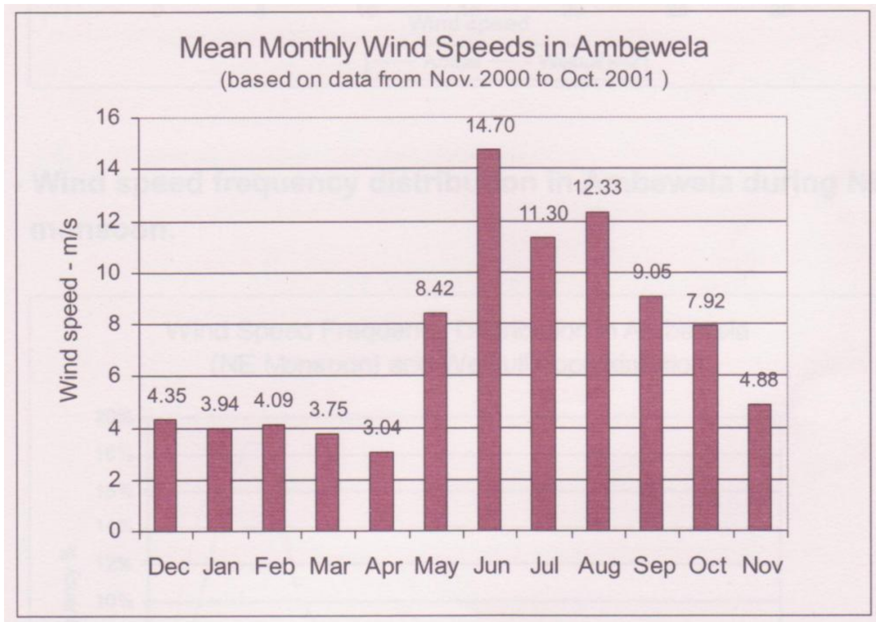

Fig. 3 Mean monthly wind speeds in Ambewela

Source:Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka

2.4 Wind Turbine selection for Ambewela

This study is done using web based software in the "The Swiss Wind Power Data Website". The web site is mandate by Federal Department of the Environment, Transport, Energy and Communications, Swiss Federal Office of Energy (SFOE), Switzerland. Switzerland is a leading country for wind power generation.

2.5 "The Swiss Wind Power Data Website" [4] - Wind Profile Calculator

Wind Profile calculator enables an estimate for the vertical wind speed profile, i.e. the increase of wind speed with height above ground.

2.6 Explanations for the Wind Profile

On the ground, the wind is strongly braked by obstacles and surface roughness. High above the ground in the undisturbed air layers of the geotropic wind (at approx. 5 km above ground) the wind is no longer influenced by the surface. Between these two extremes, wind speed changes with height. This phenomenon is called vertical wind shear. In flat terrain and with a neutrally stratified atmosphere, the logarithmic wind profile is a good estimation for the vertical wind shear:

$$v_2 = v_1 \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)}$$

The reference wind speed v_1 is measured at height h_1. v_2 is the wind speed at height h_2. z_0 is the roughness length. The suitable roughness length for the Ambewela site is 0.03 which describe the land type of 'open agricultural land without fences and hedges; maybe some far apart buildings and very gentle hills'. When height above ground, wind speed and roughness length defined, the software calculate the wind speed for different elevations. The result obtained for the Ambewela site is as in figure 9.

Please specify parameters

height above ground	40	m	
wind speed	7.31	m/s	
roughness length z_0 (see table below)	0.03	m	Refresh

Result

height above ground	wind speed
150 m	8.65 m/s
140 m	8.58 m/s
130 m	8.51 m/s
120 m	8.43 m/s
110 m	8.34 m/s
100 m	8.24 m/s
90 m	8.13 m/s
80 m	8.01 m/s
70 m	7.88 m/s
60 m	7.72 m/s
50 m	7.54 m/s
40 m	7.31 m/s
30 m	7.02 m/s
20 m	6.61 m/s
10 m	5.90 m/s

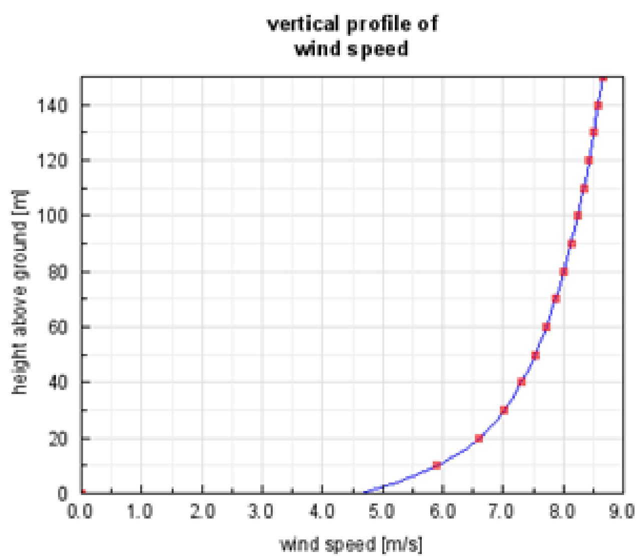

Fig. 9 Vertical profile of wind speed in Ambewela obtained from web based software

2.7 Weibull Distribution

The web based tool can be used to approximate a wind speed distribution with a Wiebull function. The obtained Weibull parameters may subsequently be used in the power calculator to estimate the power production of a wind turbine. Since the Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka Report have the wind speed distribution data for the two monsoons separately, I developed a wind speed distribution data for the whole year by combining the two monsoons data. The results are as below.

Table 10 Calculated Wind Speed Distribution using Measured Data for whole year

Wind Speed for SWM	%	No. of hr	Wind Speed for NEM	%	No. of hr	Wind Speed for whole yr	Total hrs	Total %
0	0.98	42.6	0	3.6	132.2	0	174.8	2.18
1	1.35	58.6	1	6.0	220.3	1	279.0	3.48
2	1.85	80.4	2	10.0	367.2	2	447.6	5.58
3	2.96	128.6	3	15.0	550.8	3	679.4	8.48
4	3.70	160.7	4	18.5	679.3	4	840.0	10.48
5	4.65	202.0	5	17.8	653.6	5	855.6	10.67
6	6.25	271.5	6	10.0	367.2	6	638.7	7.97
7	8.00	347.5	7	8.4	308.4	7	656.0	8.18
8	8.80	382.3	8	4.9	179.9	8	562.2	7.01
9	8.60	373.6	9	3.0	110.2	9	483.7	6.03
10	7.20	312.8	10	1.4	51.40	10	364.2	4.54
11	6.20	269.3	11	0.5	18.40	11	287.7	3.59
12	5.20	225.9	12	0.3	11.00	12	236.9	2.96
13	5.21	226.3	13	0.3	11.00	13	237.3	2.96
14	5.00	217.2	14	0.2	7.30	14	224.5	2.80

15	5.00	217.2	15	0.1	3.70	15	220.9	2.76
16	4.75	206.3	16	0.0	0.00	16	206.3	2.57
17	4.30	186.8	17	0.0	0.00	17	186.8	2.33
18	3.40	147.7	18	0.0	0.00	18	147.7	1.84
19	3.50	152.0	19	0.0	0.00	19	152.0	1.90
20	3.10	134.7	20	0.0	0.00	20	134.7	1.68
	100	4344		100	3672			100

Using the calculated wind speed distribution i.e. wind speed frequency for each wind speed, produce the weibull wind speed distribution for the Ambewala site.

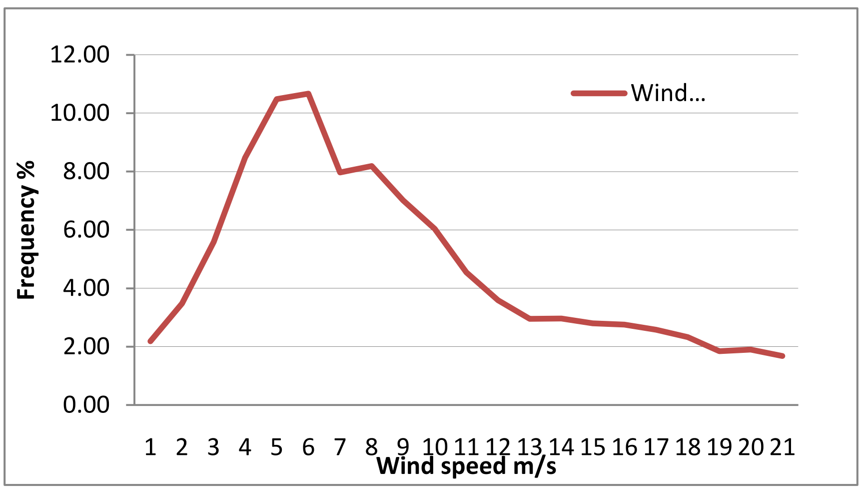

Fig. 10Measured Wind Speed Distribution Data for whole year

Class	Frequency in %
0 - 1 m/s	5.66
1 - 2 m/s	5.58
2 - 3 m/s	8.48
3 - 4 m/s	10.48
4 - 5 m/s	10.67
5 - 6 m/s	7.97
6 - 7 m/s	8.18
7 - 8 m/s	7.01
8 - 9 m/s	6.03
9 - 10 m/s	4.54
10 - 11 m/s	3.59
11 - 12 m/s	2.96
12 - 13 m/s	2.96
13 - 14 m/s	2.80
14 - 15 m/s	2.76
15 - 16 m/s	2.57
16 - 17 m/s	2.33
17 - 18 m/s	1.84
18 - 19 m/s	1.90
19 - 20 m/s	1.68
Sum	99.99

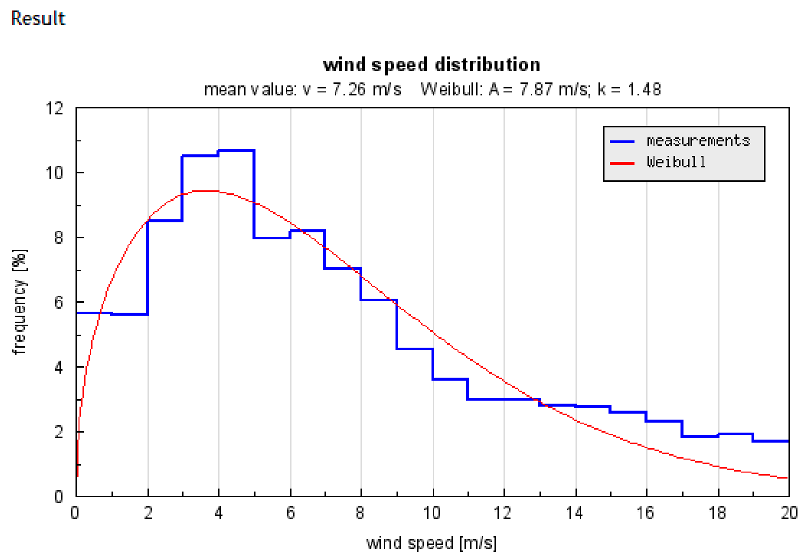

Fig. 11Weibull Wind Speed Distribution Data for whole year [4]

The measured data and weibull distribution matches with Weibull shape factor k~1.48.

2.8 Air Density

Air density decreases with altitude and thus a wind turbine's production decreases. Air density can be calculated either from the altitude or from measurements of temperature and air pressure. In this paper air density is obtained using the measured values.

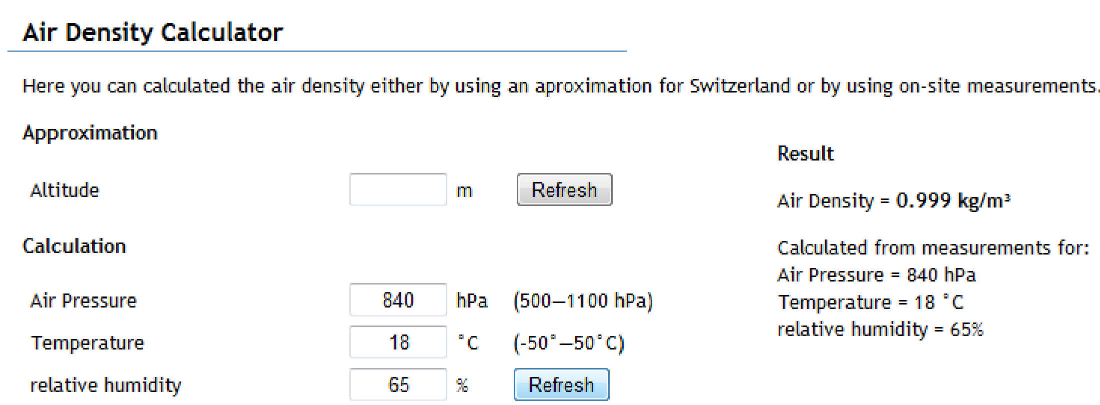

Fig. 13Air Density at Ambewela according to measured data [4]

2.9 Explanations for the power calculator - "The Swiss Wind Power Data Website" [4]

With the power calculator you can estimate the power production for a site for different turbine types. A turbine availability of 100% is assumed (no losses due to down time, icing, transformer losses, park effects etc.). For the power calculator either you can estimate the Weibull distribution for the site with Weibull calculator or the power calculator approximates a distribution for the mean wind speed that is entered. In this paper parameters of the weibull distribution is taken for the power calculations. Weibull scale factor A=7.87 and Weibull shape factor (k) = 1.48. In the power calculator in "The Swiss Wind Power Data Website" has more than 45 wind turbine data. So using the web based software we can calculate annual energy production, plant factor and hours at full capacity. Further it produces the power production distribution curve of each wind turbine when it's subjected to the site parameters.

Power Calculator

Wind speed distribution

Either you can estimate the Weibull distrubtion for your site with the Weibull calculator or the power calculator approximates a distribution for the mean wind speed that is entered.

◉ Weibull parameters A: 7.87 m/s k: 1.48

○ mean wind speed v: 7.26 m/s

Air Density

You can calculate the air density for your site with the air density calculator.

Air density: 0.999 kg/m³

Power curve

Choose a turbine type from the list or choose "user-defined power curve" and enter your own power curve in the table.

Dewind D8/80-2MW (2000 kW)

1 m/s	0	kW	11 m/s	1639	kW	21 m/s	2000	kW
2 m/s	0	kW	12 m/s	1850	kW	22 m/s	2000	kW
3 m/s	0	kW	13 m/s	1954	kW	23 m/s	2000	kW
4 m/s	51	kW	14 m/s	1997	kW	24 m/s	2000	kW
5 m/s	145	kW	15 m/s	2000	kW	25 m/s	2000	kW
6 m/s	276	kW	16 m/s	2000	kW	26 m/s	0	kW
7 m/s	457	kW	17 m/s	2000	kW	27 m/s	0	kW
8 m/s	692	kW	18 m/s	2000	kW	28 m/s	0	kW
9 m/s	985	kW	19 m/s	2000	kW	29 m/s	0	kW
10 m/s	1321	kW	20 m/s	2000	kW	30 m/s	0	kW

Result

Producer	Dewind
Type	D8/80-2MW
Capacity	2'000 kW
Rotor diameter	80 m
Power Production	4'660'452 kWh/year
Capacity factor	26.6%
hours at full capacity	2'329 h/year

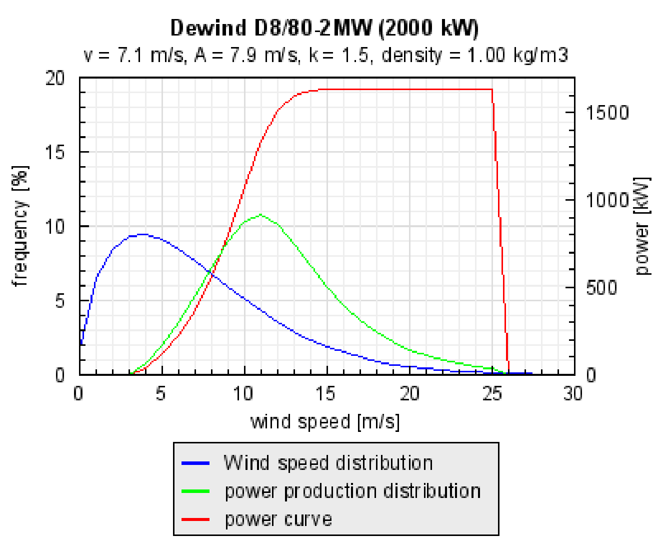

Fig. 14Result from Power Calculator when Turbine Dewind D8/80-2MW at Ambewela site [4]

2.10 Summary of the Wind Turbine Selection

Table 11 Summary of the Wind Turbine Selection

Model	Capacity (kW)	Power Prod. (kwh/yr)	Capacity Factor	Hours at full load (hrs/yr)	Energy product. kWh/kW
Leitwind LTW77	1000	3109414	35.5	3107	3109
VestasV100	1800	5306819	33.6	2946	2948
Gamesa G97	2000	5707164	32.6	2852	2854
VestasV90	1800	5001970	31.7	2777	2779
VestasV112	3000	8190553	31.1	2728	2730
Repower MM 92	2050	5588576	31.1	2724	2726
Vensys 100	2500	6736155	30.7	2693	2694
Gamesa G90	2000	5299847	30.2	2648	2650
Vestas V90	2000	5284621	30.1	2641	2642
Fuhrlander FL 600	610	1605206	30.0	2630	2631
VestasV52	850	2233885	30.0	2626	2628
Vensys 77	1500	3922828	29.8	2613	2615
Enercon E-53	810	2100470	29.6	2591	2593
Fuhrlander FL 2500-100	2500	6449272	29.4	2578	2580
Enercon E-33	330	849041	29.4	2571	2573
GE Wind Energy GE 2.5/100	2500	6424300	29.3	2568	2570
GE Wind Energy GE 1.5/77	1500	3840035	29.2	2558	2560
Gamesa G87	2000	5103301	29.1	2550	2552

Enercon E-82	2050	5207863	29.0	2539	2540
Enercon E-101	3050	7729168	28.9	2532	2534
VestasV82	1650	4153917	28.7	2516	2518
Nordex S77	1500	3760186	28.6	2505	2507
WinWind WWD-1	1016	2540689	28.5	2499	2501
Repower MD 77	1500	3742647	28.5	2493	2495
Fuhrlander FL 1500-77	1500	3678403	28.0	2451	2452
Nordex N90	2300	5594305	27.7	2431	2432
WinWind WWD-1	1045	2516519	27.5	2407	2408

According to the above table Gamesa G97 can be selected for the 2MW turbine and Leitwind LTW77 can be selected for the 1MW turbine.

2.10.1 Technical specifications for Gamesa G97 [5]

Table 12 Technical specifications for Gamesa G97

Gamesa G97		
Power	Rated power	2,000 kW
	Rated wind speed	12.0 m/s
	Cut-in/out wind speed	3.5 m/s, 25.0 m/s
Rotor	Diameter	97 m
	Swept area	7390 m^2
	Number of blades	3
	Rotor speed	9.6-17.8 rpm (variable)
Generator	Type	Doubly-fed machine

	Voltage	690 V
	Grid connection	via converter
	Grid frequency	50 / 60 Hz
	Power factor	0.95 CAP-0.95 IND throughout the power curve

2.10.2 Technical specifications for Leitwind LTW77 [6]

Table 13 Technical specifications for Leitwind LTW77

LEITWIND LTW77		
Power	Rated power	1,000 - 1,500 kW
	Rated wind speed	12.0 m/s
	Cut-in wind speed	3.0 m/s
	Cut-out wind speed	25.0 m/s
Rotor	Diameter	76.6 m
	Swept area	4,608.37 m^2
	Number of blades	3
	Rotor speed	17.8 rpm (variable)
	Material	glas-fibre reinforced plastic
Generator	Type	synchronous, permanent magnet
	Speed	17.8 rpm (variable)
	Voltage	640 V

	Grid connection	via converter
	Grid frequency	50 / 60 Hz

With considering the National Policies and the possible transmission network constrains and site constrains only 21 MW wind capacity is considered for each sites at Ambewela, Hare Park, Rantinda and 4 MW for Naula site. Then the considered total wind capacity is 67MW.

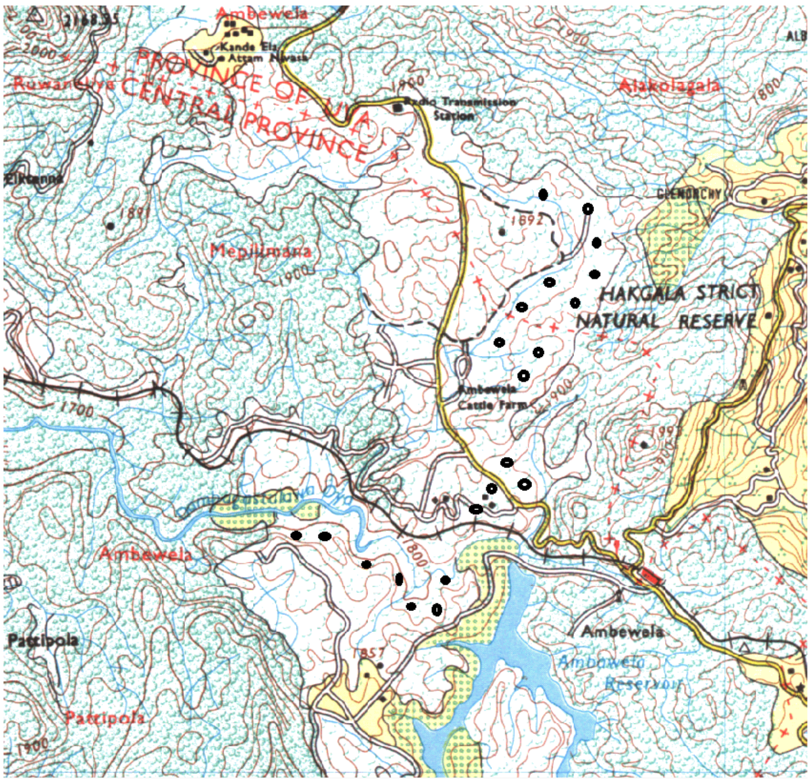

Fig. 17Map of Ambewela and its wind plants locations [7]

The black colour dots shows the locations for proposed 11 numbers of wind power plants.

Fig. 18Map of Ambewela and its wind plants locations [7]

The red colour dots shows the possible locations for wind power plants.

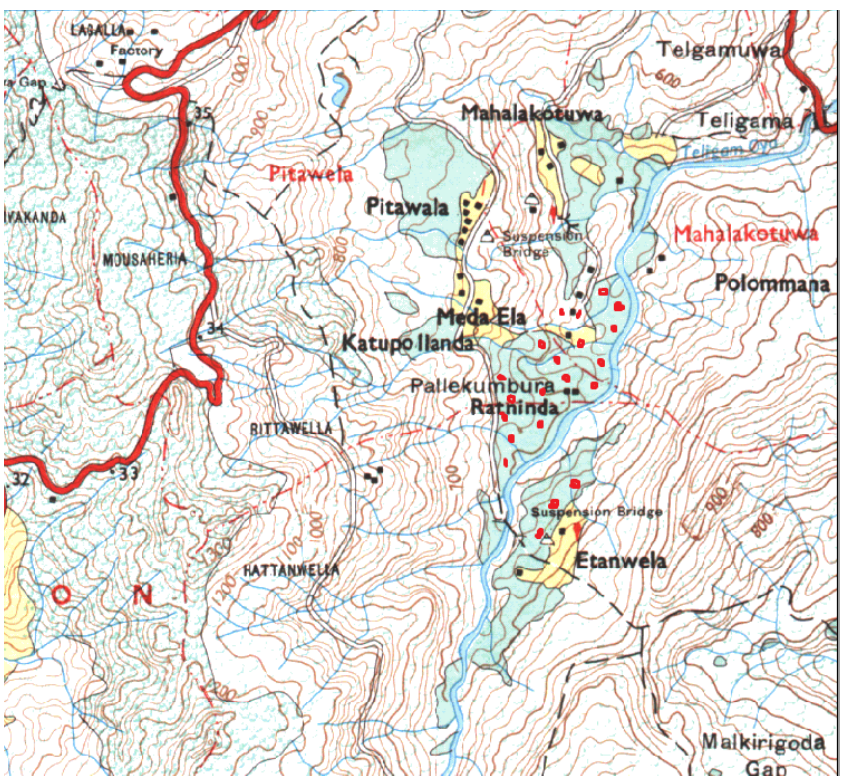

Fig. 19Map of Rantinada and its wind plants locations [7]

The red colour dots show the possible locations for wind power plants.

2.11 Possible Interconnection points in Central Province

2.11.1 Grid Substations

Kiribathkubura, Ukuwela, NuwaraEliya, Wimalasurendra, Pallekele, Naula and Badulla Grid Substations (GSS) are possible interconnecting points for the WPP. The most suitable wind plant interconnected GSSs were selected considering the distance to the GSS from the wind plant sites. The GSSs were selected to reduce the length of the interconnection line. Since Sri Lanka is a small, populated country getting the right of way for the transmission lines is much more difficult than augmenting a transformer of an existing GSS. So the closest GSSs to the wind sites were selected. The Ambewela WPP is proposed to connect to Nuwareliya GSS, the Hare Park WPP is proposed to connect to Badulla GSS, the Ratninda WPP is proposed to connect to Ukuwela GSS and the Naula WPP is proposed to connect to Naula GSS.

3.0 CONCLUTION

Wind resource plays a major role in implementing the government energy policy of converting two-energy resource (hydropower and oil) status to multiple resource status. The coal became the third energy resource since year 2011. This paper introduced the wind resource as the fourth energy resource and discussed the methodology to develop it. As a result the Central province has selected as the Candidate site for the study because it has best wind potential and the availability of measured wind data of the area. In this study Ambewela, Hare Park, Ratninda and Naula sites are identified as suitable locations for wind power extraction from Central Province, Sri Lanka. After detailed analysis of wind resources in the area the Gamesa G97 wind turbine for 2MW range and Leitwind LTW77 wind turbine for 1MW range are selected as most suitable for Central Province. The 21MW (10 wind power plants (WPP) for Ambewela, Hare Park & Ratninda sites and 4MW WPP for Naula are decided. 21MW WPP consist of ten numbers of 2MW turbines and one 1MW turbine. Further 4MW WPP consist of two 2MW turbines. In this study wind turbines are located in suitable grounds using 1:10,000 geographical maps for each site. NuwaraEliya, Badulla, Ukuwela and Naula 132/33kV Grid Substations are identified as suitable interconnection points for the above selected sites respectively.

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Software and Information technology support in virtual renewable energy laboratory based on real physical environment – ECO UQAR – UOM Potential Collaboration

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Abstract:

The present project aims at proposing a new training approach based on the communication and information technologies. This system can be easily exported to different interested growing and diversifying universities like the University of Mauritius. Specialized software and information technology is made use of to develop a virtual platform of a real physical renewable energy laboratory shared via VPN services and global web based services to different users and clients. From an engineering point of view, the concept is simple, but the computer and information technology requirements are challenging ECO UQAR is a new entity created at Université du Québec à Rimouski and aims at providing "learn by projects" training in the field of renewable energy. A physical laboratory has been set up for this purpose. The physical set up consists of a wind blower, wind turbines, solar panels, irradiation systems and other usual equipments. The whole laboratory is completely instrumented. Specialized software is used for the data acquisition, data transfer and data processing parts. In this paper, we emphasize on the virtual environment set up using LabView, the data transfer from remote wind turbine installations to the laboratory, the data acquisition within the laboratory and the security involved in using such a system. Finally, to round up the training, specialized training is offered on high level software. In this paper, we focus on one particular project whereby such software is made use of to illustrate the computational challenges involved in the use of specialized high level software.

Keywords: Virtual environment, engineering, training, wind power, renewable energy.

1. INTRODUCTION

In an attempt to limit develop the concept of sustainable development and pave the way for development in alternative renewable energy sources, it is becoming crucial for engineers and technicians to be trained in diverse aspects of renewable energies. The main problem that prevails in this field is the lack of infrastructure and the cost of equipments to develop adequate set ups for training purposes. We can imagine the size of wind turbines and the size of corresponding wind tunnels to operate the turbines. Similar limitations exist for solar panels and biomass generators. In this paper, we focus on the Wind Energy Research Laboratory (WERL) harbored ECO-UQAR physical renewable energy laboratory which aims at providing pedagogical training on different concepts of renewable energy via a "learn through projects" approach to engineers and technicians. In the second part of this paper, we illustrate the use of different software made use in this approach and the computational and security challenges encountered. In the third part of this paper, we emphasize on the multiple location data acquisition and training technique made use of in this laboratory through a virtual platform. This laboratory allows for users around the world to have access to real –time visualization of the whole system via motorized VPN cameras and the ability to access the quantitative data of the set up via the virtual instrumentation platform. Furthermore, the indoor laboratory is connected via a high speed data acquisition system to a real 50 kW wind turbine and solar panel platform via Wi-Fi to enable real wind turbine and solar data analysis in outdoor conditions. Such installations and equipments are very expensive, however, specialized software and information and communication technology (ICT) have allowed for distance access to users dispersed all around the world and an idea exchange platform with minimal cost.

2. MOTIVATION & LITERATURE REVIEW

In engineering education, it becomes necessary to develop interaction with equipment in green power field using real systems or simulation environments. Such activities are generally indispensable to consolidate the theoretical concepts learned in classroom [1-4]. The major difficulty with this domain is the lack of industrial system that can be used easily in academic issues and the non existence of scaled laboratory can be installed in institution context. It is still difficult to have pertinent data of measured power without moving on machines power. However, recent progress in communication tools has helped managerial staff, engineers and technicians to enhance productivity and optimize industrial systems without the need for any physically platform. Moreover, actual automation technology allow for remote control and often involves more complex situations implicating the real-time data exchange, video streaming of different plant sections, and finally, the reception of process input commands and controller program modification. These methods have been introduced for the first time by service and equipment providers to allow the distance troubleshooting with clients. Moreover, in a market becoming more and more global, the methods of remote control and monitoring are the ultimate trend for manufacturers to stay ahead respective industry. Consequently, the business intelligence is becoming a significant advantage for the industries in the actually ever-changing business environment [5-7].

Moreover, it is important to adapt engineers and eventually technicians to rapid technological changes in automation systems. The solution can be based on training of graduate engineers and, also it is necessary to provide required skills for our future graduates during academic training (both engineers and technicians). In fact, their academic content, also, needs to be constantly updated upon current technologies and future trends.

The literature review demonstrates that it exists some related works involving distance learning or remote experiments [1, 5, 8, 9]. However, only virtual setup is treated and they do not imply real time monitoring with effective operators monitoring the equipment [2, 4, 8]. The present work is original because it implies real time collaboration between distant teams of students on a common problem. Furthermore, it integrates the interaction between future technicians and engineering students.

3. PHYSICAL SETUP

ECO UQAR proposes a real physical multi renewable energy source bench test with an aim to allow students to learn the different aspects of renewable energies related technologies through applied projects and setting up of bench tests. The laboratory contains a wind blower whose speed can be varied. The wind speed controller is connected via a data acquisition card to a computer. In a short term, we wish to simulate real wind in the blower from anemometry collected data and analyze behavior of wind turbines according to different wind regimes. This section of the laboratory is completely instrumented; that is, the parameters of the different sections are measured. For instance, the speed of the wind coming from the wind blower is measured and the data recorded in real time. The same applies to the instantaneously evolving turbine speed, voltage and current at the exit of the generator, at the exit of the batteries, etc. Similarly, the laboratory contains a number of solar panels and a variable insolation lamp. Like the wind section, the solar section is, also, completely instrumented. The light intensity and the output voltage and current are all measured. The laboratory is, furthermore, equipped with a biomass generator. The three energy sources are of very different types but are coupled using a control panel. Fig. 1 represents a schematic representation of the laboratory while Fig. 2 shows the actual in-door set up. Fig. 3 shows the whole physical set up, whereby data from out-door installations are made available to the in-door laboratory for analysis. The out-door installation is part of WERL equipments. Data from the real large scale outdoor installation is injected in the instrumentation system of ECO-UQAR to address issues that will not be possible in the indoor laboratory like the wind variability, insolation cycles, aeroelastic phenomena, icing, etc. A National Instruments® DAQ acquisition system is made use at the WERL outdoor installation as well as in the ECO-UQAR indoor installation for optimized compatibility.

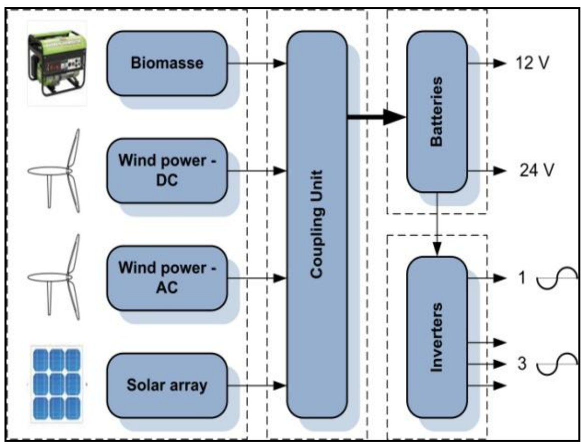

Figure 9: Schematic representation of the green power installation

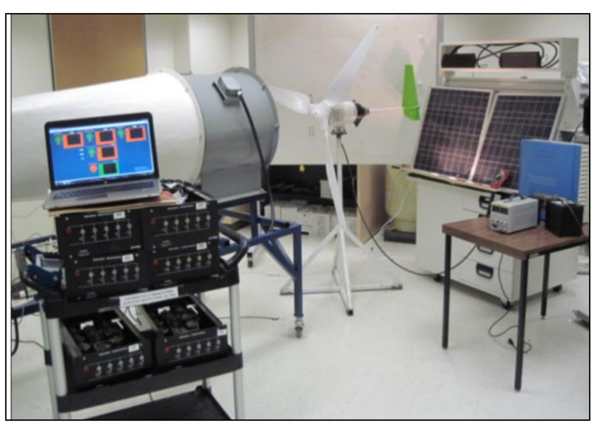

Figure 10: Indoor physical set up of ECO-UQAR

Figure 11:Data exchange between outdoor installation and ECO UQAR

4. SOFTWARE CHALLENGES AND CONSIDERATION

In the first place, the choice and optimization of the laboratory components have been supported by HOMER software. HOMER is specialized software developed at the National Renewable Laboratory which integrates different characteristics of commercial wind turbines, solar panels, diesel units etc. By choosing a particular site, the software can calculate based upon a financial optimization technique the best choice scenario. (Energy coupling or not, number of solar panels, wind turbines, etc).The laboratory set up was based on HOMER analysis only for training purposes. However, as many other software, the problem resides in the lack of flexibility as the software is not open source. As we mentioned, HOMER optimization technique is based on a financial consideration itself dependent on resource availability and cost. For instance, if the site has low insolation but high wind penetration, the software will prioritize use of wind turbines. However, sometimes special considerations are required, for instance, in our case, we super charge diesel unit with compressed air from wind turbines during low energy demands to increase diesel efficiency by about 30%. This will completely alter the financial consideration. However, this cannot be specified to the software. Thus, effort is being made, within ECO-UQAR, in collaboration with the TechnoCentre Eolien to propose more flexible, open source software.

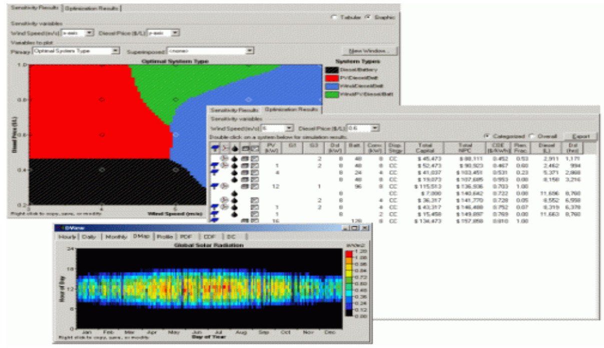

Figure 12:HOMER interface

A similar problem is faced with wind potential analysis software. Computational fluid dynamics (CFD) terrain aerodynamics is run to evaluate the wind potential of different regions and the energy assessment is calibrated via characterisation of the machines within ECO-UQAR laboratory. Furthermore, in order to avoid wake interaction between the turbines, wake modelling can, also, be performed by our software. Fig. 5 below show the streamlines of the wind speed over the region and the wakes modelling using high level CFD modelling conducted over a region in Safi, Morroco.

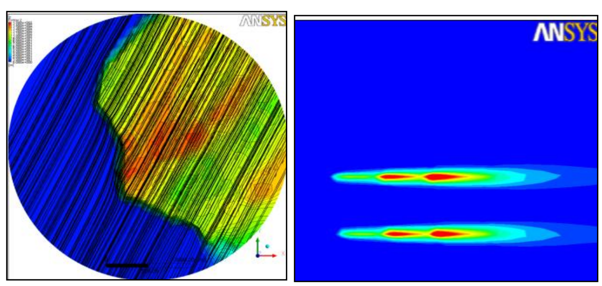

Figure 13: Energy and wake assessment via CFD terrain aerodynamics to evaluate wind turbine requirements

Energy assessment via coupled aerodynamics and terrain relief consideration requires running and solving very complex Navier Stokes equations on morphed meshes on terrains whilst applying turbulence models and considering atmospheric and temperature stratification. Though available software is very advanced, some problems still persist. The main one is computational requirements. Such simulations take very long to resolve. We do not have any access to the software core to define particular parameter solving. Instead, the software always solve for all regions and all parameters. The computational limitation may become the main asset for open source software.

For the solar energy assessment part, we wish to emphasize on another problem encountered with closed source software. Solar energy assessment is achieved using a Milankovitch function. This relates solar power availability to the position of the earth with reference to the sun as well as the tilt of the former. Available software does not allow users to see the data that are taken into consideration to perform the calculation. Instead, the model only provides results. In different projects, we made used of different software for convergence analysis and all software gave very different results for the same simulation. For these reasons ECO UQAR built its own open source software for such analysis.

ECO UQAR aims at promoting coupling of various renewable energy sources. Since the output signal are very different from different sources, it is imperative to use special coupling units that can rectify the signals, upscale or downscale them for constructive superimposition. For long time commercial units have been made use of but surprisingly, many of them do not actually couple the energies but merely prioritize the higher intensity one. Within ECO UQAR, using electronics and control software like ORCAD and Simulink, a new unit that couples the energy sources is actually being developed. Here, we can well see that specialized software have an appreciable use in the design and optimization procedures in a domain like renewable energies. Furthermore, ORCAD perfectly illustrates the concept of flexibility and lean design of software to improve upon computational cost and time.

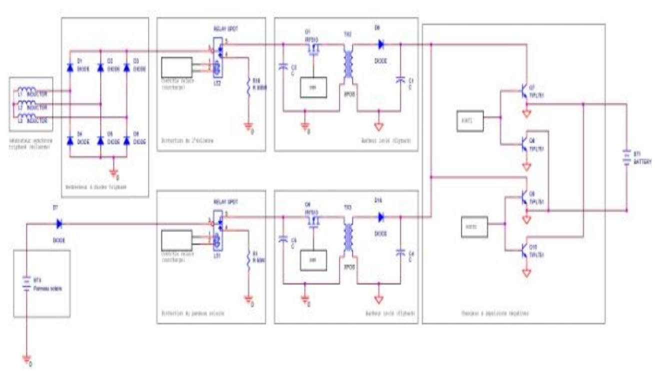

Figure 14: ORCAD based design of coupling unit optimised using Simulink

5. VIRTUAL PLATFORM

During the activities, interaction process can be divided into two categories, namely "people-to-people", and "people-to-equipment". People-to-people interactions are to happen in real-time (synchronous) and off-line (asynchronous) mode. When present in the laboratory, UQAR students have access to a computer, a large videoconference screen, webcam, microphone, speakers and an Internet connection. Distant sites students, for their part, are physically present in close proximity to the mini-plant and they can communicate to the UQAR students using the same accessories. To allow people-to-equipment interactions, a Virtual Private Network bridge (VPN) was instated between the both sites LANs (Local Area Networks) via the Internet. The programming of the controllers (Allen-Bradley CompactLogix series) was possible remotely using RSLogix5000 software.

Real-time visualization of the physical systems was possible through additional dedicated IP cameras positioned to adequately cover all mini-plant units. The applications were developed using LabView software to monitor the global system and to measure the different signals. Their video streams are accessible using any web browser software. A schematic representation of this environment between the sites is illustrated in Fig. 7. Since process control and automation applications require quick response times and high data throughput automation equipment, STRATIX 8000 switches were chosen at the core of the Ethernet-IP network.

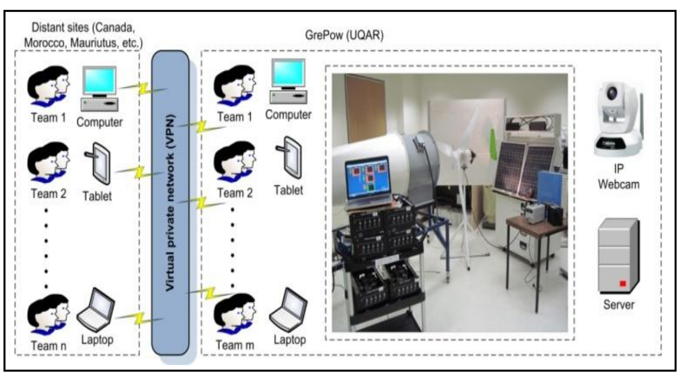

Figure 15: Virtual platform schematic

We will talk of the ICT aspects within the virtual platform while considering three different aspects: the instrumentation and server within ECO UQAR, the web based interface and the instrumentation and server within outdoor WERL facilities.

ECO UQAR can be seen as the central core of the concept. It is equipped with a wind blower, wind turbines, solar panels, insolation systems, biomass generator, coupling units and usual laboratory equipments. The whole physical unit is instrumented and using real time acquisition systems: the speed of the fan, the wind speed at the end of the blower, the temperature of the air, the rotation speed of the turbine, the insolation, the power outputs of all units, the signals at the ends of each electrical unit as well as the temperature of the batteries and all monitored. All the data are acquired using DAQ LabView unit. The LabView software has been used to set up a user friendly interface for Web use. It is very interesting to note that LabView as software and its data acquisition cards allow simple, lean design systems to be built. Previously, to monitor pressure we had special cards and software for particular sensors. With a single card with multiple channels like the NI DAQ, the process is highly simplified. Fig. 8 below shows the LabView software based, web harbored interface.

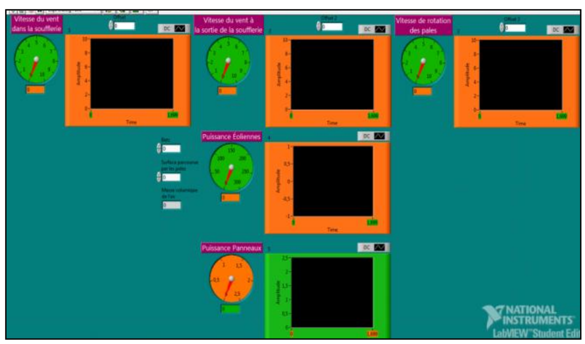

Figure 16: Virtual LabView Interface

As we can note, the interface allows for monitoring of all parameters that can be pertinent for the understanding of the renewable energy laboratory operation. Furthermore, different aspects of renewable energy courses have been integrated within the application to enable students to familiarize with certain theoretical concepts- the limit of Betz can be altered, the density of air can be changed, an albedo correction factor can be applied as well as supercharging of generators with compressed air. It is, here, evident, that software development can play major role in training and learning.

ECO UQAR is, also, equipped with IP motorized cameras to enable users over the web to access online video streams of the physical laboratory with the corresponding instrumented LabView interface. This tends to simulate a real laboratory but at distance and this has only been made possible through breakthroughs in software and ICT.

The instrumentation LabView interface and the online video streams from IP camera are made available on a secured website. The website has, also, been set up by UQAR students in line with the "learn by project" strategy. The website is harbored within ECO UQAR domain on an internal server.

The same server is used to enable connection via Wi-Fi to a computer at WERL outdoor installations. At the WERL facilities situated at Pointe au Père, Rimouski, data can are recorded online via an NI DAQ on a computer acting as server. Data that can be collected come from 300 Watts wind turbines, a 50 kilowatts wind turbines, solar panels and the instrumentation of a number of control panels. To correlate the apparatus outputs with available resources, the wind speed and directions as well as the insolation are measured and recorded at all time. A buffer system is made used of and with a very short lag; data is transferred via high speed Wi-Fi to the ECO UQAR installations.

Finally, ECO UQAR offers a physical pedagogical laboratory and a real wind turbine-solar panel outdoor installation that can be viewed at in real time and the instrumentation made available simultaneously.

6. SOFTWARE FOR E-LEARNING

E-learning is the use of new multimedia technologies of the Internet to improve the quality of learning by facilitating one hand access to resources and services, on the other exchanges and remote collaboration. The experiment is based on the interactions between client and equipment suppliers and it is useful in order to develop expertise in the intervention and remote debugging. This concept is being applied by the ECO UQAR laboratory. As from winter 2012, the ECO UQAR laboratory will be made use of in a number of courses at UQAR and proposed in other educational institutions in other parts of the globe. To illustrate this, we will take the example of the wind energy course. In this course, students are familiarized with a number of concepts related to the wind energy sector and can be as diverse as aerodynamics to legal aspects of wind farm installation. It is a utopia to believe that someone can be an expert in all the different aspects of wind energy. The aim of this course is to provide a broad idea of the wind energy sector to all students and encourage each to develop an expertise in one particular aspect through an applied project. The difficulty in this is that, different projects will require different software, each of which is very costly. For example, we can think of a student who wishes to develop an expertise in blade aerodynamics using ANSYS- CFX software. The cost of the license of this software counts itself in terms of tens of thousands of dollars. Though, the WERL is well equipped with different software, it is difficult to provide this course to students in universities abroad where such facilities are not available. The e-learning process through our tailor made website allows us to propose this course with the "learn by project" approach and at the same time propose a real physical laboratory made accessible at distance. This is an advantage proposed by the ECO UQAR laboratory where breakthroughs in software and ICT technologies allows for full fledge training at distance without the need for cumbersome cost handicaps. One such project has been the implementation of a coupled wind-solar project in Morocco for water pumping purposes. This project aims at pumping water from an 85 m deep borehole in the region of Safi, Morroco for a small village of around 500 people. The pump will be completely fuelled by a couple wind-solar systems. This project integrates several aspects of renewable energy technology and can be defined as follows: to design the system, we need to evaluate equipment requirements. To do so, we need to predict pump energy needs as from water demand and consequently design the system according to the wind and solar potential of the region. High level computational fluid dynamics (CFD) simulation has been run over the region and the wind potential evaluated. Similarly the insolation of the region was simulated. From these data and ECO-UQAR designed wind turbine characteristics and bought solar panels, the number of the latter equipments was evaluated and the accessorial units (batteries, filters, etc) bought. The control system that allows coupling of the two energy sources is also designed within ECO-UQAR. Similarly, the aerodynamics of the turbines, the aeroelastic and static effects on the blades as well the control of the overall system have, also been performed by different teams of ECO-UQAR. Each team was leaded by an expert in the given field. Finally, in the light of all the equipments, a financial analysis was run to evaluate the cost and potential profitability of the project had the energy been sold. Weekly meetings regrouping the different specialized groups allowed an exchange of pertinent information via an MS-project generated project management scheme and enabled all the different actors to have an idea of the different projects and clarify different matters related to the studied technologies. Fig. 9 illustrates the project as a whole via a superposition of the equipments on the Safi region in GoogleEarth and a map of the region.

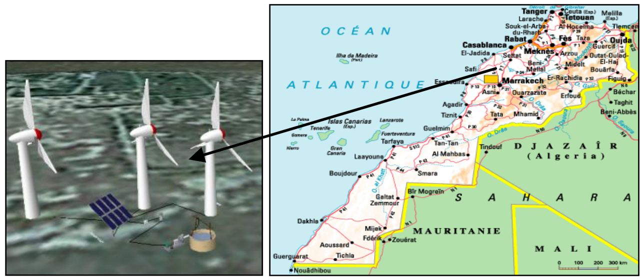

Figure 17: Project set-up and location of site

7. CONCLUSION

In this paper, we emphasize on the support provided by software and ICT in allowing training in renewable energies at distance. Furthermore, we illustrate the possibilities offered by Wi-Fi and VPN technologies to couple a real huge wind turbine – solar panel installation with an indoor pedagogical laboratory. The paper, also, features the work performed to set up a virtual interface and an online streaming of the laboratory operation made accessible to worldwide users via a secured website.

We, also, emphasize on the support provided by ICT and software to allow for optimal e-leaning possibilities and present a project where numerous software was required as well as international cooperation- a process made possible by the software and ICT advances.

In this paper, we, furthermore, identify certain weaknesses in some software. This has been mainly attributed to the close source of the tools. In many cases, the sources cannot be modified to reduce calculation time and the computational handicap becomes a real bane. In other cases, we cannot identify the model made use of in the software and it becomes very difficult to identify error sources.

However, students have shown real appreciation for ECO UQAR and we believe that this concept can become a trend in the future. We firmly believe that with improvements in internet services, computational capacity and software architecture, distance learning and collaboration over projects worldwide will become a common aspect of training.

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Strategies developed for the Small Island Developing States (SIDS) to enhance renewable energy utilization by DIREKT.

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Abstract :

Given the current global situation of scarce energy resources, rapidly rising fossil fuel prices and drastic climate changes, it is recognized that the promotion and application of Renewable Energy and Energy Efficient technologies is of vital importance for sustainable socioeconomic development in the Small Island Developing States (SIDS).

The DIREKT (Small Developing Island Renewable Energy Knowledge and Technology Transfer Network) is a teamwork scheme that involves the participation and collaboration of various universities from Germany, Fiji, Mauritius, Barbados and Trinidad & Tobago. The aim of the DIREKT project is to reinforce the science and technology competency in the domain of renewable energy through technology transfer, information exchange and networking, targeting ACP (Africa, Caribbean, Pacific) SIDS as they are more vulnerable to problems associated with the climate change. The overall objectives of the DIREKT project consist basically of enhancing sustainable collaboration between the participant countries and the EU and to transfer research results on the key topic of renewable energies, by putting up into operation "technology transfer centers" in the participant countries. To help in achieving these aims, the partners of the DIREKT

project have put up strategies for short term, medium term and long term to be applied to SIDS.

Keywords : Strategy, Small Island Developing States

1.0 Introduction

The DIREKT (Small Developing Island Renewable Energy Knowledge and Technology Transfer Network) is a teamwork scheme that involves the participation and collaboration of various universities from Germany, Fiji, Mauritius, Barbados and Trinidad & Tobago. It is a 3 year project that started in 2010 and is expected to end in 2012. During these 3 years, the aim of the DIREKT project is to reinforce the science and technology competency in the domain of renewable energy through technology transfer, information exchange and networking, targeting ACP (Africa, Caribbean, Pacific) Small Island developing states as they are more vulnerable to problems associated with the climate change. The overall objectives of the DIREKT project consist basically of enhancing sustainable collaboration between the participant countries and the EU and to transfer research results on the key topic of renewable energies, by putting up into operation "technology transfer centers" in the participant countries. Finally, the specific objective of DIREKT is to establish a long-term EU-ACP Small Island Developing States Science and Technology Network. To help in achieving the set aims and objectives, the ACP Science and Technology Programme, which is an EU programme for cooperation between the European Union and ACP region (Africa, Caribbean, Pacific) are funding the project.

Given the current global situation of scarce energy resources, rapidly rising fossil fuel prices and the potential aggravation of this through climate change, it is recognized that the promotion and application of Renewable Energy (RE) and Energy Efficient (EE) technologies is of vital importance for sustainable socioeconomic development in the Small Island Developing States that constitute the Caribbean. Taking all these problems into consideration, the DIREKT team has developed a strategic plan for short term and long term applications.

2.0 Strategy

Strategy refers to a plan of action designed to determine the basic objectives and allocating resources to its accomplishment. It determines the direction in which a set project needs to move to fulfill its mission. A strategic plan acts as a road map for carrying out the strategy and achieving long-term results that is, its end vision.

Strategic planning implies short- term to longer-term planning which is allied to the institution or project's vision, values and goals. Short-term planning normally looks at projected goals over at least a three to six month period. Medium-term planning is probably a year to eighteen months. Long-term planning would look at a very long-term goal - say over five or ten years. Thus to ensure that all the goals and objectives set by the DIREKT project are achieved within the 3 years time frame, each partner involved in the DIREKT scheme have come up with a strategic plan consisting of Short, Medium and Long- Term strategies to be implemented in their respective countries. A summary of the strategic plans of the partner countries are illustrated in this paper.

The general goal of the Technology Transfer Strategy is to stimulate greater awareness of the potential of Renewable Energy by demonstrating to the public the available RE technologies, and providing training in such technologies. It is anticipated that, with this exposure, knowledge and capacity, persons will be motivated to be engaged in innovative technologies that have the potential to unfold new economic development opportunities and promote a clean environment and sustainable future.

2.1 Strategy of Barbados

The specific objectives of the Barbadian team consist of setting up a Technology Transfer Centre that acts as a hub for the dissemination of RE material and RE technologies to the wider community. This will be done primarily through a Renewable Energy Demonstration Facility which will be a Pilot Project at the University of the West Indies, in the first instance. Further objectives consist of promoting the use of RE technology by providing awareness and training in RE technologies through Workshops, Seminars and Networking events, Strengthening the capacity of research staff by providing them with the necessary knowledge and resources, Providing closer link between research institutions and the public sector, in order to better cater for the needs of the market and Enhancing the capacity of businesses to use Renewable Energy and to develop new and innovative RE products.

2.1.1 Main Activities

A principal activity required for executing this Strategy is training, capacity development, and the dissemination of public awareness materials through Workshops, Short Courses, Seminars and Networking events. Training will be provided to administrative staff, businesses and research staff, with an emphasis on gender balance, in the following technologies:

- Application of Photovoltaic Technology
- Maintenance of Photovoltaic Systems
- Geothermal and Wind Technology
- Writing Grants and Project Proposals for RE projects

There will also be Networking events to disseminate information about the DIREKT project and available RE technologies. A second principal activity required to execute the Strategy is a Technology Transfer Centre which will be run as a Pilot Project at the University of the West Indies and will be entitled The Renewable Energy Demonstration Facility. The mission of the Renewable Energy Demonstration Facility will be to transfer innovative knowledge on Renewable Energy technologies to the University community, schools and the wider society, including the business sector and policy makers.

The Renewable Energy technologies to be displayed, tested and compared will initially be: a Fixed Solar Photovoltaic System, a Single-Axis Tracking Photovoltaic System, a Vertical Axis Wind Turbine, and simpler Renewable Energy technologies such as solar cookers and dryers, stills, solar water heaters, and solar mobile generators. A major focus in terms of display will be models to demonstrate the potential of marine power technologies; given the significant role they could play in the future Caribbean energy profile. These would include Sea Water Air Conditioning, Wave Power (onshore and offshore), and Ocean Thermal Energy Conversion (OTEC).

2.2 Strategy of Fiji

A strategy that provides solutions to these problems while contributing to the socio-economic development of the region consists of facilitating the training of businesses and decision-makers through short courses/workshops, and engaging both research institutes and businesses in a project that identifies potential RE resources for remote rural communities, and providing a learning opportunity to businesses by demonstrating to them how the appropriate RETs are designed using readily-available software.

Apart from producing the intended outcomes, such an interactive project will have hidden benefits. An important example is the opportunity to demonstrate to businesses and decision-makers the resources and the capacity available within the region (and especially within the research institutes) to carry out feasibility studies and to develop RET design models.

2.2.2 Main Activities

The key elements of the overall strategy consist of establishing a Research & Technology Transfer Centre, Strengthening the link between research institutions and the RE-related market in the Pacific, Combining the capacity building of the RE business sector with the socio-economic development of the region and Using a Pilot Project to demonstrate the efficacy of the chosen strategy.

These projects will require ongoing data collection, analysis, and installation of RETs. To ensure the sustainability of these projects, there is a need for skilled local expertise (within both the government and private sectors). Businesses need a range of expertise (from installing the masts and the equipment to predicting wind energy regime in selected regions using appropriate software).

The Fiji partner is already working closely with a number of regional energy agencies in the Pacific. These relations will be further enhanced, in keeping with the "many partners, one team" motto adopted by the Framework partners.

An implementation plan that provides for all requirements has been suggested to be as follows:

a) A Research and Technology Transfer Centre

This will be a virtual centre, and will consist of a physical office (with the appropriate communications and data-storage capacity) from where all the Research and Technology Transfer actions of this project will be coordinated. It will be an information hub which businesses, NGOs, other government and private sector organizations, as well as research institutes can access for information on all RE activities in the region. It will store information on Project DIREKT's Fiji Partner's plans and activities for the Pacific region. A website, linked to the parent Project DIREKT website maintained by the lead partners in Hamburg, will be created to provide an effective communication instrument, and to assist in the visibility of the actions of Project DIREKT's Pacific network.

b) Capacity building for businesses and decision-makers

This goal will be best achieved via a two-day workshop which will include regional research institutions as active partners in the organization and conduct of the activities, provide capacity building through a series of seminars combined with hands-on learning opportunities and local field trips and endeavor to involve other regional energy agencies through co-financing.

c) Pilot Project

The Pilot Project will act as a "proof of concept" for the R & TT Strategy. It will combine the capacity building of the RE business sector with the socio-economic development of the region, and will also involve regional research institutions in its actual action plan. The elements of this Pilot Project are outlined in a separate document.

2. 3 Strategy of Mauritius

The strategy developed by the Department of Chemical and Environmental Engineering of the University of Mauritius is the roadmap for Mauritius to address the energy and environmental challenges lying ahead which depends on innovation through science driven development of new technologies. This plan renews and extends the commitment of our Island to the environment, both resolving and supporting a future of cleaner energy.

2.3.2 Main Activities:

Therefore, the main objectives of the Department are:

- To promote more efficient use of energy and increase the use of renewable energy.
- Embark on projects to explore and harness all potential for local sources of renewable energy and to reduce dependency on imported fossil fuels
- Support programs to reduce consumption of fossil fuels, achieve greater efficiency in the use of energy in enterprises, offices, homes, public sector, transportation sector and in hotels
- Support programs for research and analysis pertaining to the development of renewable source of energy and consumption trends and to ensure environmental sustainability
- Embark on energy management programs through networking with local and international partners
- Create awareness campaigns on energy saving and the use of renewable energy sources

Moreover, to propagate the notion and implementation of renewable energies throughout the island, the University targets at the following:

- Availability, security and diversity of supply with particular focus on renewable energy

- Affordability with a view to ensuring socio-economic development of the country taking into account the financial sustainability of the utility
- Energy efficiency and conservation, given the high volatility of the prices of fossil fuels, in particular oil
- Targets for Efficiency in the Electricity Sector
- Introduce sustainable energy topics in all the programs at tertiary level.
- Run programs as a permanent activity to create awareness of the benefits of energy efficiency, renewable energy and sustainable living, including information on incentives/deterrents and rights/obligations for consumers.

However, the development of a sustainable energy economy affects the way of life of people, so it is important to develop not only a broad appreciation of sustainable energy and the resulting environmental benefits, but also to transfer knowhow and skills, including practical engineering skills in areas such as energy efficiency and renewable energy technologies. Thus, relevant educational materials on sustainable energy will be developed by the Department and the transferring of knowhow will be achieved through:

- Knowledge creation which will boost up Pure and Applied Research and Development and build a Platform for innovative ideas

- Knowledge diffusion by Promoting Emerging sectors, Inculcating industrial skills, Promoting lifelong learning and continuous professional development and promoting innovative e-learning system.

- Investing in resources by recruiting, retaining and rewarding quality people; Ensuring sustainable staff professional development, enhancing provision for modern high technologies, Developing and optimizing infrastructure and equipment, Exploring sources of funding through national, regional and

International collaboration and Strengthening networking role nationally and internationally.

- Community outreach by assisting community in developing, monitoring and enhancing renewable energies and by Promoting civic engagement

2.4 Strategy of Trinidad and Tobago

Trinidad and Tobago is the most industrialized of the Caribbean Community (CARICOM) countries and its energy requirements are among the highest in the region. One current challenge is that, due to an increasing population size and industrialization, Trinidad and Tobago's energy needs are increasing. The Government of Trinidad and Tobago has expressed a commitment to the development of an Energy Policy that includes Renewable Energy.

National Renewable Energy Strategies will have to be developed to meet the objectives of an Energy Mix Policy, as outlined in the Framework for Development of a Renewable Energy Policy for Trinidad and Tobago. To be effective, these Strategies must clearly be developed as a step-wise process and must also be implemented within the broader framework of carbon reduction strategies, consistent with the draft National Climate Change Policy that is presently being developed under the global objective of reducing emissions of greenhouse gases, as outlined in the Kyoto Protocol to which Trinidad and Tobago is a signatory.

2.4.2 Main activities

In its Budget of 2010-2011, the Government of Trinidad and Tobago introduced tax measures to support opportunities for small-scale, low-cost applications of Renewable Energy in residential, commercial, and other institutional sectors. To maximize effectiveness of energy use, appropriate measures for energy efficiency and conservation must also be undertaken. It is expected that these knowledge will significantly impact on capacity building, awareness creation, public outreach, and market growth and expansion in Renewable Energy in Trinidad and Tobago.

As Medium- and long-term strategy identified by the Government of Trinidad and Tobago are: Carbon Reduction; Mass Transportation; Green Buildings; Education through Capacity Building and Awareness Creation; Research and Development; The Creation of an Enabling Environment; Energy Efficiency and Conservation; and, Appropriate Institutional Arrangements.

The Trinidad Component of the DIREKT Project will effectively contribute to the development of the Renewable Energy Sector in Trinidad and Tobago in a manner that is entirely consistent with the Regional and National Strategies for Renewable Energy. The first is the organization and delivery of Seminars designed to increase public awareness of Renewable Energy Technologies, and to provide training and capacity development in RE. The second is the establishment of a Technology Transfer Centre which will essentially be a database and e-platform that can bring together information relevant to RE technologies and facilitate the interaction of RE stakeholders, e.g. researchers, businesses, students, and the general public. The third is the Pilot Project proposed for the Trinidad Component of the DIREKT Project, which are essentially the establishment, operation and display of a Renewable Energy Powered Laboratory at the University of the West Indies.

2.5 Strategy of Germany

The long term goal of the Research and Transfer Centre - "Application of Life Sciences" (RTC-ALS) is to be the leading Renewable Energy Technology Transfer Center for developing countries in Northern Germany and well known internationally. The RTCALS will make use of their strengths to promote the center and will not focus on engineering solutions for energy related topics. Consequently, the general direction of the RTC-ALS should be the strategic direction of making use of the strengths to take advantage of the opportunities. Besides this general approach the weakness as regards in-depth knowledge of the circumstances within developing countries should be dealt with in appropriate time. The general direction will take advantage of a multidisciplinary approach by combining inputs from various partners on a national and international level. Furthermore, all results will be specifically published for the various target groups to make sure that the RTC-ALS will become a widely known partner.

2.5.2 Main activities

To reach this overall goal various sub-goals were created with different timelines with consequent actions as follows:

- Leading Renewable Energy Technology Transfer Center for developing countries in Northern Germany to determine indicators for goal achievement
- Establishing a second pillar next to RE research topic which might be of additional use(e.g. capacity building for energy related jobs) and establishing contacts/access to networks.
- Publishing articles related to RE in developing countries on a national and international level.
- Promoting cooperation with partners in developing countries for proposal writing, Knowledge oriented proposal
    - Support for local actors orientation
    - Application oriented proposal
- Establishing contact with national and international organizations present in developing countries.
- Observing national development of RE activities from other organizations (HEI's, NGO's, foundations) to find outwho is active in the field of RE transfer/projects in developing countries

- Positioning and Marketing of RTC within the HAW and adjoining events/publications
- Setting-up of a concept for the Technology Transfer Hub(according to the DIREKT proposal) and its realization Concept

3.0 Conclusion

With the development of a strategic plan by each partner involved in the DIREKT project, it is certain the specific aims and objectives set up for the promotion of Renewable Energies in developing countries will be met and that same principle can be extended to other developing countries to enjoy a safe and clean future.

4.0 Acknowledgement

We would like to express our thanks to all the partners of the DIREKT team for providing information on their strategic plans.

OTHER RENEWABLE TECHNOLOGIES

Knowledge exchange and application of hydro power in developing countries

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Abstract:

This paper presents activities of the so-called 'Fakultätsplattform Entwicklungszusammenarbeit' of the Technische Universität München (an association that supports knowledge exchange with developing countries) with the focus on the design of a micro hydro power plant for a renewable energy vocational school that is being realized in collaboration with two Cameroonian partners. The power plant which is situated in a remote area will provide the school with electricity and serve as an example for the education of the students. During a two-week research stay in Foumban close to Bafoussam several possible sites have been surveyed. Result of the trip was a feasibility study that examined four different layout options. Due to social and ecological reasons a site was chosen where only part of the water discharge at a natural step is used. A head of 10.88 m is gained within approximately 100 m of D = 0.5 m penstock. The hydro power plant has got an estimated output of 15 kW. A crossflow turbine combined with a synchronous generator will supply the island network. As hydrological data is scarce emphasis has been placed on ensuring flood protection.

Keywords: Knowledge exchange, international collaboration, hydro power, regional involvement

1. PREFACE

We can learn from history that engineering know-how in terms protection from natural hazards as well as the control of water and food supply paved the path to civilization. Nowadays building infrastructure is the basis of a developed society and therefore civil engineers are essential to form it. This issue has been the notion for the foundation of a platform for knowledge exchange at the Faculty for Civil Engineering and Geodesy at the University of Technology in Munich, Germany (www.ez.bv.tum.de).

The scope of the initiative is manifold. Its core form lectureships which were held at Jordan University of Technology and Eduardo Mondlane University in Mozambique, where support is also given to build up a hydraulics laboratory. These courses comprise topics of renewable energy supply for buildings and hydraulics respectively hydraulic engineering. In the hydraulic laboratory practical trainings are given for students and teachers for which certain measurement devices are being provided. The work has been highly recognized by the Mozambican Prime Minister who even visited the Hydromechanics Laboratory of the TUM while being on state visit in Germany in May 2011.

Additionally to the academic exchange joint projects between students from Germany and countries in Latin America and Africa are being realized with the involvement of the local population. For instance the power supply for a medical care center in Burkina Faso was designed as well as the electrification of a primary school in Mozambique; a kindergarten with autonomous power supply was planned and constructed near Cape Town. Various projects were conducted in the Ecuadorian rain forest where among others the drinking water supply of a village and a micro hydro power plant were designed [1, 2].

In 2010 a letter of intent has been signed by the association 'Green Step e.V.'[10] and TUM's platform for knowledge exchange aiming to build a hydro power plant (approx. 15 kW) for the electrification of a renewable energy vocational school in Foumban near Bafoussam in Cameroon. The power plant shall not only serve as power supply but also as an example for the students. During a research trip in May 2011 a possible site was located and two Cameroonian partners were identified:

- Action pour un Développement Équitable, Intégré et Durable (ADEID), which builts different plants from renewable sources and operates several micro hydro power plants and
- Institut Universitaire de Technologie de Douala, Cameroon.

[10] green step is the vocational school's executing organization.

Within this consortium the partners work collaboratively on the survey of the site, the design of the plant and on clarifying legal issues.

2. INTRODUCTION

A vocational training school for renewable energies is being erected close to Foumban, Cameroon. Its focus lies on practical application such that the students gather experience in production, distribution, installation and maintenance of these technical products as such responsibilities are generally not being taught in this country. Consequently pico hydro power plants and solar thermal systems will be produced and sold in the school [3]. Therefore power is not only needed to provide classrooms with electricity but also to operate the manufacturing machinery such as a lathe, welding rectifiers and drills. However, as the main function of the facility is to serve as an example for the students special emphasis is put on it to fulfill this requirement. Additionally to these conditions the generated energy should be used to electrify the quarters in the vicinity of the plant. This issue will contribute to improve the living conditions and enhance development.

To successfully realize the scheme local and international partners work on their particular fields of expertise under the general management of 'Green Step'. The association 'Ingenieure ohne Grenzen' (Germany) works on the school's business plan, the 'University of Applied Sciences in Regensburg' (Germany) and the 'University of Guelph' (Canada) design a pico hydro power turbine that will be produced and sold at the school. The 'Fakultätsplattform Entwicklungszusammenarbeit' constructs the hydro power plant in collaboration with ADEID and the University of Douala. ADEID is also responsible for legal issues (e. g. water rights) whereas the latter assists in providing hydrological data. Finally Green Step brings the partners together, handles the funding, deals with social aspects and runs the school.

An appropriate site for the hydro power plant has been found in the proximity of the school. The constructional tasks include the overhaul of an already existing weir integrating the intake structure with a sand trap (Fig. 1). An approximately 100 m long penstock with a head of 10.88 m will deliver the water to a cross flow turbine generating 15 kW. The power house is placed on the left embankment to ensure flood protection. The design of the structure minimizes the ecological impact. An already existing channel on the right embankment serves as a fish pass.

Fig. 7 Downstream view with weir overhaul and intake structure

3. SCOPE

The school's scope is to educate students in renewable energy technologies which makes it obvious to provide the school with energy from such sources. The poor reliability of electricity supply makes an independent island grid evident. A feasibility assessment has been made for various systems whereas a high potential for hydro power has been identified due to the reliable precipitation and the topography of the area. Consequently, within a field trip the school's hydro power supply has been examined for possible installation sites in its proximity and relevant data has been collected for further analysis.

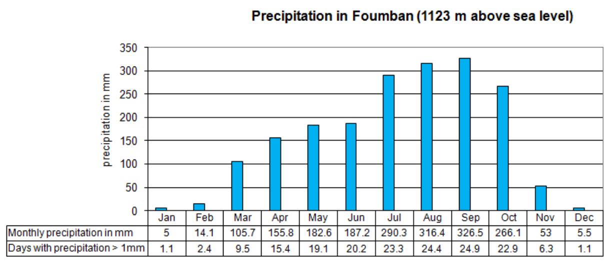
Off-site tasks included negotiations with stakeholders and material suppliers as well as gathering particular local know-how. Many examples show that a sustainable development of comparable projects could only be realized in collaboration with future associates, local authorities and residents who help with information and labour. So a quite decisive concern is the legal and administrative part of the planning so that ADEID's experience and expertise in erecting locally built water turbines is a major benefit.

4. HYDROLOGY

4.1 Climatic boundary conditions

Cameroon is characterized by a great variation of climatic types. This is why it is called 'Africa in miniature'. It ranges from the wet southern equatorial regions to the arid parts in the 'Extreme North'. Cameroon can be subdivided into four climatic and geographic zones: the Sudano-Sahelian, the savanna, the coastal, and the tropical forest [4].

Foumban, the location of the hydro power installation is located in the tropical forest zone which has mostly well-watered surface water. The surface is mainly covered by metamorphic and igneous rocks. The climatic type of this area is named 'Equatorial monsoon'. It is determined by two distinct seasons. The dry season lasts from November to March, the rainy season from April to October. Precipitation maximum can be observed in July to September. The total annual precipitation in Foumban is around 1908 mm.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly precipitation in mm	5	14.1	105.7	155.8	182.6	187.2	290.3	316.4	326.5	266.1	53	5.5
Days with precipitation > 1mm	1.1	2.4	9.5	15.4	19.1	20.2	23.3	24.4	24.9	22.9	6.3	1.1

Fig. 8 Average annual precipitation in Foumban [7]

4.2 Hydrologic characteristics

Cameroon has got two major catchment areas. The area around Foumban is part of the western highlands, also called the 'Cameroon Volcanic Line'. It is part of the Atlantic drainage basin, which is dominated by the Sanaga river system. The catchment area of the river at the installation site is characterized by a longitudinal tributary area, which ranges around 11.5 km from the spring to the installation site. It has several smaller confluences.

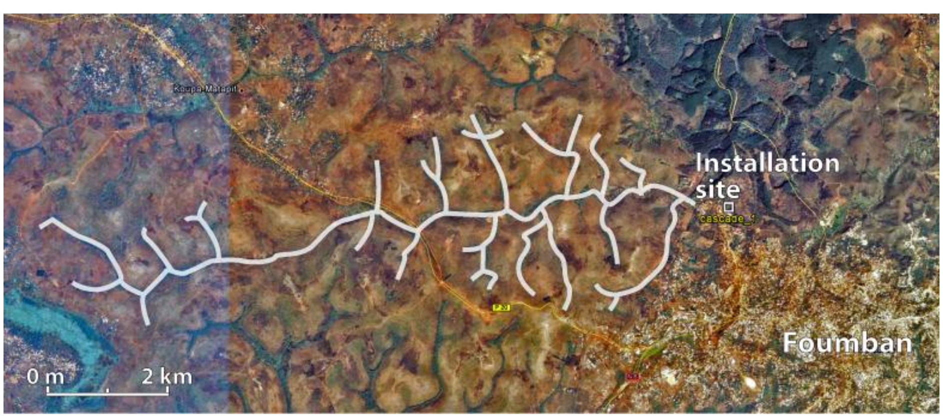


Fig. 9 Catchment area (source google.maps)

In order to get approximated discharge variation values, comparisons to neighboring river gauges have been done. The following Fig. 10 shows the hydrograph of the rivers Noun and Mbam[11]. The run off has been normalized by the annual average yielded out of the monthly mean values. The red line indicates the base flow reduced hydrograph of the Noun catchment area (excluding the outflow of Bamendjing reservoir). Through its very similar characteristics, this curve should fit the hydrograph at the site best.

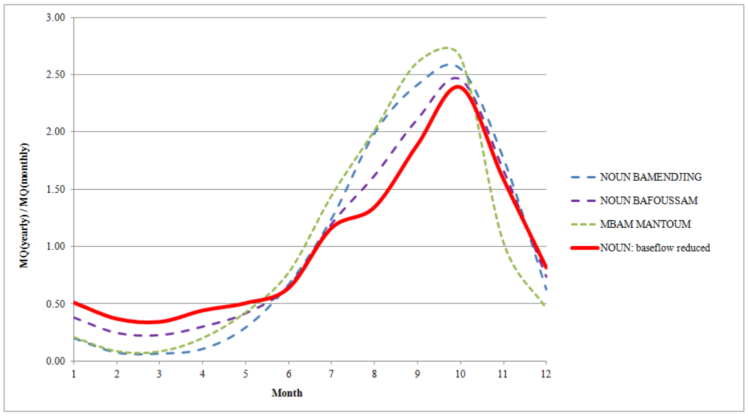


Fig. 10 Discharge hydrograph of gauges at comparable neighboring rivers [6]

The discharge measurements available have all been conducted during dry season, so that they can be assumed as low level discharges. This has also been verified by local residents. Currently further data is yielded with two fixed level gauges that have been installed and operated by ADEID. One is located above the weir intake; the other one is placed close to the powerhouse installation site. A resident, working close to the site will check the water level daily and hand the data over to ADEID.

4.3 Conclusions

Unfortunately there is a major lack of hydrological data, however, the project is not endangered as the site boundary conditions are nearly perfect. It has to be mentioned that the power output requirement allows a comfortable safety margin – for low run offs and for flood events. Due to the insecure run off data special emphasis has to be placed on flood security. The discharge measurements were done in May which is at the end of the dry season (see Fig. 10). Hence one can conclude that the measurements reflect run off minima.

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11 Distances and directions of gauges from site; measurement period. Noun, Bamendjing, 43 km west, 1965-1973. Noun, Bafoussam, 48 km south-west, 1952-1975. Mbam, Mantoum, 36 km south-east, 1965-1980.

5. SITE SURVEY

The first step of the on-site research was to get a better understanding of the geographic, hydraulic and morphologic situation in the school's surrounding. Therefore the most important task was to explore the water course of the close-by river and possible feeder streams.

5.1 Discharge measurement

In order to get an estimate of current discharge at different parts of the river, several measurements were conducted. The techniques used were based on flow velocity and cross section analysis. At specific locations hydraulic methods were applied e. g. flux approximation at critical flow conditions. Subsequent to the on-site measurements two fixed water gauges were installed by ADEID to assess the annual flow duration curve. The data is needed to estimate flood scenarios as well as energy yield.

5.2 Surveying data

The possible sites were surveyed with a tachymeter. The exact head differences were of major interest but also the elevation and position of probable penstock tracks were captured.

5.3 Flood security and occurrence

Assessing the difficulty of flood protection is a quite hard but also essential task in the planning process in such areas. Due to the fact that there is almost no reliable river discharge or area precipitation data available for most parts of Cameroon one has to rely on other sources. The most efficient and easiest way was traced by consulting the nearby residents and workers around the sites. As this information is rather vague and most likely to be biased it is even more important to set a sufficient safety margin. Concerning the occurrence of flood incidence one statement of a local worker was like "about two to three times a year for about one week the water level is about here" – just to give an idea. Historical maximum flood levels of this creek are essential for the design, however, information on it could not be collected.

5.4 Sites

The investigations resulted in two possible installation sites with quite different characteristics. Each site would further allow two different layout options each (see Fig. 11 and Fig. 12).

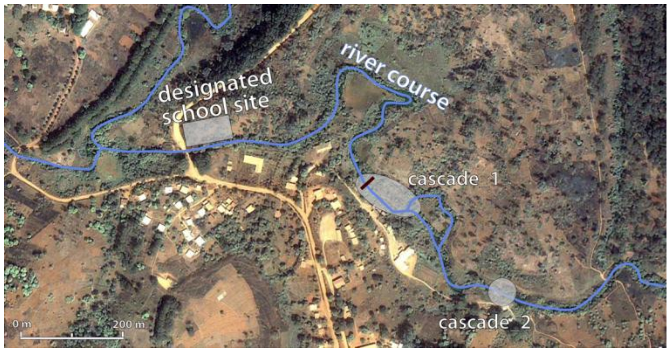

Fig. 11 Overview of geographical position of different installation sites (GPS data on google.maps)

Fig. 12 Possible installation sites, left: weir at cascade 1, right: cascade 2

The following table gives a comparison between the two possible installation sites and their different layout options.

Tab. 1 Comparison of different installation sites and layout options

Installation site comparison	**Big cascades with already existing weir ("cascade 1")**	**Cascade below local washing area ("cascade 2")**
Head	10.88 m	3.71 m
Discharge	approx. 300 – 500 l/s	approx. 1 m^3/s
Power Output	**10 - 30 kW**	**15 - 25 kW**
Inlet structure	+ (integration into already existing weir)	- (to be built at left embankment)

Water rights / Usage	**+ / -** (water partly used only by local water supply company SNEC – negotiations ongoing)		**-** (intensively used as the local washing and bathing area)	
Layout type	**Layout 1**	**Layout 2**	**Layout 1**	**Layout 2**
	penstock along embankment	penstock on cascade course	conventional turbine	water wheel
Penstock length	○ ca. 100 m		+ ca. 10 – 15 m	+ /
Flood safety	+	-	○ / -	○
Overall result	+	-	-	○ / -

5.4.1 Big cascades with already existing weir ("cascade_1")

At the grand cascade an output of 10 kW to 30 kW depending on the abstraction can be generated. With a head of 10.88 m only a minor part of the water is needed to meet the required power output. The first layout (cascade_1 – layout 1) marks the option where the penstock is aligned along the orographically left embankment of the cascade (see Fig. 13). This is also the preferred layout. The advantage of this is a more or less constant penstock slope and therefore fewer pipe bends. A second central pro is that it is less prone to damage caused by floods as it is away from the main flow path and does not need to be fixed upright above the ground. The advantageous location of the intake structure as well as of the powerhouse makes this option the preferable one.

Fig. 13 Installation site "cascade_1" with two different layout options

Another possibility for the penstock track would be to guide it along the cascade course itself (cascade_1 – layout 2). There are some islands along the cascade where a fixation on the underground rock would be possible. The big issue here is the flood risk as at higher flow rates this layout can be affected by floating debris. However, the underground conditions are clear and do not bear any risks.

5.4.2 Cascade below local washing area ("cascade_2")

Cascade 2 offers an output potential of 15 to 25 kW. One option for this cascade would be the use of a conventional turbine with a short penstock track of only around 10 to 15 m (cascade_2 – layout 1). The intake could be placed at the orographically left side right above the cascade whereas the powerhouse would be located on a minor rocky spot. As the discharge is quite high ($Q \approx 1\ m^3/s$) the use of great pipe diameters or more than one pipe would be necessary.

Fig. 14 Two different layout options at "cascade_2"

Using an overshot water wheel is another option, although it comes along with a number of uncertainties (cascade_2 – layout 2). The intake situation is similar to layout 1. A channel will have to be constructed to lead the water right above the wheel with a diameter of around 2.50 m. The water wheel could be stationed as indicated in Fig. 14. The generator and electrical equipment could be placed on top of the embankment. The power transmission can be realized with a gear belt. Here, difficulties arise in terms of a high constructional effort, especially concerning the fixation and foundation. The latter is also quite undetermined due to the lack of investigation of the underground conditions. Another drawback is the safety issue, as the area above the site is intensively used by the residents as their local washing and bathing area.

A comparison regarding flood security leads to the fact, that a conventional turbine with penstock brings the advantage of being placed more hidden. The second issue is that a turbine- / powerhouse can be easily fixated on the underground and does not have to bear with dynamic forces as a water wheel does.

5.5 Conclusions

As the first option at the big cascade promises to be the most attractive the main focus will be put on this one. The second cascade below the local washing area can be an alternative to "cascade_1" although its power output is smaller. As the location is strongly used by locals, compensatory measures would be necessary.

6. DESIGN

In the following layout 1 of the big cascades is being elaborated. Due to flood security reasons the powerhouse will be placed 2 m above the regular water level of the plain. There a perfect place was found where the powerhouse can be anchored to the rocks and natural shelter is provided. Including the height of the powerhouse structure the geodetic head reduces to 8.38 m.

Fig. 15 Overview of intake situation at "cascade_1"

6.1 Intake

The intake structure is placed on the orographically left side and will be integrated in the weir (see Fig. 16). The tulip-like inflow opening is incorporated in a locked housing which also includes the sand trap. This structure guarantees the entitled amount of water for SNEC and the slaughterhouse. Emphasis is put on safety issues as locals fish on the weir and children play/swim in its proximity. The opening of the whole structure is parallel to the main flow direction and equipped with a narrow rack. It should be noted that frequent rack cleaning will be necessary and will be conducted by the school staff.

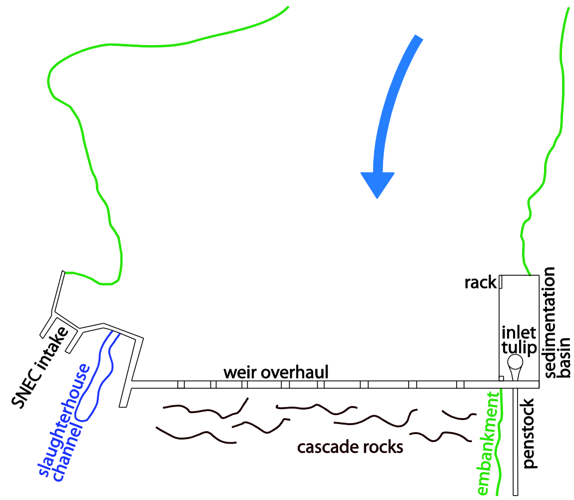

Fig. 16 Sketch of weir and intake situation

6.2 Pipe layout

As a constant pressure turbine is proposed (see Chapter 6.3) the Darcy-Weisbach equation underlies the pipe design in the following notation according to the energy plan (Fig. 17).

$$H_{geo} = \frac{8Q^2}{D^4\pi^2 g}\left(\frac{\lambda l}{D} + \zeta_I + \sum \zeta_B\right) + \frac{Q^2}{A^2_{Nozzle\perp} 2g} \quad (1)$$

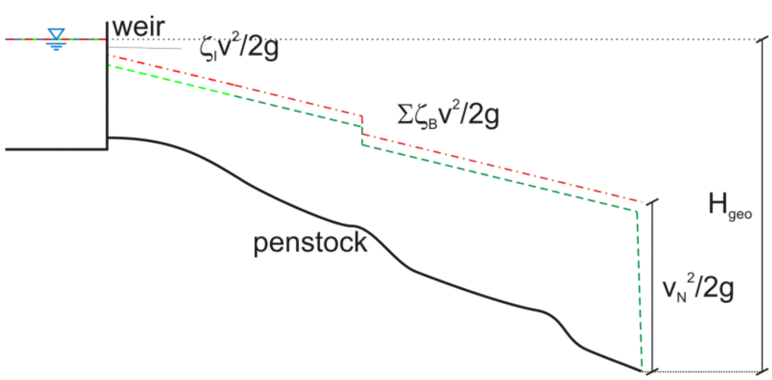

Fig. 17 Energy plan of the proposed layout

Applying Eqn. (1) the pipe diameter was optimized using the data in Tab. 2 and a discharge depending efficiency factor between 40% and 76%.

Tab. 2 Input data

Geodetic head	H_{geo} = 8.38 m	Kinematic viscosity	$\nu_{(25°C)}$ = 9E-7 m²/s
Pipe length	l = 100 m	Inflow loss	ζ_I = 0.5
Roughness	k_s = 8E-6 m	Sum of bend losses	□ζ_B = 2.5

Examining Eqn. (1) for different pipe diameters and appropriate turbine layouts (see Chapter 6.3) yields Fig. 18. From the plot it can be seen that a pipe diameter[12] of 0.50 m is essential for a reasonable output but also maintainable water hammer pressure peaks. The nozzle area is subject to the turbine design in 6.3.

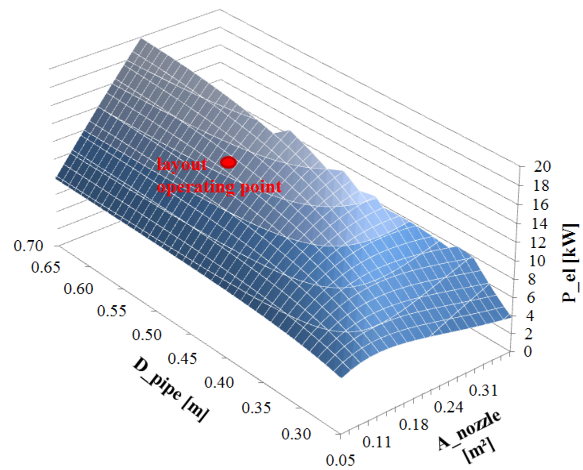

Fig. 18 Operating point of the system – pipe diameter dimensioning

The use of two or more smaller pipes does is not an alternative as can be seen from Fig. 18. The following specifications were yielded with a pipe diameter of 0.50 m.

Tab. 3 Hydro power plant specifications for different discharges

Q [m³/s] (discharge)	A_{nozzle} [m²] (adjusted nozzle	H_n/H_b (net head / gross	v_{pipe} [m/s] (pipe velocity)	v_{nozzle} [m/s] (velocity at nozzle)	Δp [bar] (Joukowsky hammer)	p_{total} [bar] (total max. pressure)	P [kW] ($\eta_{HPP} \cdot \rho \cdot g \cdot Q \cdot H_N$)

12 PVC pipe diameters in Cameroon were considered only: d = 0.125 m, d = 0.25 m, d = 0.50 m

	area)	head)					
0.100	0.031	99%	0.51	3.19	0.98	1.80	**4.5**
0.150	0.047	98%	0.77	3.17	1.48	2.30	**7.8**
0.200	0.064	96%	1.02	3.15	1.97	2.79	**10.7**
0.250	0.080	95%	1.27	3.12	2.46	3.28	**13.3**
0.300	0.097	92%	1.53	3.08	2.95	3.77	**14.3**

6.3 Turbine

A crossflow turbine has been chosen due to its robust construction and perfect applicability at the suggested site. Crossflow turbines, also called Ossberger or Banki turbines are radial-flow impulse turbines. Because of their low maintenance requirements and simple construction they are frequently used as small and micro hydro power plants in remote areas. As the mechanical system is not very sophisticated, repairs can easily be performed by local mechanics. The proposed discharge ranges from 0.025 to 13 m^3/s for heads of 1 to 200 m [8].

Although the peak efficiency of a crossflow turbine is somewhat less than other conventional turbines it has the advantage of a flat efficiency curve under varying load. This can yield better annual performance at variable discharge rates. To achieve good part-load efficiency it is possible to divide the split runner and turbine chamber at a ratio of 1 to 2 at varying flow rates [9]. Since the turbine runs at low speed it is not severely affected by suspended solids. The high durability, low price, simple construction and reliable operation make these turbines ideal for the use in developing countries.

6.4 Constructional tasks

6.4.1 Weir overhaul / intake construction

A lot of leakages that currently exist in the weir make an entire overhaul mandatory. In order to be able to exploit a steady discharge by the facility it is important to keep a constant water level above the weir. In the event of very high discharges a secured HQ-release will be provided on the weir crown. The concreting process of the weir will be carried out section by section.

6.4.2 Penstock fixation

The fixation of the penstock depends on the underground conditions. At "layout 1" there is a certain thickness of the top soil layer. Below the soil, solid rock is expected as it forms the basis of the whole cascade. At the current stage it is assumed that the reinforcing steel can be anchored to these rocks. In order to give final instructions further underground and fixation analysis is mandatory.

6.4.3 Powerhouse

The powerhouse contains the core of the whole facility and therefore requires special safety precautions. First issue to be considered is flood protection. As the generator and further electric equipment is located in the powerhouse it has to stay dry under any conditions. Further safety precautions against electric shock have to be performed. In addition all facilities must be inaccessible for any unauthorised person (health safety, sabotage etc.).

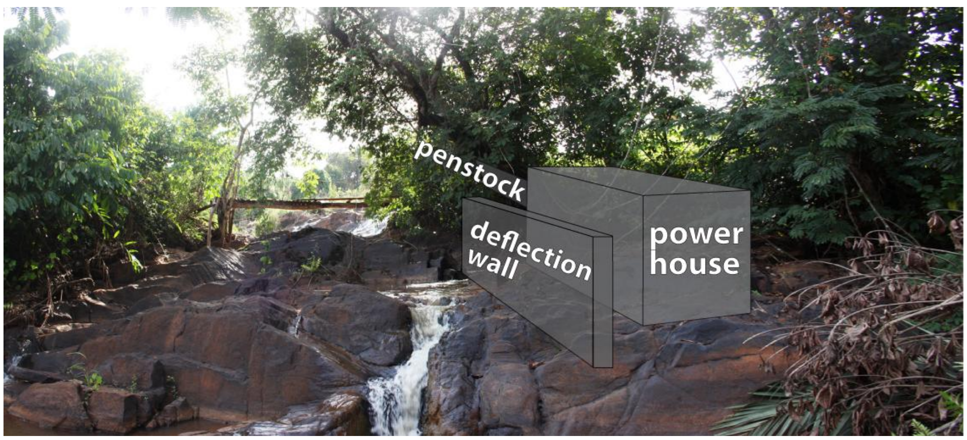

Fig. 19 Sketch of powerhouse construction and layout

7. SOCIAL AND ECOLOGICAL IMPACT ASSESSMENT

The main issue regarding ecological consequences of the new built hydro power plant concerns the fish and hydrologic fauna friendliness of the whole structure. As the weir will be kept in its actual dimensions there will not be deterioration for organisms through the construction. Nevertheless an improvement of the current situation will be aspired. Fish harming through the turbine can be avoided by a rack with narrow spacing at the intake; the velocity head is negligible anyway. Additionally a channel supplying a slaughterhouse with water can be modified to serve as a fish pass. The site is ideal because already existing structures are used. Therefore the plant will not have an impact on the flood security of the residents.

8. EDUCATION CONCEPT

The hydro power education will focus on hydraulics, hydraulic engineering and hydrology. A concept for descriptive courses has been published in [10]. However, an entire engineering course cannot be offered – and is not intended. Basic applicable know how will be provided so that the students are enabled to conduct similar projects. This prerequisite implies secure underground conditions and flood safety for both – the plant itself and the surrounding area. Ecological impact minimization and awareness will be the principles to be taught.

9. OUTLOOK

Result of the current work is that construction can be done very efficiently under the evaluated circumstances. With the examined site layout the ecological impact can be minimized to an almost negligible value. The social impact on the local residents can be rated throughout positively. Long term operational safety has a very high priority.

To be able to give a final proposition and determination of all duties necessary there is still research to be done and already in progress. This is for example the recording of a hydrograph, currently organized by ADEID by installing a fixed water level gauge. The issue of electrical distribution, control and supplying the energy consumers will be dealt in another study. All in all the proposed design serves as an example for a hydro power plant built in an area where hydrological data is scarce but flood security can be guaranteed. It improves the living quality of the locals whereas an ecological deterioration cannot be identified.

10. ACKNOWLEDGEMENTS

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The potential of using renewable sources of energy in Mauritius

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Abstract:

The rich nations are experiencing different crises while vulnerable countries like Mauritius can only be spectators and watch the negative impacts of climate change on their already fragile economy. The current energy crisis is one example: the price of fossil fuel is going up constantly and the situation is becoming worse owing to the unrest in supplier countries as well as the constant threats from Somalian pirates in the Indian Ocean seas. The effects of CO_2 emissions due to the use of fossil fuels on climate, the degradation of air quality and populations' health due to pollution should not be ignored.

The only way forward to face the problems mentioned is to become self-dependent on energy by the use of clean and renewable sources of energy, preferable those available locally. The habits of the population need to change and there is a need for better awareness on the proper use of energy. This work aims at highlighting the potential of locally available sources of renewable energy such as solar, wind, and others for domestic or other uses.

The country is already making full use of its bagasse and hydro sources of energy while there is a potential to further exploit solar and wind for generation of power. The use of other sources such as geothermal and piezoelectric-generators may also be considered in the medium and long terms. It is expected that the investment cost on the required facilities would become more affordable in the future.

Keywords: Clean and Renewable Energy, Energy Self-dependency

1. INTRODUCTION

The Republic of Mauritius exports mainly to European countries. The current recession being faced by all countries, including Europe has already started to affect the Mauritian economy. The signs are that the economic situation would be getting worse in 2012 and Mauritius is doing its best to mitigate the impact of the world economic slowdown. The Mauritian textile, sugar and tourist sectors have all been continuously re-adjusting their respective strategies as well as carrying out reforms to be able to survive. So far the country has done well but the further challenges ahead will require still more creativity and reforms.

Just like reforming the existing economic pillars, diversification of the Mauritian economy has always an important issue in the Mauritian economic agenda and the country is looking for investment in new sectors. The recent budget speech has, among others, put a lot of emphasis on facilitating SMEs. The latter are encouraged to develop their marketing strategy and government is ready to help them in that endeavour.

Energy is a very important factor that always comes into the equation when considering social and economic development of any nation. With the continuous increase of activities in the country, the demand for energy is also increasing. The energy generated in Mauritius has increased from 2015.9 GWh in 2005 to reach 2668.7 GWh in 2010 [1]. Acording to Elahee [2], the expected demand in 2015 would be around 3340.0 GWh.

Dependence on fossil fuels may make countries like Mauritius increasingly vulnerable. The world is expecting to face further increases in price of its oil due to the instability in some of the OPEC countries, coupled with the recent US and EU sanctions against Iran. The constant threats from Somalian pirates in the Indian Ocean seas and may make the problem worse for Mauritius. The world has a limited reserve of oil and, as such, it is very unlikely that the price of oil will go down, unless an alternative and cheap source of energy is found. The pollution due to the use of fossil fuels and its impact on the quality of air and health should not be ignored. Furthermore, the tsunami in Japan in 2011 has shown that nuclear energy might not the ideal alternative to fossil fuels.

To sustain its economic growth Mauritius should be able to meet its increasing energy demand as well as face the current world economic crisis. Therefore there is a real challenge to Mauritius and there is a need to becoming more creative and to tap further the locally existing sources of energy. Like many tropical countries, Mauritius has a substantial potential to tap renewable energy (RE) sources that are abundantly available. This paper highlights the present status of the use of RE in Mauritius and discusses the potential of tapping new resources for the future.

2. USE OF RENEWABLE ENERGY IN MAURITIUS

Mauritius is not new to the use of RE: the country has been using renewable energy since 1903 in the form of hydro-power [3]. Mauritius is considered to be a leader in the field of RE [4]. The increase in energy demand soon after the Second World War encouraged the local authorities to consider sugar cane bagasse as a source of energy. Thus, the St Antoine Sugar Factory was the first one to export its surplus electricity, made from bagasse, to the grid in 1957 [5].

The 'Maurice Ile Durable' (MID – Mauritius Sustainable Island) project was launched in 2007 by the Prime Minister of Mauritius with a view to decreasing the island's dependency on fossil fuels and encourage the use of renewable energy sources locally available. The project also targets at improving the efficiency of the energy sector. Projects such as encouraging the use of solar water heaters and energy-efficient lighting have already been launched.

In 2010, the country produced 24.3 % of its energy requirements from available renewable energy and aims at increasing this value to around 35% by 2025. Table 1 shows the evolution of the use of renewable energy since 2008 and the target set for the future up to 2025. The goals mentioned were set out in 'Long-Term Energy Strategy' plan in 2009 as a '*roadmap to address the energy and environmental challenges lying ahead*' [6].

2.1 Hydropower

Hydropower is one of the cleanest ways of generating power [7, 8] and provides for 20% of the world's energy generation [9]. Although the initial investment is considerable, hydropower has several advantages like low operating and maintenance costs, long-life and it produces no waste [8]. Mauritius is already making full use of this source: there are 8 hydroelectric stations that can generate around 100 GWh yearly representing slightly less than 4% of its consumption [1, 6 and 10].

According to the Long Term Strategy Plan [6], there exists the possibility to generate 2GWh/year of power at on La Nicolière Feeder Canal, at Trente Chutes and use the facilities available at the Midlands Dam. The Government's strategy is to encourage investment with the setting up of mini and micro hydro plants around the island, wherever the potential exists. The power output, however, depends heavily on the weather and it can fluctuate between 5 GWh per month in a dry season to 20 GWh per month in a wet one. Since 2011 Mauritius has been facing a period of drought and has to cope for the shortage of power from hydroelectric stations with the use of coal and/or fuel oil.

Table 1 Actual and targeted power generation by source

Source of energy	ACTUAL						PROJECTION[6]		
	2008[11]		2009[1]		2010[1]		2015	2020	2025
	GWh	%	GWh	%	GWh	%	%		
Renewable									
Bagasse	486.4	19.0	485.0	18.8	550.4	20.5	13	14	17
Hydro	108.0	4.2	122.4	4.7	100.7	3.7	3	3	2
Waste to energy	-	-	-	-	-	-	5	4	4
Wind	0.4	0.0	1.5	0.1	2.5	0.1	2	6	8
Solar PV	-	-	-	-	-	-	1	1	2
Geothermal	-	-	-	-	-	-	0	0	2
Sub-total	**594.8**	**23.3**		**23.6**		**24.3**	**24**	**28**	**35**

Non-Renewable									
Fuel Oil	833.7	32.6	953.3	37.0	995.5	37.0	31	28	25
Coal	1128.7	44.1	1015.3	39.4	1039.5	38.7	45	44	40
Sub-total	**1962.4**	**76.7**		**76.4**		**75.7**	**76**	**72**	**65**
Total		**100.0**		**100.0**		**100.0**	**100.0**	**100.0**	**100.0**

2.2 Sugar cane as a source of energy

Sugar cane is a very good source of green and renewable energy [12]. During harvesting the sugar cane is separated from its top and straw, while bagasse and molasses remain following the industrial processing the sugar cane. The tops are generally used as cattle feed but have the potential of being used as a source of raw material for paper [13]. According to Chung Tze and Ramasamy [14], about 40% of the island surface area is used for agricultural purposes while 90% of that area is under sugar cane production [15]. In 2010, an area of 58,755 hectares of sugar cane plantation yielded 4,365,852 tonnes of sugar cane [16].

2.2.1 Bagasse

Bagasse is the fibrous biomass remaining after sugarcane has been processed to extract sugar. Typically sugar mills generate about 30% by mass of bagasse expressed on total amount of cane crushed [17, 18]. Bagasse is burnt to produce steam and electricity (cogeneration) for the need of the industry and the excess of electricity is usually sold to the wider consumer electricity grid [19, 20]. The cost of collection of bagasse is insignificant as it is produced and used on-site with very little storage time [21-23]. The net calorific value of bagasse is about 8000 kJ/kg at a moisture content of 48%. In 2010, 1 406 371 tonnes of bagasse was used to generate 550.4 GWh of power.

Together with ACP countries, Mauritius is playing an active role in research and development to produce new varieties of sugar cane that has a higher percentage of biomass. In 2007, the MSIRI has developed a new variety of sugar cane that can yield

15-25% more fibres. The use of high-pressure boilers has already proved to be using bagasse more efficiently [6] and this experience could benefit the country.

2.2.2 Ethanol from molasses

After extracting sugar from the cane juice, molasses is obtained and it can be distilled into ethanol. The latter has been used as a replacement for gasoline in Brazil since 1975 [24] and is gaining more popularity. According to the MSPA, Mauritius can produce an average of 35 000 tonnes of ethanol from the 150 000 tonnes of molasses that are obtained annually [12]. In the near future, the Omnicane Ethanol Holding Limited is expected to sell 15 million litres of anhydrous ethanol that would be blended with gasoline and sold as E10 fuel locally [25]. The country is encouraging the use of biofuels and plans to mix 25 million litres of ethanol with gasoline in the medium term.

2.3 Solar energy

Solar energy is free, clean and inexhaustible and available almost everywhere on our planet. Solar energy is mostly used in two forms: thermal and photovoltaic. Solar water heaters are designed to tap the heating effect of solar radiation. They are the most widespread solar energy conversion device [26] and also the most economical alternative renewable energy systems [27]. The photovoltaic (PV) devices convert sunlight directly to electricity. These devices require little maintenance and have a life of 20-30 years with low running and maintenance costs [28]. A typical solar water heater can provide about 75% of the domestic needs for hot water and may cut the monthly energy bill by at least 20% [29].

Like most tropical islands, Mauritius is blessed with abundant sunshine and benefits more than 2900 hours of sunlight per year. The Northern and South-Western parts of Mauritius receive a solar radiation of 6 kWh/m^2/day [30]. Table 2 summarises the average amount of bright sunshine received in the island.

Table 2 Number of hours of bright sunlight received in Mauritius [30]

Region in Mauritius	Hours of sunlight/day	
	Summer	Winter
High grounds	6.0	5.0
Coastal regions	7.5 to over 8.0	7.5

Despite the abundance of sunlight in Mauritius, the amount of electricity harnessed from solar power generated is still very insignificant. Therefore there is a huge potential to use solar energy in Mauritius.

2.3.1 Use of solar water heaters

In Mauritius also, solar water heating is the most common form of conversion of solar energy. To encourage the use of solar water heaters, the Development Bank of Mauritius has been providing a concessionary rate of interest on loans for their purchase since 1992. However, till 2008, only 25 000 households, out of 330 000, were using solar water heaters. In 2009, the loan facility was replaced by an outright grant of Rs 10 000 for the purchase of solar water heaters. 29 000 households have benefitted from the scheme and the number of solar waters heaters in use in the island is expected to have reached more than 50 000 but no survey has confirmed this value yet. Given the success of the grant, the Government has proposed an improved scheme that would be implemented in 2012 [31]. Undoubtedly, the number of solar heaters will continue to increase in the country.

2.3.2 Use of PV

Unlike the solar water heaters, the initial high cost of installing PV panels has been quite prohibitive and that explains why PV has not gained much popularity as a source of renewable electricity.

To encourage the use of PV as well as wind and hydro sources of electricity, the Small Scale Distributed Generation (SSDG) project was launched in December 2010. This project is limited to a capacity of 2MW over the island from a 200 'Small Independent Power Producers' (SIPP). The Central Electricity Board (CEB - the public utility compant responsible for the generation, transmission, distribution and sale of electricity in Mauritius) will pay the latter a 'Feed-in-Tariff' per kWh of electricity exported to the national grid. The Feed-in Tariff, valid for 15 years, is shown in Table 3. Currently households, drawing their electricity from the national grid, pay the CEB Rs 3.16 to Rs 8.77 per kWh consumed, depending on the total amount of electricity consumed.

Table 3 Feed-in-Tariff for SIPP [32]

Feed-in Tariff for 15 years	Source of Electricity		
	Wind	Hydro	PV
	Mauritian Rupees (Rs) per kWh		
Micro (up to 2.5 kW)	20	15	25
Mini (2.5+ to 10 kW)	15	15	20
Moyen (10+ to 50 kW)	10	10	15

In case the SIPP's annual production/consumption ratio is greater than 3, the Feed-in-Tariff is decreased by 15%.

It is expected that the project will be a boost for eventual SIPPs and that the power generated using solar PV will constitute 2% or more of the country's energy demand in 2025. On the other hand, the future of PV seems to be very bright if the following are considered:

- New technologies with solar tracking systems allow for improved energy capture as well as improved photovoltaic energy output for cloudy conditions [33, 34];
- the availability of integrated photovoltaic and thermal solar system – a device that generates electricity as well as heats water simultaneously resulting in improved efficiency [35];
- the PV technology is becoming more economical and more efficient [36].

2.4 Wind energy

Wind energy is another clean source of energy that is compatible with the environment will never run out [37]. The interest in wind energy started to grow in 1973 after the first world oil crisis [38]. The world wind energy capacity has increased from 6.1 GW in 1996 to 159.2 GW in 2009, representing an average annual growth rate of 30% [39]. The rapid growth since 1995 has led to improved efficiency and reduced cost of wind turbines making wind energy increasingly competitive [40]. To find the potential of wind energy in a country, a survey for the EU based itself on wind speeds of over 5 m/s at a height of 10 m [41].

A study carried out by the United Nations Development Programme (UNDP) in the mid 1980 [42] found that Mauritius has an annual average wind speed of 8.1 m/s at 30 m above ground level in some places and therefore can be considered for harnessing wind energy. Wind turbines were installed in the late 1980s but were destroyed by cyclones and the project was neglected.

The following wind farms projects are now being considered [10]:

- Omnicane would be installing a 22 MW wind farm at Britannia The (Omnicane, 2011);
- An 18 MW project would be installed by Aerowatt (Mauritius) in the village of Plaine des Roches ;

- Another project in Curepipe Point for on a 'Build Operate Own' model is taking form that would generate a power of 20-40 MW;
- The CEB has already carried out a feasibility study to install a wind farm with the potential of 5 GW. It is currently seeking funding for the project.

These interests clearly show that there is a potential for tapping wind energy in Mauritius and the opportunities should not be missed provided that the environment is taken care of.

2.5 Waste to energy project

Foolmauna et al. reported that in 2010, an amount of 427 680 tonnes of waste was sent to landfills in Mauritius, representing about 1 kg of waste per individual per day. While this figure is set to continue to increase, only 9% of that amount is recycled [43].

One way of reducing the volume of waste to be land-filled is by incineration [44]. If done properly, the process may be used to generate electricity. It is true that the issue of incinerating waste is still a matter of debate because of concerns of its impact on the environment as well as on the health of the people living in the vicinity of the incineration site, but new technologies are making the process more and more acceptable [45]. The EU has laid strict guidelines [46] to allow waste incineration; such legislations should be rigorously enforced in any country where waste is incinerated so as to ensure the well-being of its citizens.

Waste decomposition in the absence of air generates considerable amounts of methane gas that are liberated into the air. This gas can be used as a source of energy. Since October 2011, Sotravic, a Mauritian company, is producing about 2MW of renewable energy from landfill gas. The company is expecting to increase this its energy generation to 3MW [47].

The 'Waste-to-Energy' project by the Gamma Coventa company is currently on hold because of protests from the general public. If given the go-ahead, the project is expected to produce 20 MW of energy by combusting solid municipal waste to generating [10].

2.6 Other energy sources in Mauritius

The above-mentioned sources of energy would, undoubtedly, generate a significant amount of renewable energy. However, with increasing demands of electricity, the country needs to tap all the possible resources with a view to becoming totally dependent on its own sources of energy. In this context, another two sources of energy may be considered in Mauritius in the future: geothermal energy and electricity from the movement of vehicles on the Mauritian Motorway.

2.6.1 Geothermal energy

The core of our planet is very hot and at a temperature of around 5000 ^{0}C. The heat intensity decreases as we move from the core to the surface of our planet Earth. The thermal energy, which can be used for heating or production of electricity, is referred to as geothermal energy [48]. In 2010, the world's installed capacity for power generation from geothermal sources stood at 10 000 MW and about 70 000 GWh was produced [49].

Mauritius, being a volcanic island, may have sources of geothermal energy. According to the Mauritius Research Council, a preliminary study has shown that it is possible to tap geothermal energy in Mauritius. Experts now have establish the areas where the thermal energy may be tapped [50 -52]. Therefore additional work is needed to determine the feasibility of tapping this source of energy in Mauritius.

2.6.2 Piezoelectric-generators

Piezoelectricity is the ability of a material to produce electric power when a mechanical stress is applied to it [53]. Tests are being currently carried out in Israel on a roadway that had been embedded with piezoelectric-generators [54]. It is expected to generate up 400 kW over a stretch of 1 kilometre [55].

The technology, developed by Innowattech [56], should be able to produce 200KWh, while a four-lane highway would produce about 1MWh of electricity, per kilometer, enough to provide power to 2500 households in Israel [57].

This interesting technology might be of interest to Mauritius as the country is developing its road infrastructure. However, the feedback from the Israeli experience would indicate whether it is worth to conduct any feasibility study for the island.

3.0 CONCLUSION

This paper has highlighted the potential of using RE in Mauritius. While the cost of RE hardware is quite significant, its trend is on the decline with more and more efficient technologies on the market. There are, therefore, a lot of opportunities ahead towards making the country increasingly reliable on RE sources. Using less fossil fuel means higher savings on foreign currency as well as less pollution of the air leading to better air quality. Mauritius may thus dream to becoming a 'green' destination' for tourists with a healthier population. It would be interesting to evaluate the savings due to the latter.

Wave energy, energy from animal waste such as chicken waste have not been considered in this article, although it is believed there is considerable potential in those areas too. There is additional opportunity of generating electricity from the sun by hotels that are situated in coastal areas, where more sunlight is usually available.

There is also the opportunity of job creation: SMEs should be encouraged to design, mount and maintain installations such as solar panels, wind turbines and mini and micro hydro plants. With 330 000 households in Mauritius, one can easily imagine the potential of setting up SMEs and job creation in the field of energy.

Energy saving should become a habit. Each little gesture counts.

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The New Green Revolution: Sustainable Agriculture for the Caribbean through the Use of Renewable Energy

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Abstract:

The Green Revolution, which occurred from the 1940s to the late 1970s, saw a major boom in the Agriculture sector in many parts of the world. It was based on the introduction of chemical fertilizers and superior varieties, irrigation improvement and agricultural extension programmes. This led to dramatic increase in wheat yields and world coarse grain production. Following this, for numerous reasons, many of which were social and economic, there was a major decline in agricultural production. The main objective of this paper is to explore and propose new ways of stimulating growth in Agriculture by the introduction of the "New Green Revolution", through the use of green technologies. Different forms of renewable energy, such as solar, wind and biomass, are proposed to have greater penetration in the agriculture sector, thereby stimulating growth, creating a new revolution in Agriculture.

Keywords: New Green Revolution, Renewable Energy, Sustainable Agriculture, Caribbean.

1. INTRODUCTION

The Caribbean region has a long history in Agriculture, with this being the backbone of the economy for many of the islands. While this has been the case, the economic and social benefits have not propelled the region to the level of comfort zone or sustainability in Agriculture. In fact, experts working in this area have lamented about the "crisis in Agriculture" and the poor performance of the sector in the region. Food import bills continue to rise while the potential for food production is good if the sector is given due attention and if the necessary importance is attached to it. The University of the West Indies in Trinidad has also recognized the urgent need for revitalizing

Agriculture by the re-introduction of separate Faculties for Science and Agriculture. Revitalizing Agriculture is critical for self-sufficiency and food security for the Caribbean region.

Growing concerns about Climate Change and its effects on Small Island Developing States is also making it imperative to search for more sustainable paths in both Agriculture and the Energy sectors, which are intimately linked. This paper focuses on the application of Renewable Energy technologies in the Agriculture sector and its projected impact on food security and sustainable growth for the Caribbean region.

2. THE GREEN REVOLUTION

The Green Revolution, led by former (USAID) director William Gaud, involved a series of initiatives which occurred between the 1940s and the late 1970s, with a focus on research, development, and technology transfer. The effect of this was increased agricultural production in many parts of the world, especially in the late 1960s. This led to significant saving of more than a billion people from starvation because of the high-yielding varieties of cereal grains through the distribution of hybridized seeds, introduction of synthetic fertilizers and pesticides to farmers, expansion of irrigation infrastructure and modernization of management techniques [1]. The impact of the Green Revolution was particularly significant in India, as shown by the graph in Figure 1 [2].

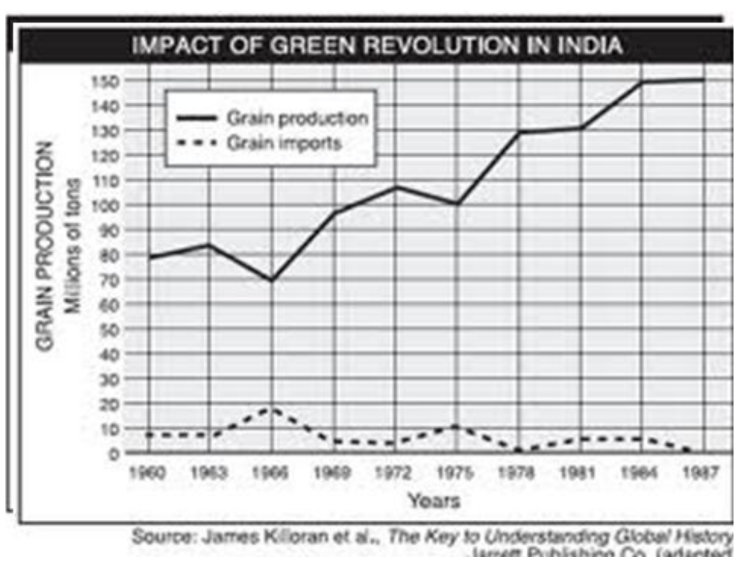

Figure 1: Impact of the Green Revolution in India

The Green Revolution was based on three pillars:

- the introduction of chemical fertilizers and superior varieties
- irrigation improvement, and
- agricultural extension programs.

The dramatic increase in wheat yields in selected countries from 1950 to 2004 is shown in Figure 2 [3], while the total world production of course grain for the same period is shown in Figure 3 [4].

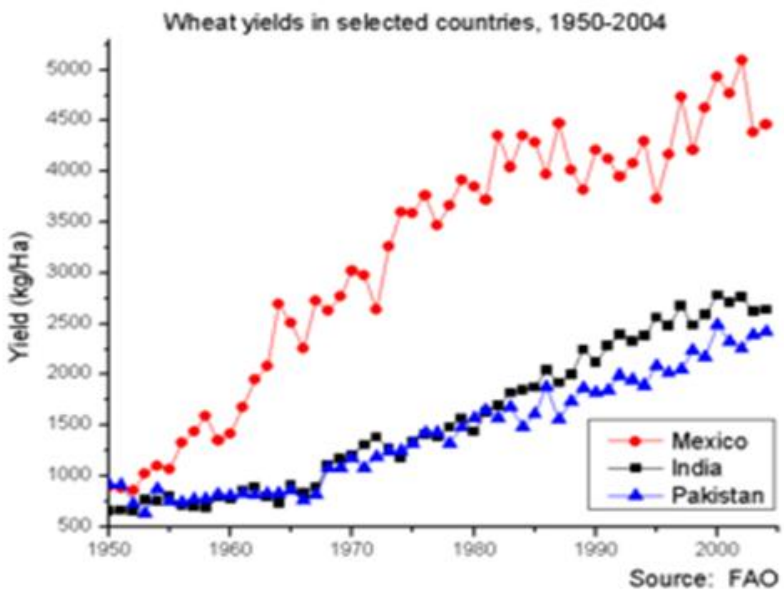

Figure 2: Wheat Yields in Selected Countries

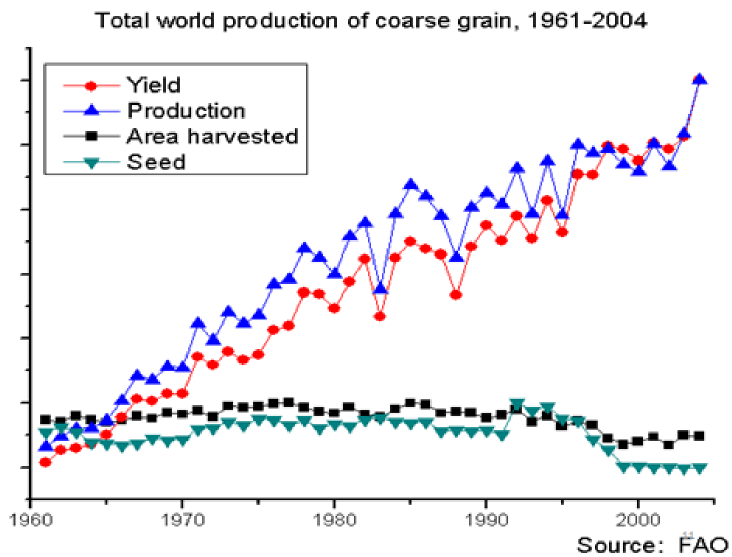

Figure 3: The Total World Production of Course Grain

2.1 Decline in Agricultural Production

The continuous increase was not sustained for many reasons. Global decline in agricultural production in recent years has its roots in many sources, of significance are social and economic factors. There are numerous challenges associated with agriculture. Insurance companies are covering less and less risky areas, and agriculture is considered high risk due to disasters such as hurricane, floods and droughts. Financial institutions do not give priority to agriculture as opposed to other businesses. Lack of resources for developmental purposes has hampered growth in this sector. Even at the University of the West Indies in the past years, the agriculture programmes were dwindling as low student intake was making it not viable. It is clear that the crisis in Caribbean Agriculture must be dealt with as a matter of urgency. Food security is paramount for the development of the region.

2.2 Climate Change

Climate change issues are especially applicable to Small Island Developing States (SIDS), such as the Caribbean, for instance, the effects of climate change on crop yields is major problem. While the Caribbean ranks low in Green House Gas (GHG) emissions at a global level, SIDS are the most vulnerable to sea level rise due to climate change. Temperature records have shown an increase in the last century, with the 1990s being the warmest decade since the beginning of the 20th century. The year 1998 also appears as the warmest year on record. Warmer sea temperatures support development of stronger hurricanes at lower latitudes, more rapid transition to category four and five, and increase the likelihood of coral bleaching.

Climate change has negative effects on agriculture, tourism, health, water security, economic and social vulnerability. Forests, livestock and fisheries are impacted upon negatively. There is threat of food security, economic sustainability, and increase in vector-borne and other heat related diseases. Even a one degree rise in temperature has dire consequences on fish, such as yellow tuna and dolphin fish. The environmental conditions become less favourable causing fish to migrate to cooler temperatures, leading to severe consequences for the region [5]. Adaptation policies for all sectors must be instituted for agriculture, land use, water resources, tourism sector and sea level rise.

2.3 The New Green Revolution

At a global level, transformation in the agriculture sector is critical. With the growth in clean technologies, agriculture could get a much needed boost by greater application of renewable energy technologies. This is being coined as the "New Green Revolution" which could mean significant increase in production, leading to greater food security. Renewable energy technologies could enhance the growth in agriculture in numerous respects, one of which is post-harvest technology.

The "New Green Revolution" will be based on:

- Climate Smart Agriculture
- Energy security
- Food security through renewable energy.

"Climate-smart agriculture" (CSA) is agriculture that *sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) while enhancing the achievement of national food security and development goals*" [6]. CSA addresses the challenges of food security, climate adaptation and mitigation in an integrated way, rather than in isolation. Trying to feed nine billion people in 2050 in a way that is not detrimental to planet Earth is one of the biggest challenges of the 21st century. There is growing competition for land and natural resources and this can seriously compromise the world's ability to grow food sustainably. In order to achieve food security, agricultural production must increase by 70% by 2050 whilst conserving the natural ecosystems [7].

Agriculture is the only sector that offers a triple win of enhanced productivity and food security, increased climate resilience and reduced GHG emissions [8]. The entire agricultural system must be redesigned to achieve this at a lower GHG emission rate. Striking the right balance between productivity and emissions per unit of agricultural product is key to this transformation. This can only be achieved by more efficient production with less of an environmental impact. Taking an integrated scientific approach and seeking innovative mitigation methods are important steps towards the transformation. National decision policies must be developed to overcome the barriers and promote change. Education programmes should be developed to adequately communicate the Science of CSA.

2.4 Renewable Energy and Agriculture

Application of renewable energy technologies can serve as an effective mitigation tool for climate change and lead to energy security for the Caribbean region. There are many drawbacks to the use of conventional fuels in agriculture. Fuel has to be transported through long and remote distances where the noise and fumes can disturb livestock. The possibility of spills is significant and this can contaminate the land. Generators require a significant amount of maintenance and in case of failure they may need replacement parts that are not always available.

Renewable energy and agriculture are a natural fit; there is a direct relationship between energy and agriculture. Solar, wind and biomass can be harvested continuously, providing farmers with a long-term source of energy, thereby increasing their income. Renewable energy can be used on farms to replace conventional fuels or it can be sold. The amount of solar energy that reaches the Earth every day is enormous. All the energy stored in the Earth's reserves of coal, oil and natural gas is equal to the energy from only twenty days of sunshine. Therefore harnessing and utilizing solar energy in a region such as the Caribbean, where the solar insolation if high year-round is important for energy security. There are innovative ways of using solar in agriculture thereby saving money, increasing self-sufficiency and reducing environmental contamination.

Solar energy offers a suitable alternative for many agriculture needs. Modern, well-designed, simple-to-maintain solar systems can provide the energy that is needed to run agricultural farms. These systems have been tried and tested around the world and have proven to be cost-effective and reliable. They have already been proven to raise the levels of agricultural productivity worldwide, and can therefore have a significant impact on Caribbean agriculture. Both solar thermal and solar photovoltaic (PV) systems have numerous applications in agricultural operations, with an end result of increasing productivity and reducing energy usage from fossil fuels. Electricity derived from PV can be used to power a load, such as a water pump, or it can be stored in a battery. A PV-powered watergate can be used to divert excess runoff and prevent flooding. These can yield beneficial results for agriculture.

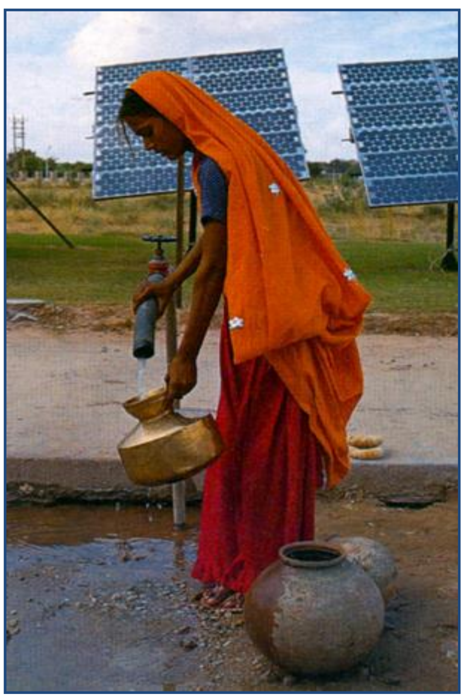

Figure 4: PV-powered Water Pump

Figure 5: PV-powered Flood gate Controller

Figure 6: PV-powered Street Lamp

(Photos courtesy I. Haraksingh)

PV modules produce electricity when the sun is shining, so some form of energy storage is necessary to operate systems at night. Photovoltaics is a well-established, proven technology with a substantial international industry network. It is increasingly more cost-effective compared with either extending the electrical grid or using generators in remote locations. The cost per peak watt of PV power is decreasing continuously, making it an attractive option for the farming industry (Figures 7 and 8) [9, 10]. PV systems are economic at remote locations and can be much cheaper than installing power lines and step-down transformers in applications such as electric fencing, area or building lighting, and water pumping for livestock watering or crop irrigation (Figure 9).

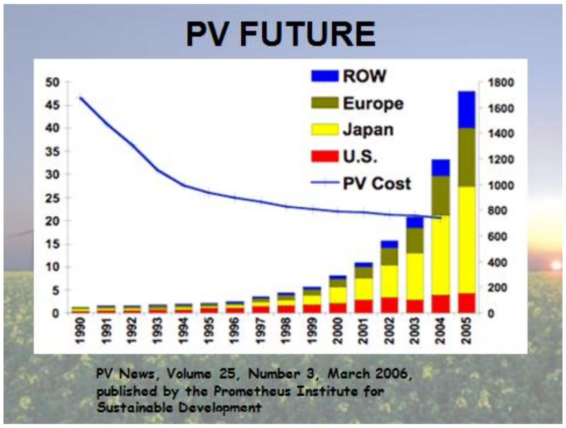

Figure 7: Cost of PV – 1990 to 2006

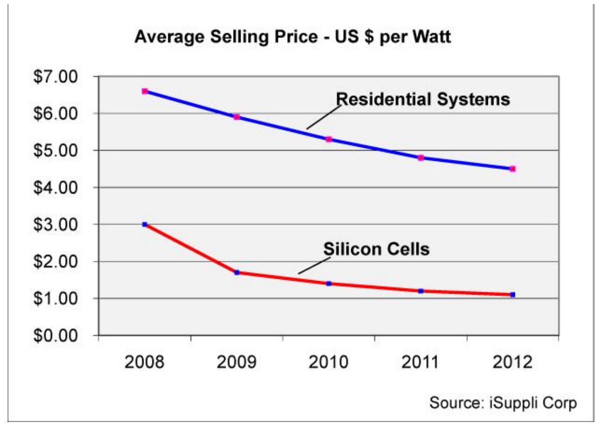

Figure 8: Cost of PV – 2008 to 2012

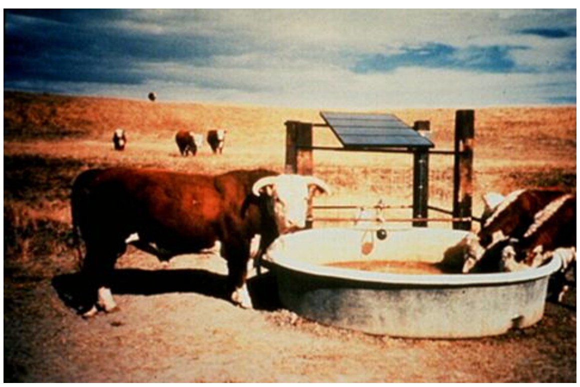

Figure 9: Livestock Watering

Figure 10: PV-powered Chicken Farm

(Photo courtesy DC Power Systems Limited)

Powering electric fans for air circulation is another solid use of PV. It has been proven that modern pig and poultry farms can double and even triple production by raising the animals in enclosed buildings. Proper lighting in agricultural buildings and enclosures can significantly reduce deaths caused among young chicks or animals due to trampling on each other. Adequate lighting in these buildings can also significantly extend working hours thereby increasing productivity. This will also facilitate repair and maintenance of equipment during evening hours. Figure 10 shows a PV-powered chicken farm in Trinidad.

PV systems can be more economical choices than conventional battery-powered lamps, providing higher quality light without emitting smoke or fumes. PV systems can also be used on farms, ranches and orchards for electric-powered egg collection and handling equipment, product refrigeration, livestock feeder and sprayer motors and controls, compressors and pumps for fish farming, electric fencing to contain livestock and battery charging.

Solar thermal systems are equally effective in agricultural farms. Crop drying is essential in Agriculture for post-harvest technology. Modern solar crop dryers are very simple, effective and hygienic. Crop dryers can be effectively used for Agriculture and Horticulture to increase yield and reduce the amount of perishables. In many instances curing of products is essential for enhancing the shelf life and this can be adequately achieved through the use of solar dryers. This will ultimately achieve not only an increase in income, but would allow the possibility of food preservation for much longer periods, leading to a greater measure of food security.

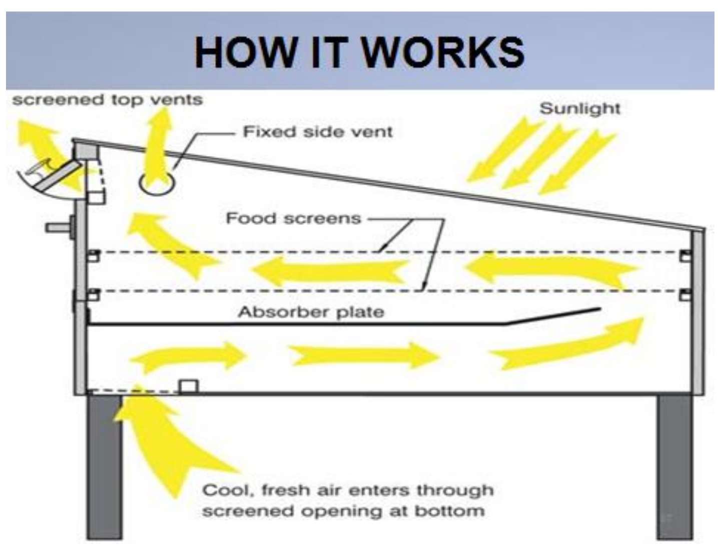

Figure 11: Working Principle of a Solar Dryer

Other solar thermal systems, such as solar water heaters, can also be effectively incorporated into agricultural operations yielding higher agricultural productivity, particularly in livestock operations. Simple solar water heaters providing low to medium temperature hot water (140 degrees F or 60 degrees C) can be used for cleaning of pens and equipment for raising poultry. These systems require a solar collector, a storage tank, plumbing and pumps. There are many commercially available systems on the market and they offer simple installation procedures. Barbados in the Caribbean is a world leader in solar hot water systems, providing systems of high standards throughout the Caribbean and beyond.

Figure 12: Solar Water Heater **Figure 13: Solar Water Heater**

(Photo courtesy Solar Dynamics Limited) (Photo courtesy Apex Caribbean Limited)

Wind Energy offers superb options in the agricultural sector. Small wind systems can provide power that can be used directly or stored in batteries. These systems are very reliable in areas that get enough consistent wind. The systems can be very cost-effective and reliable for many power needs on farms and ranches. The space at the base of the wind turbines can be effectively utilized for farmers to plant crops and generate wind power simultaneously. Since these systems can be stand-alone in remote settings, farmers can have a sense of security not having to depend on the central grid for power [11].

Figure 14: Wind Energy

Photo courtesy Warren Gretz, NREL

Cooling is one of the most important steps in post-harvest handling chain. By reducing the temperature of produce respiration rate can be greatly reduced thus extending shelf life and preserving the quality of the produce. The initial cooling, processing, and cold storage of fresh fruit and vegetables is among the most energy intensive segments of the food industry. Solar assisted cooling can be extremely beneficial to the industry. Renewable energy powered technologies, such as back-up generators, PV-powered evaporative cooling and solar chillers can be effectively utilized in the food preservation aspects of agriculture.

There are additional options for alternative energy use in Agriculture. These include production of liquid fuels from indigenous plants and agricultural crops and the use of biomass residues to power biomass gasification units that produce both heat and electricity (combined heat and power). These renewable liquid fuels include biomass-derived ethyl alcohol (ethanol) and biodiesel (derived from various types of vegetable oils). The liquid fuels option sometimes requires large-scale cultivation and processing of a crop to produce the renewable fuel economically. This can pose a dilemma with respect to the land use for food or fuel. Production of ethanol can be derived from sugar cane, corn, cassava, or sugar from beet and the production of biodiesels from plant oils, such as palm oil, coconut oil, Jatropha oil and other seed crops [12].

Alternatively, the renewable fuel may be produced on a small scale, often in conjunction with a farmer's other agricultural crops. The end result for the farmer is to reduce the cost of motive power, electricity and heat, and to increase the reliability of adequate affordable energy supplies. Small modular gasification technology has important potential for farmers' cooperatives. Such systems use a wide variety of biomass residues, such as coconut shells, coffee husks, wood wastes, and other woody biomass, to produce a high-quality gas that can provide heat, shaft horsepower and electricity.

Biomass is broken down thermochemically in gasification systems by heat and oxygen to produce a synthesis gas that can be used to power internal combustion engines, boilers, furnaces, dryers and chillers.

Combined heat and power systems allow a high degree of cogeneration. In the sugar cane industry the raw material, sugar cane, uses its own fuel for processing, with other side benefits. It has high thermal (steam) demand for processing, while its demand for mechanical energy is low. The Caribbean sugar cane breeding research centre is located in Barbados. Strategic research is conducted to develop new varieties of fuel cane to enhance the bio-energy content to meet future challenges. Barbados is undergoing reform of its sugar cane industry in this regard [13]. Research includes High Quality Breeding, Genetic Base Broadening, High Biomass and Multipurpose Cane Varieties, Maturity, Breeding strategies and the genetic basis for important agronomic traits.

Figure 16: Sugar Cane Breeding

Source: West Indies Sugar Cane Breeding Station

But there are many critiques of biofuels: food insecurity, ecosystem destruction and inaccurate climate science. Some of these include land use being diverted away from food production to crops for biofuels leading to scarcity of food. This can lead to increase in world food prices operating costs by 40% in less than 1 year. It has been touted that "*filling the tank of an SUV with ethanol once requires enough corn to feed a person for a year*" (*E-Parliament*).

Clearing of rainforests, grasslands and other ecosystems for biofuel production, removal of vital carbon sinks leading to massive release of CO_2 stored in these systems can all result in eco-system destruction. Studies show as a result of this land clearance and other emissions related to biofuels production, there are more GHG emissions than conventional fuels (*Science*). This leads to a dichotomy for which a solution is yet to be found.

Possible solutions can be fuels based on non-edible sources; sustainable biofuels can be synthesised from waste cooking oils and waste organic materials produced from sugar cane processing can be used for generating electricity. This leads to third generation biofuels, fuels from algae gases. It has been claimed that the region's technical exportable bioenergy potential over the long term (2050) is projected to be amongst the highest per capita. If Guyana, Jamaica and Barbados adopt the latest technology these countries could co-generate a total of 100 megawatts of electricity by burning sugarcane bagasse. *(Luis Moreno, president IDB president Inter-American Development Bank)* [14].

At the global level, International Energy Agency (IEA) Ministers recognise that current energy trends are not sustainable and that a better balance must be found between the three Es:

- energy security
- economic development
- protection of the environment.

Energy is part of many environmental problems, including climate change, and must be part of the solution. Focus must be placed on Energy Efficiency and Energy Conservation and there must be a deepened focus on Renewable Energy applications in Agriculture. There must be a concerted shift to sustainable Agriculture. The manner in which energy for Agriculture is produced and consumed is crucial to the sustainable development of the Caribbean region. Renewable Energy technologies must be employed in Agriculture as a matter of urgency. IEA study suggests that renewable energy alone has the potential to contribute 21% of the reductions in energy-related CO_2 emissions necessary to maintain levels in the atmosphere of no higher than 450 parts per million (ppm) [15], as targeted by the Inter-Governmental Panel on Climate Change (IPCC).

The New Green Revolution must also incorporate the Green Economy Initiative (GEI) which seeks to bring awareness to innovative responses to investment in energy efficiency and low-carbon technology. Greening of the economy with reference to Agriculture means reconfiguring the infrastructure necessary to deliver better returns on capital investments, while reducing greenhouse gas emissions in its operations.

GEI is designed to assist governments in greening of their economies by reshaping and refocusing policies, investments and spending towards a range of sectors, including sustainable agriculture and forests. This can generate a demand for workers at all skill levels thereby reducing unemployment, causing a reduction in poverty, enhancing of tourism activities, stimulating growth in the economy and protecting the environment from the devastating effects of climate change. The end result is the stimulation of growth in sustainable Agriculture.

3. CONCLUSION

Caribbean Agriculture has been on the decline for decades. Increasing importation has been a direct result of the inability to produce in a sustainable manner. With exports on the decline, economic growth in agriculture is stunted. However, together with adequate government policies and fiscal incentives, innovative technological advances can have a significant impact and can further stimulate growth to the extent that Agriculture can become economically viable and impact positively on export earnings. These measures form the "New Green Revolution" where renewable energy is the base for energy generation and utilization within the agricultural sector. The Caribbean region is therefore poised to undergo a "New Green Revolution" in the next two decades through the use of renewable energy technologies.

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Renewable Global Status Report 2012

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Abstract:

The *Renewables Global Status Report* (GSR) is the industry standard of reports of its kind. In just six years, the GSR has become the most frequently referenced report on renewable energy business and policy, serving a wide range of audiences from investors and government decision makers to students, project developers, researchers, and industrial manufacturers.

Over the years, the GSR has expanded in scope and depth, in parallel with tremendous advances in renewable energy markets and industries. The report has become a major production that involves the amalgamation of thousands of data points, hundreds of reports and other documents, and personal communications with experts from around the world.

The report is a true collaborative effort among several authors, REN21 Secretariat staff and Steering Committee members, regional research partners, and more than 100 individual contributors and reviewers. The REN21 GSR provides nowadays a unique overview of the status of renewable energy worldwide, covering markets, investments, industries, policies and rural (off-grid) renewable energy in developing countries.

Keywords: Renewable Energy, Industry, Policy Landscape, Investments, Rural Energy

Introduction

Renewable energy markets and policy frameworks have evolved rapidly in recent years. This report provides a comprehensive and timely overview of renewable energy market, industry, investment, and policy developments worldwide. It relies on the most recent data available, provided by a network of nearly 400 contributors and researchers from around the world, all of which is brought together by a multi-disciplinary authoring team. The report covers recent developments, current status, and key trends; by design, it does not provide analysis or forecast the future.

Renewable Energy Growth in All End-Use Sectors

Renewable energy supplied an estimated 16.7% of global final energy consumption in 2010. During 2011, renewables continued to grow strongly in all end-use sectors: power, heating and cooling, and transport.

In the power sector, renewables accounted for almost half of the estimated 207 gigawatts (GW) of electric capacity added globally during the year. Wind and solar photovoltaic (PV) accounted for about 40% and 30% of new renewable capacity, respectively, followed by hydropower (nearly 25%). By the end of 2011, total renewable power capacity worldwide reached an estimated 1,360 GW, up 8% over 2010; renewables comprised more than 25% of total global power-generating capacity (estimated at 5,360 GW in 2011) and supplied an estimated 20.3 %]% of global electricity. Non-hydropower renewables reached a total of approximately 390 GW, a 24% increase over 2010.

The heating and sector offers an immense yet untapped potential for renewable energy deployment. Heat from biomass, solar and geothermal sources already represents a significant portion of the energy derived from renewables and the sector is slowly evolving as countries (particularly in the European Union) are starting to enact supporting policies and to track the share of heat derived from renewable sources. Trends in the heating (and cooling) sector include an increase in system size, expanding use of combined heat and power (CHP), the feeding of renewable heat and cool into district heat networks, and the use of renewable heat for industrial purposes.

Renewable energy is used in the transport sector in the form of gaseous and liquid biofuels; liquid biofuels provided about 3% of global road transport fuels in 2011, more than any other renewable energy source in the transport sector. Electricity powers trains, subways, and a small but growing number of passenger cars and motorised cycles, and there are limited but increasing initiatives to link electric transport with renewable energy.

Solar PV grew the fastest of all renewable technologies during the period from end-2006 through 2011, with operating capacity increasing by an average of 58% annually, followed by concentrating solar thermal power (CSP), which increased almost 37% from a small base, and wind power (26%). Demand is also growing rapidly for solar thermal heat systems, geothermal ground-source heat pumps, and some solid biomass fuels, such as wood pellets. The development of liquid biofuels has been mixed in recent years, with biodiesel production expanding in 2011 and ethanol production down slightly compared with 2010. Hydropower and geothermal power are growing globally at rates of 2–3% per year. In several countries, however, the growth in these and other renewable technologies far exceeds the global average.

In several countries, renewables represent a rapidly growing share of total energy supply:

- In the European Union, renewables accounted for more than 71% of total electric capacity additions in 2011, bringing renewable energy's share of total electric capacity to 31.1%. Solar PV alone represented nearly half (46.7%) of new capacity that came into operation. The renewable share of consumption is rising in parallel (although not as rapidly since much of the capacity is variable solar and wind). In 2010 (latest available data), the share of total electricity consumption was 19.8% (up from 18.2% in 2009), and renewables represented 12.4% of gross final energy consumption (compared to 11.5% in 2009).
- Germany continues to lead in Europe and to be in the forefront globally, remaining among the top users of many renewable technologies for power, heating, and transport. In 2011, renewables provided 12.2% of Germany's final energy consumption, 20% of electricity consumption (up from 11.6% in 2006), 10.4% of heating demand (up from 6.2%), and 5.6% of transport fuel (excluding air traffic).
- In the United States, non-hydropower renewable generation has increased at an average annual rate of almost 13% over the past three years. Nine states generated more than 10% of their electricity with non-hydro renewables in 2011, up from two states a decade ago. All renewables accounted for about 11.8% of U.S. primary energy production in 2011, up from 10.9% in 2010.
- China ended 2011 with more renewable power capacity than any other nation, with an estimated 282 GW; one-quarter of this total (70 GW) was non-hydro. Of the 90 GW of electric capacity newly installed during the year, renewables accounted for more than one third, and non-hydro renewables were more than one fifth.
- Several countries and states met higher shares of their electricity demand with wind power in 2011 than in 2010, including Denmark (nearly 26%), Spain (15.9%), and Portugal (15.6%); four German states met more than 46% of their electricity needs with wind; the state of South Australia generated 20% of its demand from wind; and the U.S. states of South Dakota and Iowa produced 22% and 19% of their power from wind, respectively.

The top seven countries for renewable non-hydro electric capacity—China, the United States, Germany, Spain, Italy, India, and Japan—accounted for about 70% of total capacity worldwide. The ranking was quite different on a per-person basis, with Germany in the lead followed by Spain, Italy, the United States, Japan, China, and India. By region, the EU was home to nearly 37% of global non-hydro renewable capacity at the end of 2011, and the BRICS[13] nations accounted for almost 26%; their share has been increasing in recent years, but virtually all of this capacity is in China, India, and Brazil.

Even so, renewable technologies are expanding into new markets. In 2011, around 50 countries installed wind power capacity, and solar PV capacity is moving rapidly into new regions and countries. Interest in geothermal power has taken hold in East Africa's Rift Valley and elsewhere, and solar hot water collectors are used by more than 200 million households, as well as in many public and commercial buildings the world over. Interest in solar heating and cooling is on the rise in countries around the world, and the use of modern biomass for energy purposes is expanding in all regions of the globe.

Across most technologies, renewable energy industries saw continued growth in equipment manufacturing, sales, and installation during 2011. Solar PV and onshore wind power experienced dramatic price reductions resulting from declining costs due to economies of scale and technology advances, but also due to reductions or uncertainties in policy support. At the same time, some renewable energy industries—particularly solar PV manufacturing—have been challenged by falling prices, declining policy support, the international financial crisis, and tensions in international trade. Continuing economic challenges (especially in traditional renewable energy markets) and changing policy environments in many countries contributed to some industry uncertainties or negative outlooks, and by the end of 2011, there was a noticeable slowdown in the number of new projects.

[13] Brazil, Russia, India, China, and South Africa

SELECTED INDICATORS		2009	→	2010	→	2011
Investment in new renewable capacity (annual)[1]	billion USD	161	→	220	→	257
Renewable power capacity (total, not including hydro)	GW	250	→	315	→	395
Renewable power capacity (total, including hydro)[2]	GW	1,170	→	1,260	→	1,360
Hydropower capacity (total)[2]	GW	915	→	945	→	970
Solar PV capacity (total)	GW	23	→	40	→	> 69
Concentrating solar thermal power (total)	GW	0.7	→	1.3	→	1.8
Wind power capacity (total)	GW	159	→	198	→	238
Solar hot water/heat capacity (total)[3]	GWth	153	→	182	→	232
Ethanol production (annual)	billion liters	73.1	→	86.5	→	86.1
Biodiesel production (annual)	billion liters	17.8	→	18.5	→	21.4
Countries with policy targets	#	89	→	96	→	112
States/provinces/countries with feed-in policies[4]	#	82	→	86	→	92
States/provinces/countries with RPS/quota policies[4]	#	69	→	72	→	74
States/provinces/countries with biofuels mandates[5]	#	57	→	71	→	73

Note: Numbers are rounded. Renewable power capacity including hydropower is rounded to nearest 10 GW; renewable capacity not including hydropower, and hydropower capacity data are rounded to nearest 5 GW; other capacity numbers are rounded to nearest 1 GW except for very small numbers and biofuels, which are rounded to one decimal point.

1 Investment data are from Bloomberg New Energy Finance and include all biomass, geothermal, and wind power projects of more than 1 MW, all hydropower projects of 0.5-50 MW, all solar power projects of more than 0.3 MW, all ocean energy projects, and all biofuel projects with an annual capacity of 1 million litres or more.

2 Hydropower data and, therefore, also renewable power capacity including hydro, are lower relative to past editions of the GSR due to the fact that pure pumped storage capacity is no longer included with the hydropower data. For more information see Note on Reporting and Accounting on page X.

3 Solar heat data include glazed capacity but not capacity of unglazed systems for swimming pool heating.

4 Feed-in and RPS/quota policy totals for 2011 also include early 2012.

5 Biofuel policies for 2010 and 2011 include policies listed under both the biofuels obligation/mandate column in Table 3, Renewable Energy Support Policies, and those listed in Reference Table R14, National and State/Provincial Biofuel Blend Mandates, whereas data for 2009 and earlier have included only the [former/latter].

Figure 18 Selected Indicators for 2012

A Dynamic Policy Landscape

At least 118 countries, more than half of which are developing countries, had renewable energy targets in place by early 2012, up from the 96 reported in the *Renewables 2011 Global Status Report (GSR 2011)*. Renewable energy targets and support policies continued to be a driving force behind increasing markets for renewable energy, despite some setbacks resulting from a lack of long-term policy certainty and stability in many countries.

The number of official renewable energy targets and policies in place to support investments in renewable energy continued to increase in 2011 and early 2012, but at a slower adoption rate relative to previous years. Several countries undertook significant policy overhauls that have resulted in reduced support; some changes were intended to improve existing instruments and achieve more targeted results as renewable energy technologies mature, while others were part of the trend towards austerity measures.

Renewable power generation policies remain the most common type of support policy; at least 107 countries had some type of renewable power policy by early 2012, up from the 96 countries reported in the *GSR 2011*. Feed-in-tariffs (FIT) and renewable portfolio standards (RPS) are the most commonly used policies in this sector. FIT policies were in place in at least 65 countries and 27 states by early 2012. While a number of new FITs were enacted, most related policy activities involved revisions to existing laws, at times under controversy and involving legal disputes. Quotas or Renewable Portfolio Standards (RPS) were in use in 19 countries and at least 54 other jurisdictions, with two new countries enacting such policies in 2011 and early 2012.

Policies to promote renewable heating and cooling continue to be enacted less aggressively than those in other sectors, but their use has expanded in recent years. By early 2012, at least 19 countries had specific renewable heating/cooling targets in place and at least 17 countries and states had obligations/mandates to promote renewable heat. Numerous local governments also support renewable heating systems through building codes and other measures. The focus of this sector is still primarily in Europe, but interest is expanding to other regions.

Biofuel blending mandates for transport fuels existed in at least 23 countries at the national level and in 26 states and provinces by early 2012, with three countries enacting new mandates during 2011 and at least six increasing existing mandates. Transport fuel-tax exemptions and biofuel production subsidies also existed in at least 19 countries. At the same time, Brazil’s mandated ethanol blend level was reduced, partly in response to low sugarcane yields, while long-term ethanol support policies in the United States were allowed to expire at year's end.

Thousands of cities and local governments around the world also have active policies, plans, or targets for renewable energy and climate mitigation. Almost two-thirds of the world’s largest cities had adopted climate change action plans by the end of 2011, with more than half of them planning to increase their uptake of renewable energy. Many of the institutions encouraging co-operation among cities in local renewable energy deployment saw increased membership and activities in 2011, including the *EU Covenant of Mayors* (with over 3,000 member cities). Most activity has occurred in North American and European cities, although 100 demonstration cities exist in China, and cities in Argentina, Australia, Brazil, India, Mexico, South Africa, South Korea, and elsewhere undertook initiatives to support renewable energy deployment in 2011.

Policymakers are increasingly aware of renewable energy’s wide range of benefits—including energy security, reduced import dependency, reduction of greenhouse gas (GHG) emissions, prevention of biodiversity loss, improved health, job creation, rural development, and energy access—leading to closer integration in some countries of renewable energy with policies in other economic sectors. Globally there are more than 5 million jobs in renewable energy industries, and the potential for job creation continues to be a main driver for renewable energy policies. During 2011, policy development and implementation were also stimulated in some countries by the Fukushima nuclear catastrophe in Japan and by the UN Secretary-General's announced goal to double the share of renewables in the energy mix by 2030.

There has been little systematic linking of energy efficiency and renewable energy in the policy arena to date, but countries are beginning to wake up to the importance of tapping their potential synergies. Efficiency and renewables can be considered the "twin pillars" of a sustainable energy future, with renewables reducing the emissions of pollutants per unit of energy produced, and energy efficiency improvements reducing energy consumption altogether. Improving the efficiency of energy services is advantageous irrespective of the primary energy source, but there is a special synergy between energy efficiency and renewable energy sources. In the EU, the United States, and elsewhere, countries are beginning to link the two through targets and policies; at the global level, the UN Secretary-General's initiative on Sustainable Energy for All highlights the interlinkages among energy access, energy efficiency improvements, and renewable energy deployment. Policies have also begun to address the efficiency of renewable energy systems themselves.

Investment Trends

Global new investment in renewables rose 17% to a record USD 257 billion in 2011. This was more than six times the figure for 2004 and almost twice the total investment in 2007, the last year before the acute phase of the recent global financial crisis. This increase took place at a time when the cost of renewable power equipment was falling rapidly and when there was uncertainty over economic growth and policy priorities in developed countries. Including large hydropower, net investment in renewable power capacity was some USD 40 billion higher than net investment in fossil fuel capacity.

One of the highlights of 2011 was the **strong** performance of solar power, which blew past wind power, the biggest single sector for investment in recent years. Another highlight was the performance of the United States, where investment increased by 57% relative to 2010, mainly as the result of developers rushing to take advantage of federal incentive programmes that were coming to an end.

The top five countries for total investment were China, which led the world for the third year running, followed by the United States, Germany, Italy, and India. India displayed the fastest expansion in investment of any large renewables market in the world, with 62% growth. Developing countries saw their relative share of total global investment slip back after several years of consistent increases; developing countries accounted for USD 117 billion of new investment in 2011, compared with USD 140 billion in developed countries.

Rural Renewable Energy: Special Focus

Significant technological innovation and cost reductions of renewable energy technologies, along with improved business and financing models, are increasingly creating clean and affordable renewable energy solutions for individuals and communities in developing countries. For a majority of very remote and dispersed users, decentralised off-grid renewable electricity is less expensive than extending the power grid. At the same time, developing countries have begun deploying more and more grid-connected renewable capacity, which is in turn expanding markets and further reducing prices, potentially improving the outlook for rural renewable energy developments.

Rural renewable energy markets in developing countries differ significantly across regions: for example, Africa has by far the lowest rates of access to modern energy services, while Asia presents significant gaps among countries, and Latin America's rate of electrification is quite high. In addition, there exists a large number of active players in this sector, and participants differ from one region to the next. The rural renewable energy market is highly dynamic and constantly evolving; it is also challenged by the lack of structured frameworks and of consolidated data sets.

In addition to a focus on technologies and systems, most developing countries have started to identify and implement programmes and policies to improve the ongoing operational structures governing rural energy markets. Most countries are developing targets for electrification that include renewable off-grid options and/or renewably powered mini-grids; there is also some use of grid-connected renewable electricity. In the rural cooking and heating market, advanced cookstoves fueled by renewable sources are gaining impetus as reliable and sustainable alternatives to traditional biomass cookstoves. Such developments are increasing the attractiveness of rural energy markets and developing economies for potential investors.

After many years of relatively slow political, technical, financial, industrial, and related developments, the impressive deployment of all renewable energy technologies and the reduction of the cost represent an important opportunity that points to a brighter future. However, further efforts will be necessary to reach the outlined objectives: the International Energy Agency estimates that annual investment in the rural energy sector needs to increase more than fivefold to provide universal access to modern energy by 2030.

2011 Market and Industry Highlights and Ongoing Trends

WIND POWER. Wind power capacity increased by 20% in 2011 to approximately 238 GW by year-end, seeing the greatest capacity additions of any renewable technology. As in 2010, more new capacity was added in developing countries and emerging markets than in OECD countries. China accounted for almost 44% of the global market (adding slightly less capacity than it did in 2010), followed by the United States and India; Germany remained the largest market in Europe. Although its market share remained relatively small, the offshore wind sector continued to expand, with the use of larger turbines and movement into deeper water, farther from shore. The trend towards increasing the size of individual wind projects and larger wind turbines continued; at the same time, the use of small-scale turbines is increasing, and interest in community wind power projects is on the rise in several countries.

SOLAR PHOTOVOLTAIC (PV). Solar PV saw another year of extraordinary market growth. An estimated 30 GW of operating capacity was added, increasing total global capacity by 74% to more than 69 GW. The trend towards very large-scale ground-mounted systems continued, while rooftop and small-scale systems continued to play an important role. For the first time ever, solar PV accounted for more capacity additions in the EU than any other technology. While the EU again dominated the global market, led by Italy and Germany, markets expanded in other regions, and China has rapidly emerged as the dominant player in Asia. Although 2011 was a good year for consumers and installers, manufacturers struggled to make profits or even survive amidst excess inventory and falling prices, declining government support, slower market growth for much of the year, and significant industry consolidation. Module manufacturing continued its marked shift to Asia, mainly at the expense of European firms.

BIOMASS FOR HEAT, POWER, AND TRANSPORT. The growing use of biomass for heat, electricity, and transport fuels has resulted in increasing international trade in biomass fuels in recent years; wood pellets, biodiesel, and ethanol are the main fuels traded internationally. Biomass, in the form of both solid and gaseous fuels, continues to provide the majority of heating produced with renewable energy sources. Markets are expanding rapidly in Europe in particular, where biomass use in district heat systems rose more than 23% in 2010 (latest available data). An increasing trend, also taking place largely in Europe, is the use of biomethane (purified biogas) that can be injected directly into the natural gas network and used to produce heat and power and to fuel vehicles. Biogas produced from domestic-scale digesters is used increasingly for cooking, and to a smaller extent for heating and lighting, in China, India, and elsewhere.

Biomass power capacity increased from about 66 GW in 2010 to more than 71 GW at the end of 2011. The United States leads the world in biomass-based power generation, with other significant producers in the EU in addition to Brazil, China, India, and Japan. Most sugar-producing countries in Africa generate power and heat with bagasse-based CHP plants. Improvements in the logistics of biomass collection, transport, and storage over the past decade, and growing international trade (particularly in pellets), have helped to remove constraints on plant size, and the size of facilities in some countries is increasing as a result.

Ethanol and biodiesel are the primary renewable fuels in the transport sector. During 2011, ethanol production declined slightly for the first time in more than a decade, but biodiesel production continued to rise globally. Several airlines began to operate commercial flights using various biofuels blends, and interest in advanced biofuels continued to increase, although production levels remain relatively low. Limited but growing quantities of gaseous biofuels (mainly biomethane) are fuelling trains, buses, and other vehicles, particularly in Europe.

CONCENTRATING SOLAR THERMAL POWER (CSP). More than 450 megawatts (MW) of CSP was installed in 2011, bringing global capacity to almost 1,760 MW. Spain accounted for the vast majority of capacity additions, while several developing countries launched their first CSP plants, and industry activity expanded its attention from Spain and the United States to new regions. Parabolic trough plants continued to dominate the market, but new central receiver and Fresnel plants were commissioned during 2011 and others were under construction. Although CSP faced challenges associated with rapidly falling PV prices and the Arab Spring, which slowed development in the Middle East-North Africa region, significant capacity was under construction by year's end.

SOLAR THERMAL HEATING AND COOLING. Solar heating capacity increased by an estimated 27% in 2011 to reach approximately 232 GW_{th}, excluding unglazed swimming pool heating. China again led the world for solar thermal installations, with Europe a distant second. Most solar thermal is used for water heating, but solar space heating and cooling are gaining ground, particularly in Europe. The year 2011 was difficult for parts of the solar thermal industry due to the economic situation in northern Mediterranean countries and the general negative outlook across much of Europe. China remained dominant in the global solar heating industry, a position that it has held for several years, and export of Chinese products has increased considerably in recent years.

GEOTHERMAL HEAT AND POWER. Geothermal energy provided an estimated 205 TWh (736 PJ) in 2011, one-third in the form of electricity (with an estimated 11.2 GW of capacity) and the remaining two-thirds in the form of heat. At least 78 countries used direct geothermal energy in 2011. Most of the growth in direct use was associated with ground-source heat pumps (GHP), which can provide heating and cooling and have experienced growth rates averaging 20% annually. Geothermal electricity saw only modest expansion in 2011, but the rate of deployment is expected to accelerate with the movement into new markets in East Africa and elsewhere. While expansion in the geothermal power industry is hampered by high risk inherent in the development of new resources and lack of awareness, geothermal power is advancing due to the development of new technologies, such as binary-cycle plants and hydraulic enhancement (EGS), which are expanding the range of producible resources and improving the economy of existing plants.

HYDROPOWER. An estimated 25 GW of new capacity came on line in 2011, increasing global installed capacity by nearly 2.7% to approximately 970 GW. Hydropower continues to generate more electricity than any other renewable resource, with an estimated 4,300 TWh produced during 2011. Asia was the most active region for new projects, while more mature markets focused on retrofits of existing facilities for improved output and efficiency. Hydropower is increasingly providing balancing services through expansion of pumped storage capacity, in part to accommodate the increased use of variable solar and wind resources. Companies reported increased sales in 2011, and large manufacturers have been investing in new plants and acquiring smaller firms to address billions of dollars in backlogs.

OCEAN ENERGY. After years that saw development of only small pilot projects, global ocean power capacity almost doubled in 2011. The launch of a 254 MW tidal power plant in South Korea and a 0.3 MW wave energy plant in Spain brought total global capacity to 522 MW. A number of additional projects—small pilot-scale, and utility-scale—were under development in 2011, designed to test and demonstrate various technologies for full commercial applications in the near future. Continued investment and strategic partnerships are coalescing around several key wave and tidal technologies that look poised for deployment on a large scale in coming years.

ANNUAL ADDITIONS/PRODUCTION IN 2011

	New capacity investment	Hydropower capacity	Solar PV new operating capacity	Wind power capacity	Solar hot water/heat capacity[1]	Biodiesel production	Ethanol production
1	China	China	Italy	China	China	United States	United States
2	United States	Vietnam	Germany	United States	Turkey	Germany	Brazil
3	Germany	Brazil	China	India	Germany	Argentina	China
4	Italy	India	United States	Germany	India	Brazil	Canada
5	India	Canada	France	UK/ Canada	Italy	France	France

TOTAL CAPACITY AS OF END-2011

	Renewable power capacity (not including hydro)	Renewable power capa-city (inclu-ding hydro)	Biomass power capacity	Geothermal power capacity	Hydropower capacity	Solar PV capacity	Solar PV capacity per capita
1	China	China	United States	United States	China	Germany	Germany
2	United States	United States	Brazil	Philippines	Brazil	Italy	Italy
3	Germany	Brazil	Germany	Indonesia	United States	Japan	Czech Republic
4	Spain	Canada	China	Mexico	Canada	Spain	Belgium
5	Italy	Germany	Sweden	Italy	Russia	United States	Spain

		Wind power capacity	Renewable power capacity per capita (not including hydropower)[2]	Solar hot water/heat capacity[1]	Solar hot water/heat capacity per capita[1]	Geothermal heat installed capacity	Geothermal direct heat use[3]
1		China	Germany	China	Cyprus	United States	China
2		United States	Spain	Turkey	Israel	China	United States
3		Germany	Italy	Germany	Austria	Sweden	Sweden
4		Spain	United States	Japan	Barbados	Germany	Turkey
5		India	Japan	Brazil	Greece	Japan	Japan

Note: Rankings are based on absolute amounts of investment, power generation capacity or biofuels production; per capita rankings would be quite different for many categories (as seen with per capita rankings for solar PV, renewable power, and solar hot water/heat capacity). Country rankings for hydropower would be different if power generation (TWh) were considered rather than power capacity (GW) because some countries rely on hydropower for baseload supply while others use it more to follow the electric load and match peaks.

1 Solar hot water/heating rankings are for 2010. Based on capacity of glazed systems (excluding unglazed systems for swimming pool heating).

2 Per capita renewable power capacity ranking considers only those countries that rank among the top seven for total installed capacity, not including hydro.

3 In some countries, ground-source heat pumps make up a significant share of geothermal direct use capacity; the share of heat use is lower than the share of capacity for heat pumps because they have a relatively low capacity factor. Rankings are based on 2010 data.

Figure 19 Top 5 Countries

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See GSR 2012 Footnotes

Promoting Renewable Electricity Generation in Developing Countries – Findings from Comparative Analyses in South America

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Abstract:

Access to electrical energy has a key role with regards to socio-economic development and poverty alleviation in particular. Local generation and use of renewable energy offer significant potential for local economic development as well as different environmental benefits. However, in many regions, the lack of electrification is a major impediment to economic development. Even though most of the South American countries have specific and defined strategies as well as plans to improve renewable energy generation, actual implementation is threatened by a wide range of legislative, financial, political and technological problems.

This paper presents the key findings of a study carried out as part of the Renewable Electricity Generation in South America (REGSA) project, which comprises comparative analyses of the legislative and institutional frameworks as well as the technical and socio-economic potential of electrical power generation by means of renewable energy in South America and in particular Bolivia, Brazil and Chile. In addition, the paper analyses the results of a mapping of best-practice renewable electricity generation projects in South America and the EU. Finally, it will conclude with some suggestions for fostering renewable electricity generation in developing countries.

Keywords: Developing Countries, Latin America, Renewable Energy, Electricity Generation

1. The REGSA project

A well-established energy infrastructure that reliably supplies the population with electricity is an indispensable element in the process of socio-economic advancement in developing countries. Many South American countries, however, suffer a considerable lack of energy infrastructure. In addition to their different environmental benefits, renewable energy (RE) offers meaningful potential for improvement of energy supply and security in South America as well as poverty alleviation. Particularly rural and difficult-to-access regions can benefit from the implementation of RE with regard to the independent nature of RE generation.

The Renewable Electricity Generation in South America (REGSA) project is a technology and knowledge transfer project funded by the European Union. The project's overall objective is to promote renewable electricity generation in South America and contribute to increasing RE utilisation in Bolivia, Brazil and Chile.

In order to achieve good and sustainable results through technology and knowledge transfer in the field of RE between the REGSA partners, it is first essential to investigate the current situation and to explore existing structures. Within the framework of the work package 2 (WP2) of REGSA a survey was conducted with the objective of a comparative analysis of political and institutional frameworks for RE development and the status quo analysis of RE generation in South America.

1.2. Related literature

Studies that analysed the situation of RE policy making and the use of REs in South America have been conducted at different times in the past. Subsequently some examples of international studies that are thematically similar to the one presented in this paper are given.

In 1999 the GTZ published the first edition of the TERNA country survey conducted on behalf of the German Federal Ministry for Economic Cooperation and Development. Since then, three updated editions have been published – in 2002, 2004 and 2009. In the revised versions new country surveys were added and previous ones were updated. The survey sampled developing and emerging countries in Latin America, Africa, the Middle East and Asia. The survey aims to provide information that helps interested players to access new RE markets. It puts together detailed information about the framework and policy conditions in the surveyed countries as well as about the current RE situation (Posorski R. and Werner D. 2009).

In 2004 the GTZ published a paper in cooperation with the United Nations Economic Commission for Latin America and the Caribbean (ECLAC), focusing on the current status of RE in Latin America and the Caribbean with regard to policy making and baseline conditions. After presenting a background review of past efforts to promote REs in the region, it divides the area into six subregions comprising several neighbouring countries. The subregions are analysed with regard to the current state of renewables in the region. Moreover obstacles and opportunities for the penetration of

REs and RE policy making are described. The paper points out the importance of the sustainability of RE production. This remark relates to the fact that the intensive use of hydroelectric power and power from biomass in some countries is practised without considering the negative environmental and social effects it generates. Finally, the need for improved cooperation between important governmental, non-governmental and private organisations and institutions is expressed (GTZ and ECLAC 2004).

The global energy network institute published a paper on the RE potential in Latin America in 2009. It aims to give an overview of the RE potential in every Latin American country and thus contribute to RE development in general, the reduction of greenhouse gases and their consequences. Every country was analysed individually for its solar power, wind power, hydro power, geothermal power and biomass potential. The paper provides a multitude of maps illustrating the potential distribution of these RE sources in the different countries. One of the main outcomes was that the big share that REs have in energy generation in Latin America is somewhat misleading because it almost entirely comprises hydro energy and biofuels. For a number of reasons the authors doubt the adequacy of the large-scale use of these RE sources. At the same time they see big potential for the expansion of the other ones (Meisen P. and Krumpel S. 2009).

In 2011 the MIT Center for Energy and Environmental Policy Research published a paper on support schemes for REs in South America. Initially it describes the South American perspective on REs from the security-of-supply point of view as well as from the economic point of view. It then reviews the RE support schemes that have been, are and could be developed in South America and names the most important support schemes, laws and stakeholders in each of the ten surveyed countries. It identifies long-term energy auctions as the main instrument for RE promotion in South America and leaves the question open if the increasing efforts to implement REs into the energy mix will be successful (Batlle C. and Barroso L.A. 2011).

In 2011 the UNEP's Technology Needs Assessment project presented the first edition of a new series called Technology Transfer Perspectives. This first edition investigates the possibilities for diffusing REs on the basis of a number of case studies of enabling frameworks in developing countries. Sample regions include South America. The report objective is to "provide insights for governments on how to reform their policies and institutions so as to provide clear and stable incentives that promote diffusion of climate-friendly technologies". The report is divided into two parts: enabling frameworks addressing specific technologies and enabling frameworks addressing multiple technologies. One major finding is that there is no "one" solution for the successful transfer and diffusion of technology. This obstacle is addressed by specifying appropriate policies and actions individually for each surveyed country (Haselip J. et al. 2011).

Within the framework of the work package 2 (WP2) of the REGSA project, this new survey was conducted with the objective of a comparative analysis of political and institutional frameworks for RE development and the status quo analysis of RE generation in South America.

2. South American energy markets

Figure 1 shows a map of South America.

Figure 1 Map of South America (http://www.world-atlas.us)

The majority of all the countries that were researched for this survey display a similar energy market model. Table 1 shows the market designs and methods of electricity pricing by country.

Table 1 Market designs, methods of electricity pricing and existence of capacity payments in the surveyed countries.

	Argentina	Bolivia	Brazil	Chile	Colombia	Ecuador	Paraguay	Peru	Uruguay	Venezuela
Market model	Pool financial BC	Pool financial BC	Pool financial BC	Pool financial BC	Pool(PX) financial BC	Pool financial BC	Monopoly	Pool financial BC	Pool financial BC	Monopoly
Wholesale market operation spot price	Marginal cost hourly	Marginal cost hourly	Marginal cost hourly	Marginal cost hourly	Power exchange price hourly	Marginal cost hourly		Marginal cost hourly	Marginal cost hourly	
Capacity payment				Yes	Yes	Yes		yes		

The by far dominating energy market model is that of a pool marked with bidding competitions. In this case electricity generators obtain capacity rights in competitive auctions held by public utilities. These markets are wholesale-operated, meaning that the wholesale price (the marginal cost) is set by the generators hourly (Lennard, J. 2003). This market model is presented by Argentina, Bolivia, Brazil, Chile, Ecuador, Peru and Uruguay. In the Colombian energy market, on the other hand, electricity is not sold at the hourly marginal cost but at the hourly power exchange price. Retailers act as intermediaries who buy and sell electricity at spot markets where energy is being traded and the power exchange price is set hourly. Consumers buy electrical energy from those retailers and can choose the cheapest one (Posorski R. and Werner D. 2009).

Chile, Colombia, Ecuador and Peru present capacity payments, i.e. additional costs for energy purchase during peak periods, as an indication for greater energy demand and therefore an incentive for the creation of new capacity (Lennard, J. 2003), (Oren S.S. 2000).

Paraguay and Venezuela are the only two countries surveyed that have kept the integrated model of a public monopoly.

3. Renewable energy support schemes in South America

In the first decade of the 21st century the vast majority of South American countries have come to realise that renewable energies (RE) are an inevitable part of their future energy supply (Batlle C. and Barroso L.A. 2011), (Haselip J. et al. 2011). Initiatives to promote RE generation emerged in a variety of forms on national and local levels. Fiscal and tax incentives, soft loans and RE funds are moderate ways to support the implantation of REs and can be found in many countries. However, a number of countries have also introduced more impelling measures. Energy contract auctions, tenders, renewable portfolio standards and capacity payments have become an important and in some countries *the* major instrument for RE market stimulation (Batlle C. and Barroso L.A. 2011), (Haselip J. et al. 2011).
Subsequently, the main steps in the implementation of RE in each country surveyed are described.

In **Argentina** in 2007 the secretary of energy passed the 26 190 law, which aims to increase the percentage of renewable energy sources in power supply to at least 8% by 2016. To reach that target the Ministry of Federal Planning, Public Investments and Services (Ministerio de Planificación Federal, Inversión Pública y Servicios) initiated a programme for the generation of RE (RENGEN) in 2010 (Posorski R. and Werner D. 2009), (IEA 2010). The system operator CAMMESA (Compañía Administradora del Mercado Mayorista Eléctrico S.A.) and the public service corporation ENARSA play an important role in this plan, as they hold energy contract auctions and guarantee energy purchase (Batlle C. and Barroso L.A. 2011).

In 2007 **Bolivia** passed a national development plan (Plan Nacional de Desarrollo) in which the government commits itself to the complete electrification of Bolivia by 2025. To achieve that goal, the governmental programme, Electricity for Living with Dignity (Electricidad Para Vivir con Dignidad), among other efforts was initiated and coordinated by the Vice Ministry of Electricity and Alternative Energies. This programme also promotes the use of REs. For example, the biggest project within the programme, the Decentralized Infrastructure for Rural Transformation (Infraestructura descentralizada para la transformación rural – IDTR), has a budget of $15 million that exclusively promotes the implementation of solar home systems for rural electrification (Rutschman I. 2010).

In 2002 **Brazil** introduced a feed-in programme for wind and biomass energy called the PROINFA (Programa de Incentivo às Fontes Alternativas de Energia Elétrica) programme (Batlle C. and Barroso L.A. 2011). Prior to that the Brazilian government enacted the 10438 law, which was responsible for the start of PROINFA (IEA 2002), however was not specific to RE development. It was connected to energy purchasing contracts with the state-owned company Eletrobras but was criticised for a lack of efficiency. In 2007 a second initiative to foster REs was launched by implementing a reduction of cost for transmission and distribution tariffs beneficial to the consumer and

subsidised by the government (Batlle C. and Barroso L.A. 2011). Today the energy contract auctions have become the major instrument for general market expansion and RE market stimulation in Brazil. Pre-investment appraisal subsidies and tax incentives are also present in Brazil.
The production of electricity through hydroelectric power plants covers the majority of Brazil's electricity demand and is treated preferentially compared to the other RE resources. Therefore it must be viewed separately from them.

In 2008 **Chile** passed the 20.257 law, which aims to increase the RE share in energy production to 5% by 2010 and 10% by 2024 (Wright S. and Adlerstein-Gonzalez S. 2009). Generators that do not fulfil this obligation by the prescribed time will be fined US$28/MWh and US$42/MWh after a three-year violation period. With not enough RE projects in sight it has become questionable if the renewable portfolio standard will be successful. Energy providers have asked for alternative solutions such as a feed-in tariff (Batlle C. and Barroso L.A. 2011).

In 1995 **Colombia** created a national development plan for alternative energies (Plan de Desarrollo Nacional de las Energías Alternativas), which makes suggestions for strengthening RE sources. However, this proved to be nothing more than lip service, as no action was taken in the years to follow (Projekt-Consult GmbH and Loy D. 2007). In 2001 the Colombian government created a framework for the promotion of renewable energies with the passing of the 697 law. This law was designed for developing the Program of Rational and Efficient Use of Energy and Other Forms of Non-Conventional Energy, PROURE (Programa De Uso Racional y Eficiente de Energía y Fuentes no Convencionales). Since then the promotion of RE has emerged in the form of tax incentives. PROURE is supervised and led by the Ministry of Mines and Energy (Projekt-Consult GmbH and Loy D. 2007). In 2010 the 180919 resolution was issued and follows an action plan to further develop PROURE from 2010 to 2015 (Mojica K. Y. C. 2011).

In 2000 **Ecuador** introduced a feed-in tariff for photovoltaic energy generation. However, the Ecuadorian government has never fulfilled its duty of payment, which it imposed upon itself. Minor efforts to promote PV technology were made in 2003 and 2006 by setting up a few hundred isolated systems. The rural electrification project for Amazonian homes (Perva) presently aims to electrify 15,000 households with PV systems until 2013 (Batlle C. and Barroso L.A. 2011). In 2011 the administrative institution, CONELEC (Consejo Nacional de Electricidad), passed the regulation, CONELEC 004/11, which introduces a feed-in tariff for the next fifteen years regarding energy generation from wind, sunlight, water, biomass and geothermal sources (Gipe P. 2011). However, due to the recent regulation passed by president Correa that enables the state to fully regain control of the countries electric system, private investments are expected to be held back significantly (Batlle C. and Barroso L.A. 2011).

In **Paraguay** 99% of the generation capacity is hydroelectric. No incentives for the development of other REs exist and no initiatives are presented (Batlle C. and Barroso L.A. 2011).

In 2005 **Peru** passed the law of promotion and use of non-conventional energy recourses in rural, isolated and frontier zones of the country, law no. 28546 (Peru 2005). A regulation with force of law was passed in 2008 proclaiming the fostering of REs a matter of national interest and exigency. This regulation, called the 1002 decree, promotes wind, solar, geothermal, hydroelectric and biomass power generation. Hydroelectric power is only considered an RE source if it comes from power plants of 20 MW installed capacity or less. It furthermore specifies that the Ministry of Energy and Mines must define a target percentage of the share of RE in the national electricity consumption every five years. For the first five-year period this percentage was set to 5% (SNMPE 2011). To achieve these goals the country has now introduced energy contract auctions in order to stimulate RE investment.

In 2005 **Uruguay's** Ministry of Energy and Mines and the national energy supplier UTE (Administración Nacional de Usinas y Trasmisiones Eléctricas) took their first step in integrating REs into their energy mix by enacting the 389/005 decree. It allowed UTE to call for tenders for RE generation projects. But the limitations were too many and thus only one small wind power project was realised. In 2006 the 77/006 decree was issued where limitations had been reduced but not sufficiently (UNFCCC – CDM – Executive Board 2006). In this manner the policy process continued increasing project sizes, lately attracting wind power projects of up to 150 MW (Batlle C. and Barroso L.A. 2011). In 2009 the 18.585 law was passed, which promotes solar thermal energy. It requires hotels, hospitals, public buildings and new buildings to generate 20% of the energy needed to heat water with solar/thermal power (Epp B. 2010).

In **Venezuela** no initiatives for the development of other REs exist and no incentives are presented. In 2009 the Organic Law of the Electric System and Service (Ley Orgánica del Sistema y Servicio Eléctrico) came into effect. In article 21 the government raises the prospect of a development plan for the national electric power system that will include the use and development of renewable energies. However, a development plan incorporating these targets has yet to be created (Batlle C. and Barroso L.A. 2011), (Venezuela 2010).
The Tables 2, 3 and 4 give a summarised overview of the institutional and legal frameworks in the different countries.

Table 2 Overview of the institutional frameworks in Argentina, Bolivia, Brazil, Chile and Colombia.

	Argentina	Bolivia	Brazil	Chile	Colombia
Policies	Secretaría de Energía (SENER)	Vice Ministry of Electricity and Alternative Energies (Ministry of Hydrocarbons and Energy)	Ministério de Minas e Energia (MME)	Ministerio de Energía	Ministerio de Minas y Energía
Regulator	Ente Nacional Regulador de la Electricidad (ENRE)	Electricity Supervision and the Social Control Authority (AE)	ANEEL	Comisión Nacional de Energía (CNE)	Comisión de Regulación de Energía y Gas (CREG)
Supervisor	ENRE	Electricity Supervision and the Social Control Authority (AE)	ANEEL	Superintendencia de Electricidad y Combustibles (SEC)	La Superintendencia de Servicios Públicos Domiciliarios (SSPD)
System operator	CAMMESA	National Committee for Charge Dispatch (CNDC)	Operador Nacional del Sistema Eléctrico (ONS)	Centro de Despacho Económico de Carga (CDEC)	XM filial de ISA S.A
Planning	Ministerio de Planificación Federal, Inversión Pública y Servicios	Vice Ministry of Energy Development (Ministry of Hydrocarbons and Energy)	Empresa de Investigación Energética (EPE)	Comisión Nacional de Energía (CNE)	Unidad de Planeación Minero Energética (UPME)

Environmental authority	Secretaría de Ambiente y Desarrollo Sustentable (SEMARNAT)	Ministry of the Environment and Water	Ministério do Meio Ambiente	Ministerio del Medio Ambiente y CONAMA	Ministerio del Ambiente, Vivienda y Desarrollo Territorial
RE promotion	Dirección Nacional de Promoción (DNPROM)			Centro de Energías Renovables (CER)	
Conflict solving	ENRE			Panel de Expertos	Superintendencia de Servicios Públicos Residenciales

Table 3 Overview of the institutional frameworks in Ecuador, Paraguay, Peru, Uruguay and Venezuela.

	Ecuador	Paraguay	Peru	Uruguay	Venezuela
Policies	Federal Ministry of Policies/ Ministerio de Electricidad y Energía Renovable (MEyER)	Viceministerio de Minas y Energía	Dirección General de Electricidad	Ministerio de Industria, Energía y Minería	Ministerio del Poder Popular para la Energía Eléctrica (MPPEE)
Regulator	CONELEC	ANDE	Dirección General de Electricidad	Unidad Reguladora de Servicios de Energía y Agua (URSEA)	MPPEE
Supervisor	CONELEC	ANDE y Contraloría General de la República	Organismo Supervisor de la Inversión en Energía (OSINERG)		MPPEE
System operator	CENACE	ANDE	Comité de Operación Económica del Sistema Interconectado Nacional (COES)	Administración del Mercado Eléctrico (ADME)	MPPEE
Planning	CONELEC	ANDE y Secretaría Técnica de Planificación	Ministerio de Energía y Minas	Dirección Nacional de Energía y Tecnología Nuclear (DNETN)	MPPEE
Environmental Authority	Ministerio del Ambiente	Consejo Nacional del Ambiente (CONAM) y	Consejo Nacional del Ambiente	Dirección Nacional de Medio Ambiente	MPPEE y Ministerio del Ambiente

		la Secretaría del Ambiente (SEAM)		(DINAMA)	
RE promotion	MEyER	ANDE	Fondo Nacional del Ambiente (FONAM)	DNETN	Dirección General de Energía Alternativa
Conflict solving					

Table 4 Overview of the legal frameworks in the different countries.

	Argentina	Bolivia	Brazil	Chile	Colombia	Ecuador	Paraguay	Peru	Uruguay	Venezuela
General law	Law 24.065	Electricity law 1604	Law 10 848	General Law of Electric Service (DCL4)	Laws 142 and 143	Law of the Electricity Sector Regime (LRSE, ROS 43)	Law 167/93	Law of electric concessions	National Electricity Law (Law no. 14.694)	Organic Law of Electric System and Service
Renewable law	Law 26 190		Law 10438	Law 20.257	Law 697 and resolution 180919	CONELEC - 004/11		Law no. 28546 and decree 1002	Law 18.585 and decree 77/06	

4. Renewable energy generation in South America

The data that is the basis for this comparative analysis dates back to 2009 (Argentina, Colombia, Peru and Bolivia) and 2010 (Brazil, Ecuador, Uruguay, Chile and Germany). Fig. 1 shows the share that each of the renewable energy sources – water, wind, sunlight and biomass – have in the entire range of energy generation technologies of the different countries.

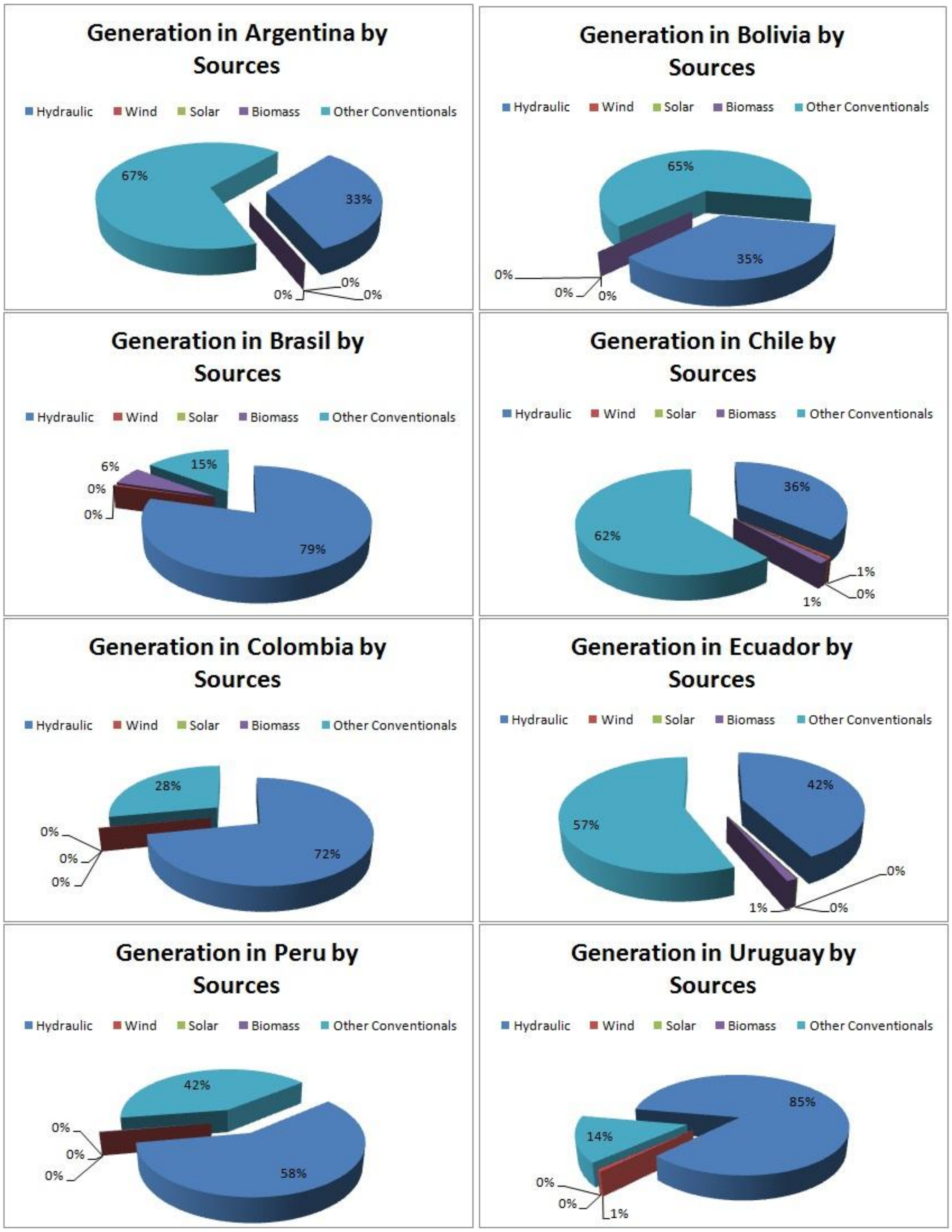

Figure 1 Distribution of the energy generation among the different energy sources in the countries surveyed.

The most obvious fact displayed in Fig. 1 is that hydroelectric power is the dominating RE in South America. Argentina, Bolivia and Chile generate approx. one third of their entire energy from water power, Brazil and Colombia about three quarters and Uruguay almost covers its whole energy demand with water power. Ecuador and Peru are somewhere in the middle. Furthermore, Fig. 1 shows that all other RE sources only play an insignificant role in the energy production of these countries. In Brazil the production of biofuels from biomass is quite important for the transportation sector and in Chile and Ecuador this also amounts to about one percent of the country's energy generation.

Energy production from wind accounts for approx. half a percent in Brazil and Chile and 0.7% in Uruguay. Solar power generation is practically non-existent in the surveyed countries. It has no or less than a 0.1% share in the different countries' energy production.
For a more detailed analysis it is necessary to put these percentages into perspective of the amount of energy that the single countries produce. In Brazil for example, which is the country with the biggest energy demand of the surveyed countries, the 0.43% that wind energy contributes to the energy production represents 927 MW installed capacity and the 6% that is the energy production from biomass equals 7.8 GW installed capacity.

4.2 The controversy of hydroelectric power

On average RE contributes 54% to the energy supply of the surveyed countries. That is quite an impressive number especially compared with ratios of OECD countries, which do not even come close to that figure. However, this impression can be very misleading. As we have seen above REs are dramatically underrepresented with the exception of hydroelectric energy. Fig. 3 illustrates the dominating position that hydroelectric power generation takes among the REs in the countries surveyed.

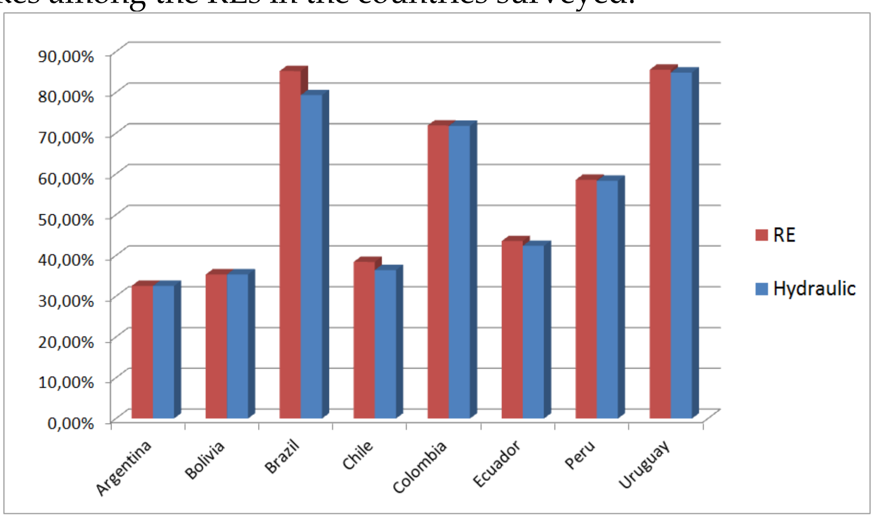

Figure 3 Share of RE and hydroelectric power in the entire range of energy production technologies of the different countries.

Whether or not hydroelectric power can be called sustainable and in some cases even renewable is somewhat questionable and therefore problematic. This applies particularly to large-scale hydroelectric plants, which of course make up the biggest share of installed hydroelectric capacity (Meisen P. and Krumpel S. 2009).
There are two main reasons for this controversy. Firstly, many South American countries have become dependent on hydroelectric energy production. That makes them very vulnerable to dry periods and the ensuing fall of water levels. Secondly, large hydroelectric projects have been the cause for large environmental and social problems. The damming up of big rivers and the consequent flooding of vast areas has led to the

loss of valuable natural reserves and was the reason for the relocation of indigenous peoples from their traditional territory (UNFCCC – CDM – Executive Board 2006).

Even though it is arguable to what extent these criticisms are applicable, it becomes clear that some perceive large-scale hydroelectric generation as not the most adequate solution.

6. Conclusion

The survey showed the existence of similarities and differences among South American countries regarding RE development. Particularly in the comparison of preferences for the different RE technologies, similarities become apparent. The fact that all RE sources besides hydroelectric only play an insignificant role in the energy production is certainly partly due to the level of complexity that is inherent to the different RE technologies. But it may well be suspected that a lack of appropriate RE incentives is also a reason.
Furthermore, the analysis shows that there are initiatives for the development and the promotion of RE in South America. However, despite the big RE potential, large-scale implementation of RE generation has yet to be realised.

All in all the survey conducted in the WP 2 shows that most of the countries surveyed perceive RE to be an inevitable part of their future energy supply. It is thus crucial that existing efforts are duly supported by means of appropriate knowledge and technology transfer.

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Energy Efficiency & Management

Efficiency Optimisation of Three-Phase Induction Motor using Swarm Intelligence

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Abstract:

Renewable energy is becoming more and more important with the current environmental issues. Many research projects are being conducted to implement the renewable technologies mainly in developing countries and small island developing states. Another way of reducing the environmental impact is to increase efficiency at the energy utilization end. More than half of the world's electrical energy generated is consumed by electric machines. Thus, improving the efficiency in electrical drives brings along two benefits as economic saving and reduction of environmental pollution. Efficiency optimisation of three-phase induction motor can be achieved through optimal control and design techniques. Optimal control is more practical because the motor efficiency cannot be improved for every operating point by optimising machine design. A three-phase induction motor can be controlled via indirect field orientation which offers an improvement in the dynamic response of the system. However, it is observed that in many applications, the field orientation operate under constant flux for different amount of load torque and this reduces the efficiency of this control scheme. In this study, a loss model equation is developed for the three-phase induction motor to establish the relationship between the rotor flux and total electrical losses. Imperialist Competitive Algorithm (ICA) is compared to Particle Swarm Optimisation (PSO) to evaluate the optimal rotor flux that minimizes the motor losses at specific load torques. Simulation results show the effectiveness of using field orientation control with swarm intelligence and the superiority of ICA over PSO.

Keywords: Energy Efficiency, Optimization, Induction Motor, Motor Losses

1. INTRODUCTION

In order to reduce electrical energy consumption, the efficiency of utilization can be increased. This means can reduce the burden on renewable energy production as electrical energy demand keeps increasing. The induction motor is widely used in industrial practice since they are more rugged, require less maintenance and are less costly than their counterpart, the dc motor. The wide range of motor ratings available coupled with advancement in torque and speed control technologies have further contributed to its success [1]. Achieving energy efficient control is important in the induction motor. It is estimated that more than around 50% of the world electric energy generated is consumed by electric machines and so improving efficiency in electric drives is important [2]. That is mainly, for two reasons: economic saving and reduction of environmental pollution [2].

A lot of developments have been made in the field of efficiency optimisation of three-phase induction motor through optimal control and design techniques. Optimal control is more important because the motor efficiency cannot be improved for every operating point by optimising machine design [3].

In many applications of constant speed operation, the induction motor operates under partial load for long periods such as mine hoist load [3] and spinning drive in textile industry. In these applications making the induction motor to operate at reduced flux is important so as to maintain a balance between iron (core) and copper losses.

In this paper a loss model controller (LMC) is developed for the three-phase induction motor based on the two-phase controller described in [4]. Then for different load torque the value of optimal flux is determined by using swarm intelligence.

2. MODELLING THE INDUCTION MOTOR

The dynamic model of an induction motor considers transients that occur during load variations and frequency changes. This model of induction motor also considers the instantaneous effects of variations in voltage, current, stator frequency, torque disturbances [5].

Normally the direct-quadrature transformation is used to model the induction motor so as to obtain constant inductance matrix terms [5]. The relationship between abc parameters and qd0 parameters is as follows [6]:

$$\begin{bmatrix} f_q \\ f_d \\ f_0 \end{bmatrix} = \left[T_{qd0}(\theta) \right] \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \tag{1}$$

where f can represent the phase voltages, current or flux linkages and

$$\left[T_{qd0}(\theta) \right] = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \tag{2}$$

The voltage flux equations [6] in arbitrary frame (ω) is given by

Stator Voltages

$$V_{qs} = R_s I_{qs} + p\lambda_{qs} + \omega\lambda_{ds} \tag{3}$$

$$V_{ds} = R_s I_{ds} + p\lambda_{ds} - \omega\lambda_{qs} \tag{4}$$

$$V_{0s} = R_s I_{0s} + p\lambda_{0s} \tag{5}$$

Rotor voltages

$$V_{qr} = R_r I_{dr} + p\lambda_{dr} + (\omega - \omega_{r)}\lambda_{qr} = 0 \tag{6}$$

$$V_{dr} = R_r I_{dr} + p\lambda_{qr} - (\omega - \omega_{r)}\lambda_{dr} = 0 \tag{7}$$

$$V_{0r} = R_s I_{0r} + p\lambda_{0r} = 0 \tag{8}$$

Stator flux:

$$\lambda_{qs} = L_s I_{qs} + L_m I_{qr} \tag{9}$$

$$\lambda_{ds} = L_s I_{ds} + L_m I_{dr} \tag{10}$$

$$\lambda_0 = L_0 I_{0s} \tag{11}$$

<u>Rotor flux</u>

$$\lambda_{qr} = L_m I_{qs} + L_r I_{qr} \quad (12)$$

$$\lambda_{dr} = L_m I_{ds} + L_r I_{dr} \quad (13)$$

$$\lambda_{0r} = L_0 I_{0r} \quad (14)$$

The torque equation of the motor is

$$T_e = \frac{3}{2}\frac{P}{2}\left[\lambda_{ds} I_{qs} - \lambda_{qs} I_{ds}\right] \quad (15)$$

In terms of base quantities

$$F=\omega_b\lambda \quad (16)$$

$$X=\omega_b L \quad (17)$$

The final circuit of the three-phase balanced induction motor in the synchronous frame where $\omega = \omega_e$ are given in Figs. 1 and 2.

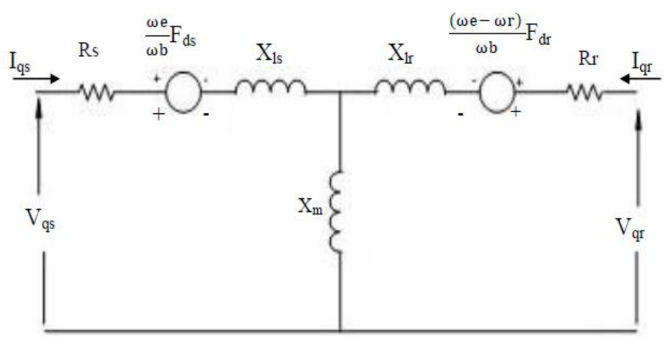

Fig. 20 Q-axis of induction motor

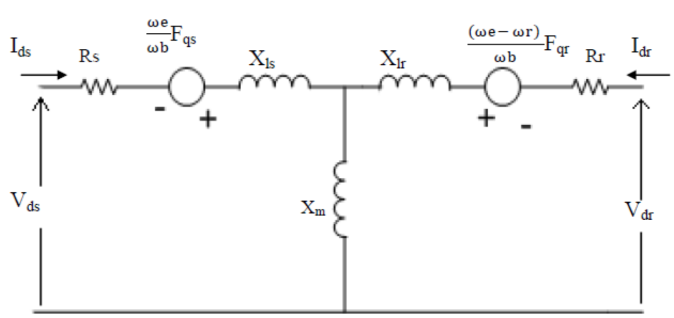

Fig. 21 D-axis of induction motor

2.1 Simulink Model of the Induction Motor

The three-phase induction motor can be simulated via Simulink using Krause model [7]. The equations describing this model are as follows:

$$I_{qs} = \frac{1}{X_{ls}}(F_{qs} - F_{mq}) \tag{18}$$

$$I_{ds} = \frac{1}{X_{ls}}(F_{ds} - F_{md}) \tag{19}$$

$$I_{qr} = \frac{1}{X_{lr}}(F_{qr} - F_{mq}) \tag{20}$$

$$I_{dr} = \frac{1}{X_{lr}}(F_{dr} - F_{md}) \tag{21}$$

where F_{mq} is the q-axis saturation and is given by

$$F_{mq} = X_m(I_{qs} + I_{qr}) \tag{22}$$

F_{md} is the d-axis saturation and is given by

$$F_{md} = X_m(I_{ds} + I_{dr}) \tag{23}$$

Eq. (18)-(21) are then substituted in Eq. (22) and Eq. (23) as well as in the voltage equations (base form) Eqs. (3), (4), (6) and (7) in order to eliminate the current terms. The resulting voltage equations are then solved for flux linkages per second. The equations are as follows.

$$F_{qs} = \omega_b \int \left[V_{qs} - \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}}(F_{mq} + F_{qs}) \right] dt \tag{24}$$

$$F_{ds} = \omega_b \int \left[V_{ds} + \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}}(F_{md} + F_{ds}) \right] dt \tag{25}$$

$$F_{qr} = \omega_b \int \left[V_{qr} - \frac{(\omega_e - \omega_r)}{\omega_b} F_{dr} + \frac{R_r}{X_{lr}}(F_{mq} - F_{qr}) \right] dt \tag{26}$$

$$F_{dr} = \omega_b \int \left[V_{dr} + \frac{(\omega_e - \omega_r)}{\omega_b} F_{qr} + \frac{R_r}{X_{lr}}(F_{md} - F_{dr}) \right] dt \tag{27}$$

Eqs. (22) and (23) can be expressed as

$$F_{mq} = X_{ms} \left[\frac{F_{qs}}{X_{ls}} + \frac{F_{qr}}{X_{lr}} \right] \tag{28}$$

$$F_{md} = X_{ms}\left[\frac{F_{ds}}{X_{ls}} + \frac{F_{dr}}{X_{lr}}\right] \quad (29)$$

where

$$X_{ms} = \left(\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}\right)^{-1} \quad (30)$$

$$T_e = \frac{3}{2}\frac{P}{2\omega_b}\left[F_{ds}I_{qs} - F_{qs}I_{ds}\right] \quad (31)$$

$$\omega_r = \int\left(\frac{P}{2J}\right)(Te - T_L)dt \quad (32)$$

These equations are then implemented in Simulink as described in [8].

3. INDIRECT FIELD ORIENTED CONTROL

Field oriented control (FOC) is basically a software algorithm that utilises the position of the rotor combined with two-phase currents to generate a means of instantaneously controlling the torque and flux. Field-orientated controllers control both the magnitude and phase of the AC quantities and are thus referred to as vector controllers. FOC produces controlled results that have a better dynamic response to torque variations in a wider speed range compared to other scalar methods [9].

The Indirect FOC (IFOC) scheme requires as input the rotor speed, the d axis rotor flux and the desired operating speed. From these data the required control currents are generated.

Some equations derived for rotor flux orientation [6] are as follows:

$$I_{qr} = -\frac{L_m}{L_r}I_{qs} \quad (33)$$

$$\lambda_{dr} = L_m I_{ds} \quad (34)$$

$$I_{ds} = \frac{R_r + pL_r}{R_r L_m}\lambda_{dr} \quad (35)$$

$$I_{qs} = \frac{4T_{em}L_r}{3PL_m\lambda_{dr}} \tag{36}$$

$$\omega_{sl} = \frac{R_r L_m I_{qs}}{L_r \lambda_{dr}} \tag{37}$$

The value of ω_{sl} is integrated to find the slip angle, θ_{sl}.

$$\theta_{sl} = \int \omega_{sl} \tag{38}$$

The synchronous angle θ_e is found by adding θ_{sl} with θ_r.

$$\theta_e = \theta_r + \theta_{sl} \tag{39}$$

where

$$\theta_r = \int \omega_r = \text{rotor angle} \tag{40}$$

From these equations the control scheme is implemented in Simulink.

4. HYSTERESIS CURRENT CONTROLLER

In order to generate the pulses to drive the voltage inverter, hysteresis modulation (HM) is used. Hysteresis modulation is a feedback current control method where the motor current tracks the reference current within a hysteresis band. The IFOC generates sinusoidal reference currents of desired magnitude and frequency that is compared with the actual motor line current [10].

5. THE DC-TO-AC VOLTAGE INVERTER

A voltage inverter receives dc voltage at the input and converts it to ac at appropriate frequency and voltage. Fig. 3 shows a three-phase inverter circuit with the switches in each diode [11].

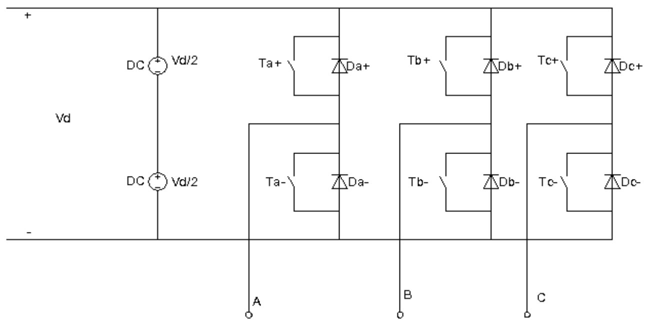

Fig. 3 Three-phase inverter circuit

Depending on the state of the switches, the output of the inverter in the phase A, B and C will change. The switches are controlled from the output of the hysteresis current controller.

6. LOSS MODEL CONTROLLER

In this section, a formula to determine the losses of the three-phase induction motor from the speed, torque, flux and other motor parameters is derived.

The equation for a three-phase system is derived in a similar way to the two-phase system in reference [12]. However, the formula has been adapted to a three-phase balanced system.

From reference [12]:

The d axis magnetising voltage:

$$V_{dm} = \frac{\omega_e L_{rl} L_m}{L_r} I_{qs} \quad (41)$$

The q axis magnetising voltage:

$$V_{qm} = \omega_e L_m I_{ds} \quad (42)$$

Total losses of the induction motor are stator copper losses, rotor copper losses and core losses.

The total electrical loss formula can written as follows

$$P_{losses} = R_s I_{qs}^2 + R_s I_{ds}^2 + R_r I_{qr}^2 + R_r I_{dr}^2 + \frac{V_{qm}^2}{R_c} + \frac{V_{dm}^2}{R_c} \tag{43}$$

Stator losses Rotor losses core losses

When using field-oriented control, $I_{dr} = 0$

Using Eqs. (33), (34) and (36)

$$I_{qs} = \frac{4T_{em}L_r}{3PL_m\lambda_{dr}} \tag{44}$$

$$I_{qr} = -\frac{L_m}{L_r} I_{qs} = -\frac{L_m}{L_r}\frac{4T_{em}L_r}{3PL_m\lambda_{dr}} \tag{45}$$

$$I_{ds} = \frac{\lambda_{dr}}{L_m} \tag{46}$$

Eqs. (41), (42), (44), (45) and (46) are substituted in Eq. (43) and the resulting equation is simplified as follows:

$$P_{losses} = \frac{16}{9} R_s \left[\frac{T_{em}L_r}{PL_m\lambda_{dr}}\right]^2 + R_s \left[\frac{\lambda_{dr}}{L_m}\right]^2 + \frac{16}{9} R_r \left[\frac{L_m}{L_r}\frac{T_{em}L_r}{PL_m\lambda_{dr}}\right]^2 . + \frac{16}{9R_c}\left[\frac{\omega_e L_m L_{rl} T_{em} L_r}{L_r P L_m \lambda_{dr}}\right]^2 + \frac{[\omega_e L_m]^2}{Rc}\left[\frac{\lambda_{dr}}{L_m}\right]^2 \tag{47}$$

Simplifying,

$$P_{losses} = \frac{16}{9}\left[R_s + R_r\frac{L_m^2}{L_r^2} + \frac{\omega_e^2 L_m^2 L_{rl}^2}{R_c L_r^2}\right]\left[\frac{T_{em}L_r}{PL_m\lambda_{dr}}\right]^2 + \left[R_s + \frac{[\omega_e L_m]^2}{Rc}\right]\left[\frac{\lambda_{dr}}{L_m}\right]^2 \tag{48}$$

where

$$\omega_e = \omega_r + \omega_{sl} \tag{49}$$

$$\omega_{sl} = \frac{4R_r T_{em}}{3P\lambda_{dr}^2} \tag{50}$$

Efficiency (n) is given by

$$n = \frac{P_{out}}{P_{out} + P_{losses}} \quad (51)$$

where

P_{out} is the output power of the induction motor:

$$P_{out} = T_e * \omega_r \quad (52)$$

In the above equations T_e represent the applied load torque and ω_r the rotor speed. By replacing these values together with the machine parameters in Eq. (48) the optimum value of the d-axis rotor flux, λ_{dr}, can be searched by using nature inspired algorithms like ICA and PSO. The value of λ_{dr} is optimum when the sum of copper and core losses is a minimum as shown in Fig. 4.

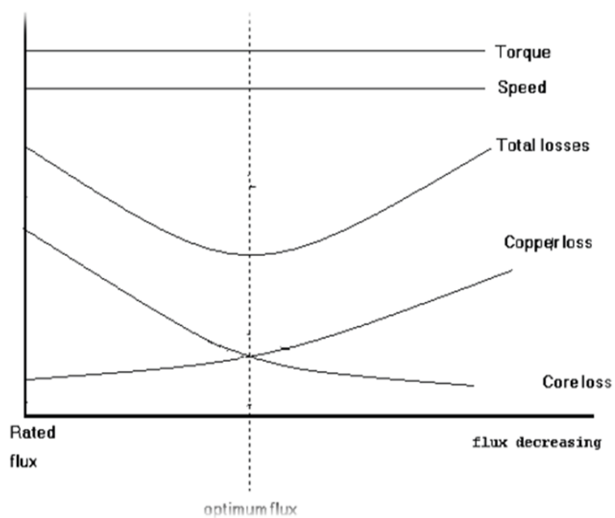

Fig. 4 Losses variation of the motor with varying flux [11].

7. IMPERIALIST COMPETITIVE ALGORITHM

Imperialism is the policy of extending the power of a government beyond its boundaries. The state may try to dominate others by direct rule or by control over market goods. Briefly, imperialism can be described as a political control over other countries in order to exploit their resources. Imperialist states compete with each other to increase their colonies and to spread their empire over the world and this competition results in the development of powerful empires and collapse of weaker ones. Imperialist states have also the tendency to assimilate colonies they have conquered by spreading their culture with the natives of the colony.

Imperialist Competitive Algorithm (ICA) [14] is modelled by an initial population of countries. Some of the countries in the population are selected to be the imperialist and the rest form the colonies of these imperialists. The distribution of colonies is based on the power of the imperialist country and the power of an imperialist is inversely proportional to its cost. That is, if an imperialist has a lower value of the cost function then it is more powerful and will have a larger share of colonies. After the distribution of colonies among imperialists, colonies start to move in search space towards their relevant empire state. The total power of an empire depends on both the power of the imperialist country and the power of its colonies.

Any empire that cannot increase its power (or prevent it from decreasing) in imperialistic competition is eliminated. This competition will gradually increase the power of powerful empires and decrease the power of weaker ones. If a colony has more power than an imperialist then the relevant imperialist swap position with this colony. The movement of colonies and position swapping towards their relevant imperialist and the collapse mechanism will cause all countries to converge to a state where there is just one empire in the world and all other countries are its colonies. The minimum cost function can then be extracted from the most powerful empire [14].

7.1 MODELLING IMPERIALIST COMPETITIVE ALGORITHM

Based on reference [14], the countries in ICA are modelled by an array as follows:

Country = $[P_1, P_2, P_3....P_{Nvar}]$

where N_{var}= dimensional optimisation problem

A country is $1*N_{var}$array.

Cost

The cost of a country is found by evaluating the cost function f at the variables $[P_1, P_2, P_3....P_{Nvar}]$

Cost = f (country)=f($P_1, P_2, P_3....P_{Nvar}$)

Population

The initial population size is N_{pop} and the most powerful empires population is N_{imp}. The remaining population is N_{col} representing the colonies.

The colonies are divided amongst the empires based on their power. The normalised cost of the imperialist is defined by

$Cn+1 = Cn + max_i \{C_i\}$

$C_i$is the cost of the ithimperialist

Cn is the cost of nth imperialist

C_{n+1} is the normalised cost

The normalised power of each imperialist, P_n, is given by

$$P_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \tag{53}$$

The initial number of colonies an empire will have is NC_n where

NC_n = round (Pn*Ncol)

The value of (Pn*Ncol) is rounded because population cannot have decimal values.

Movement of the colonies of an Empire toward the Imperialist

The colony then moves towards the empire by X units. X is a random variable with uniform distribution. The variable X is a function of the distance between the colony and the empire and β. Normally β is a constant greater than 1.

While moving toward the imperialist, a colony might reach a position that has a lower cost than the imperialist. In such a case the imperialist change position with the empire.

Total power of an empire

The total power of an empire is determined mainly by the power of the empire itself and to a small extent by the power of the colonies. The total cost TC is given by:

TC=Cost (imperialist) +μ*mean {cost (colonies of empire)} where $\mu = 0.1$

Imperialistic competition

This competition is modelled by picking some of the weakest colonies in the weakest empires and making a competition among the powerful empires to possess these colonies. The model is developed as follows:

$NTC_n = TC_n - \max_i\{TC_i\}$

where NTC_n: normalised total cost of the nth empire.

The possession probability of the nth empire is given by PP_n

$$PP_n = \left| \frac{NTC_n}{\sum_{i=1}^{N_{imp}} NTC_i} \right| \tag{54}$$

The colonies are divided among empires with greater values of D, where D is a vector defined as follows:

$$D = PP - R \tag{55}$$

where

$$PP = [PP_1, PP_2, PP_3, PP_4 \ldots\ldots, PP_{Nimp}] \tag{56}$$

$$R = [R1, R2, R3, R4, R5 \ldots\ldots., R_{Nimp}] \tag{57}$$

$R1, R2 \ldots R_{Nimp}$ are andom numbers between 0 and 1.

Collapse of an empire and convergence

Once an empire has no colonies it will collapse. After some time all the colonies will be under control of one unique empire and ideally they will have the same cost and position as the imperialist itself. In such a condition the imperialistic competition stops and the final optimum cost can be retrieved from the algorithm.

Figure 5 demonstrate the operation of ICA

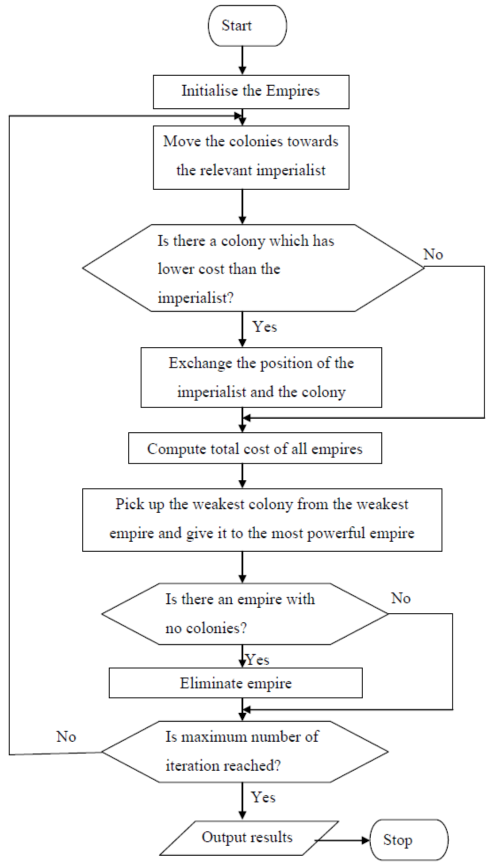

Fig. 5 Flow chart demonstrating operation of ICA

8. RESULTS AND DISCUSSION

The model developed is simulated and the following results were obtained.

The equation derived in Section 6 is plotted for a range of λ_{dr} from 0.1 to 8 and a torque of 0.5 pu. The graph obtained is shown in Fig. 6.

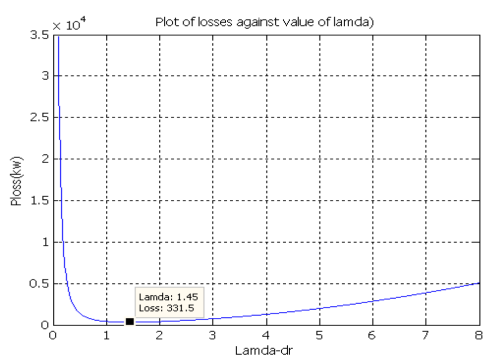

Fig. 6 Losses variation with variation in λ_{dr}

The parameters required are substituted in the formula and the optimum flux is calculated for load torques of 0.25, 0.5, 0.75 and 1 pu respectively. The parameters of the Imperialist competitive algorithmare are (Number of Countries = 200; Number of Initial Imperialists = 8; Number of decades or iterations = 30; Revolution Rate = 0.3; Assimilation Coefficient = 2; Assimilation Angle Coefficient = 0.5; Zeta = 0.02; Damp Ratio = 0.99; Uniting Threshold = 0.02). For comparison, the simulation results are also presented for a Particle Swarm Optimisation algorithm (PSO) [13] with the following parameters (Iterations =30; Inertia = 1.0; Correction factor = 1.44; Swarm size = 64).

Figs. 7 and 8 show for ICA and PSO respectively how the swarm moves in the search space to look for the value of flux that will give the minimum loss for a load torque of 0.5 pu.

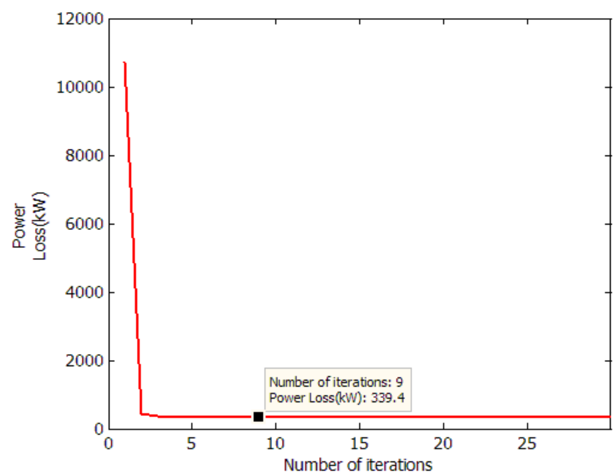

Fig. 7 Best position of imperialist against decades or number of iterations

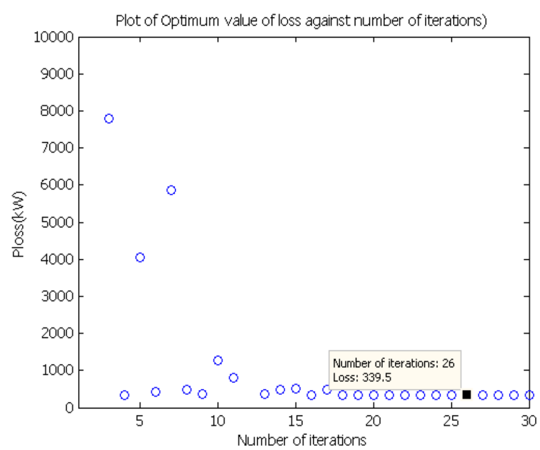

Fig. 8 Best swarm position against number of iterations

The minimum power loss is found to be 339.4 kW occurring at a flux of 1.4333

Table 1 summarises the minimum losses and optimum flux for several load torques

Table 1 Losses and optimum flux for different load torque with ICA and PSO

Load torque(pu)	Losses(kW)	Optimum Flux(Wb)	Optimum Flux(Wb)
		ICA	PSO
0.25	169.7	1.0135	1.0050
0.5	339.4	1.4333	1.4346
0.75	509.2	1.7554	1.7554
1	678.9	2.0269	2.0261

It can be concluded that Imperialist competitive algorithm is faster and more consistent than PSO. This is shown in Fig. 7 whereby the optimum solution has already been reached within 5 iterations whereas PSO takes more than 20 iterations (Fig. 8). Furthermore there is no need to adjust the parameters of ICA as opposed to PSO in order to cause the algorithm to converge to the local optima. Hence, ICA is more consistent than PSO in finding the optima in different simulation runs.

The optimum flux is fed into the IFOC block and the results obtained are shown in Table 2. The formula derived in Section 6 for efficiency is used to determine the efficiency of the motor at various level of flux.

Table 2 Comparison of efficiency with and without optimum flux

Load Torque(pu)	Efficiency without optimum flux	Efficiency with optimum flux
0.25	0.8798	0.9371
0.5	0.9246	0.9371
0.75	0.9354	0.9371
1	0.9370	0.9371

As can be seen from Table 2, running the motor with rated flux at reduced torque is not optimum. Up to 5% of energy can be saved at a load torque of 0.25 pu using this method.

Figs. 9 and 10 shows respectively the stator currents of the motor without optimum flux and with optimum flux for a load torque of 0.25 pu. Without optimum flux, stator current is about 60 A whereas with optimum flux, stator current is reduced to about 31 A when the load torque of 0.25 pu is applied at 2s.

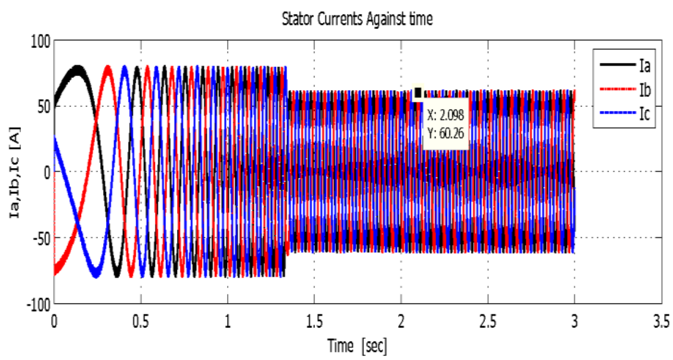

Fig. 9 Stator currents without optimum flux

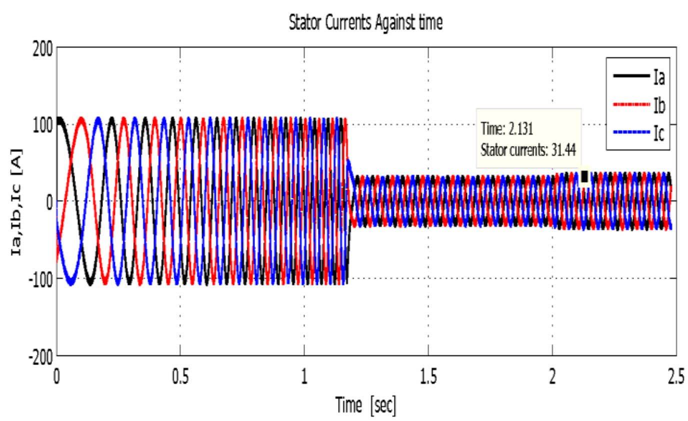

Fig. 10 Stator currents of the motor with optimum flux

9. CONCLUSION

The proposed LMC scheme for the three-phase system effectively improves the efficiency of the motor at small amount of applied torque by finding the optimum flux. This was demonstrated by the reduction in the stator current which in turn reduces the copper and core losses. The torque and speed being produced by the motor stills remains the same. Simulation results show that ICA has faster convergence and is more consistent than PSO in finding the optimum flux.

The proposed FOC based on LMC with ICA would mean a little added cost to the controller. This cost will be for an extra memory integrated chip (IC) to hold the look up table (LUT) where the pre-calculated optimal operating points are stored [4].

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Energy use in manufacturing industries evidence from Sweden

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Abstract:

This study analyses energy use and CO2 emissions in the Swedish manufacturing industries between 1993 and 2008. The performance of this sector is studied in terms of CO2 emissions, energy consumption, energy intensity, energy sources, energy prices and taxes. The results show that energy consumption, energy intensity and CO2 emission intensity have reduced significantly. The decomposition analysis evidenced that decrease in the aggregate energy intensity and the aggregate CO2 emission intensity was caused by a decrease of energy intensity and substitution fuels. The factors that have influenced the results in energy intensity and CO2 emission intensity in Swedish manufacturing industries have been mainly the increase of energy price, energy taxes, investments and inter-fuel substitution.

Keywords: Small Developing Island, Renewable Energy Knowledge, Technology Transfer

1. INTRODUCTION

Energy is a basic factor for production in the manufacturing industry. The growing population, industrialization and increasing standard of living and quality of life across the globe have substantially increased our dependence on energy. As a result, the development of conventional energy resources, the search for new or renewable energy sources, energy conservation (using less energy), energy efficiency (having the same service or output with less energy usage) and decreasing CO_2 emissions have become unavoidable topics in global politics.

However, to improve the analysis, design and evaluation of adequate energy polices, it is necessary to achieve a better understanding of the trends in energy use, energy efficiency and CO_2 emissions while considering the factors that could determine these trends. Gaining this understanding implies obtaining detailed data at various aggregation levels to apply suitable indicators and using models and methods that generate reliable and consistent information [1]. This paper describes the trends in energy consumption and CO_2 emissions in Swedish manufacturing industries between 1993 and 2008 and analyses several factors that have influenced these trends such as investments, inter-fuel substitution, energy price and energy taxes as a starting point for broader analysis.

Researchers in many fields have used various approaches to measure energy efficiency in the industrial sector with the aim of determining the specific effects of energy policies, new technologies or energy prices on energy efficiency changes and improvements, among other things. Decomposition analysis has been widely used in several studies to decompose the energy consumption and to aggregate energy intensity or CO_2 emissions into the change in intensities at the disaggregated sectoral level and the impact of changes in structural composition of the industrial sector [2-4]. For example, [5], in the context of Indian manufacturing industries, showed that improvements in energy efficiency are primarily achieved by structural changes. [6] analysed energy use in the US and found that improvements in energy efficiency were caused principally by structural changes in the economy. [7] studied EU manufacturing industries with an emphasis on CO_2 emissions and found relevant progress in the decoupling of the growth in manufacturing industries and carbon emissions.

The studies on energy efficiency and CO_2 emissions in Sweden have included a variety of topics. *(a)* [8-9] applied decomposition analyses to energy consumption and CO_2 emissions, demonstrating that fuel substitution, improvement in the energy system and processes and changes in consumption patterns have led to the decrease in CO_2 emissions in Sweden. *(b)* [10-11] analysed the relationship between investments, CO_2 emissions and energy efficiency; additionally, they demonstrated that CO_2 emissions and energy efficiency influence investment decisions in Swedish industries. *(c)* [12-13] studied energy policy and its effects on improvements in energy efficiency and identified several strategies such as energy prices, carbon and energy taxes, voluntary agreements, the application of energy management systems, audits and incentives for emission reductions facilitated by fuel substitutions. *(d)* Other studies have analysed barriers to the implementation of energy efficiency measures and the effects of some energy programs on small and medium-sized enterprises [14-15].

However, despite the important results of the previous analyses, these studies have not assessed the specific effects of energy efficiency on energy consumption and CO_2 emissions over time, nor have they analysed other variables that could determine the trends of these variables. Therefore, the main contribution of this study is an analysis of the role of energy efficiency in the trends in energy use and CO_2 emissions in the Swedish manufacturing industries that have demonstrated important improvements in energy efficiency, which should allow for the establishment of adequate strategies in the design of effective energy policy.

The results of this study show that Swedish manufacturing industries improved their energy efficiency during the sample period and that output growth has not required higher energy consumption. This led to a decrease in CO_2 emission intensity. The factors that influenced these results were mainly the increase in energy prices, energy taxes, investments and inter-fuel substitution, indicating the importance of a suitable energy policy that strengthens sustainable development in this industrial sector.

The remainder of this paper is organised as follows: Section 2 describes the methods and data used in this study; in Section 3, the results are shown and discussed; the conclusions are stated in Section 4.

2. METHODS AND DATA

In this analysis, energy and CO_2 emission intensity are defined as the energy used or CO_2 emissions generated per unit of economic production, respectively. In this study, value added is used to measure economic production to analyse trends in these indicators for Swedish manufacturing industries. Moreover, we use decomposition analysis at the manufacturing industry level to estimate and evaluate energy use and CO_2 emissions. This method examines several factors, such as the activity, structure, energy intensity and energy carbon index, which have influenced the trends in energy use and CO_2 emissions with respect to production value. This technique involves the division and decomposition of energy and emissions in the explanatory variables from aggregate data [2-3].

The technique applied is the Multiplicative Log-Mean Divisia Method explained by [16], which allows an adequate decomposition at different levels of aggregation. This method is used to determine the effects of a structural change in manufacturing industrial production on total energy consumption, which can establish several causes of a change in energy use in this sector.

Two approaches are used in this analysis: energy intensity and CO_2 emissions. The relative changes *(L)* are explained using the log percentage change where *Ln(x,y)* is the logarithmic mean of two positive numbers, i.e., $L = Ln(x,y) = (y-x)/Ln(y/x)$ [17]. These two approaches are:

The energy intensity method: In this approach, the total change in aggregate energy intensity is decomposed into a structural effect (S) representing manufacturing industrial composition, and an intensity effect representing changes in the sector's energy intensity (EI) (for more details see [2]).

$$EI_{agg} = \sum_i S_{i,t} * E_{i,t} \qquad (1)$$

$$F_{tot} = F_{str} * F_{int} \qquad (2)$$

$$F_{str} = exp\left\{\sum_i \frac{L\,(\omega_{i,t}, \omega_{i,0})}{\sum_i L\,(\omega_{i,t}, \omega_{i,0})} \ln\left(\frac{S_{i,t}}{S_{i,0}}\right)\right\} \qquad (3)$$

$$F_{int} = exp\left\{\sum_i \frac{L\,(\omega_{i,t}, \omega_{i,0})}{\sum_i L\,(\omega_{i,t}, \omega_{i,0})} \ln\left(\frac{EI_{i,t}}{EI_{i,0}}\right)\right\} \qquad (4)$$

Note: EI_{agg}: aggregate energy intensity, F_{tot}: Total change in aggregate energy intensity, F_{str}: structural effects, F_{int}: Intensity effects, ω_x: energy share of sector *i* in year *t*.

The CO_2 emission method: This method explains changes in the level of CO_2 emissions through three factors: activity as measured in terms of production, structure and the energy carbon index (for more details see [18-19]).

$$COI_{agg} = \sum_i S_{i,t} * COI_{i,t} \quad (5)$$

$$TC_{tot} = F_{str} * F_{CE} \quad (6)$$

$$F_{str} = exp\left\{\sum_i \frac{L\left(\psi_{i,t}, \psi_{i,0}\right)}{\sum_i L\left(\psi_{i,t} \psi_{i,0}\right)} \ln\left(\frac{S_{i,t}}{S_{i,0}}\right)\right\} \quad (7)$$

$$F_{ce} = exp\left\{\sum_i \frac{L\left(\psi_{i,t}, \psi_{i,0}\right)}{\sum_i L\left(\psi_{i,t}, \psi_{i,0}\right)} \ln\left(\frac{CE_{i,t}}{CE_{i,0}}\right)\right\} \quad (8)$$

Note: COI_{agg}: aggregate CO_2 emission intensity, TC_{tot}: Total change in aggregate CO_2 emission intensity, F_{str}: structural effects, F_{ce}: Energy carbon index changes, *CE*: energy carbon index effect, ψ_x: CO_2 emissions share of sector *i* in year *t*.

The main limitation of this study is the degree of analysis (aggregate manufacturing sub-sectors) because it is only for one country and is insufficient for a full examination of the changes that took place into each Swedish sub-sector separately.

2.1 Database

Data to conduct the analysis are provided by SCB (Statistics Sweden) through the Swedish Environmental Accounts and Statistical database. These organizations use data at 2-digit levels of disaggregation, according to International Standard Economic Classification (ISEC). All monetary data are converted to 2000 euro values. The time period selected in this analysis is determined by the availability of data for the inter-sectoral Swedish manufacturing industries over the period 1993-2008.

3. RESULTS AND DISCUSSION

3.1 Energy intensity and CO_2 emission intensity in Swedish manufacturing industries

The trends in energy intensity and CO_2 emission intensity are shown in the Figure 1; both indicators display the same tendencies. Energy intensity and CO_2 emission intensity have decreased by 28% and 29%, respectively as average of whole manufacturing industries. All Swedish manufacturing industries have decreased these indicators, especially in the last few years.

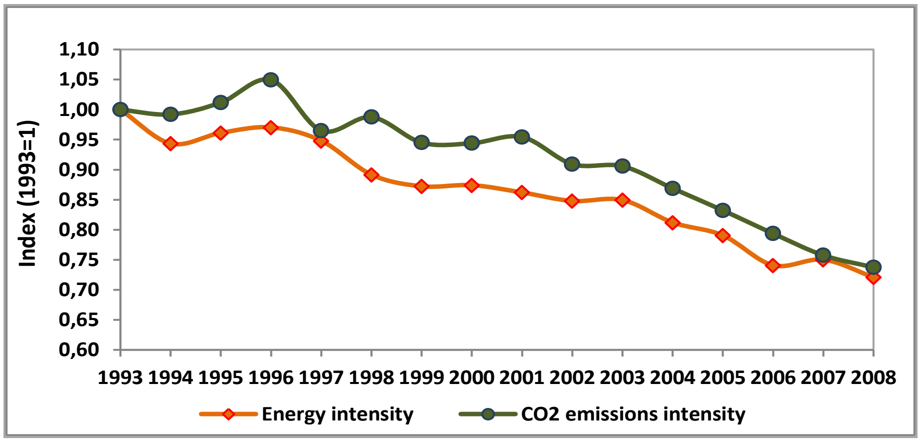


Fig. 1 Trends of energy intensity and CO_2 emission intensity for the Swedish manufacturing industries (Source: SCB (Statistics Sweden))

3.2 Decomposition Analysis

To estimate and analyze the trends in energy use and CO_2 emissions in the Swedish manufacturing industries, we apply the Multiplicative Log-Mean Divisia Method I explained in the section 2. The results of the decomposition analysis are shown in Figures 2 and 3 where a value of one indicates that the variable had no effect on aggregate intensity, energy consumption or CO_2 emissions and values greater than one indicate a contribution to greater aggregate intensity, energy consumption or CO_2 emissions, whereas values less than one indicated a decrease, which implies an increase in energy efficiency and a decrease in CO_2 emission intensity.

Energy intensity approach. Figure 2 shows the results for the decomposition of aggregate energy intensity, electricity intensity and fossil fuel intensity, where value added is the economic measures of output in the Swedish manufacturing industries. The aggregate of the energy intensity decreased considerably during the sample period. Structural and intensity effects show similar trends, indicating that both contributed to the decrease in aggregate energy intensity. However, intensity effects dominated structural effects, signifying that the decrease in aggregate energy intensity was primarily caused by a decrease in the energy intensity, which could be due to changes or improvements in technology.

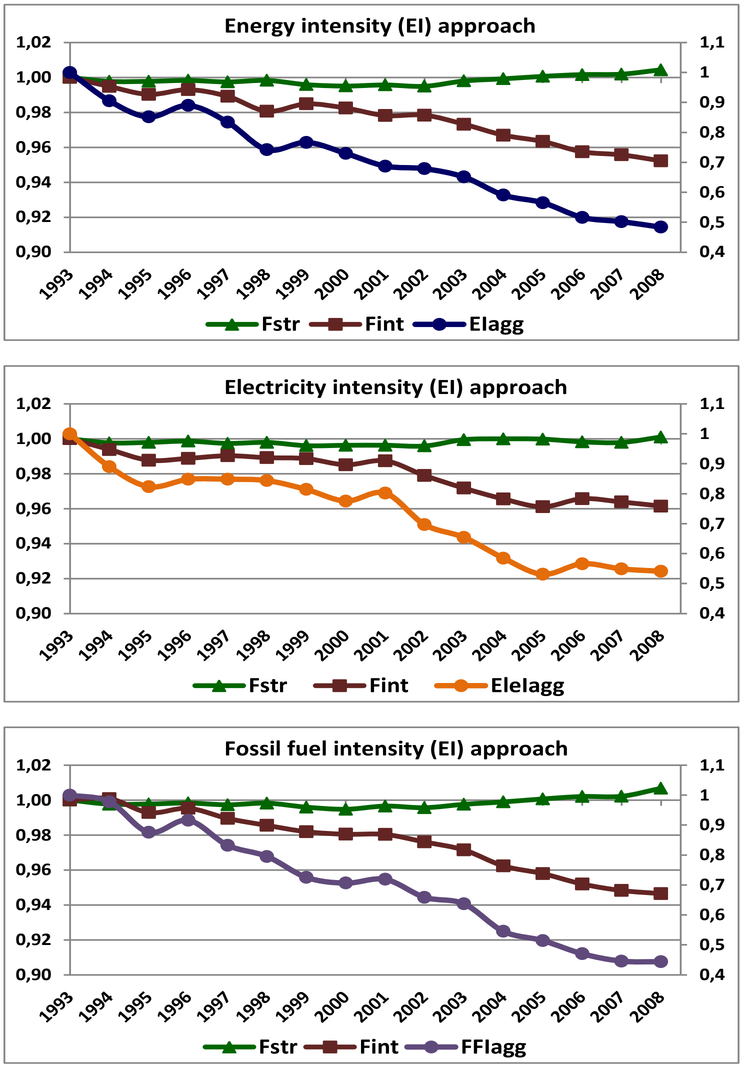
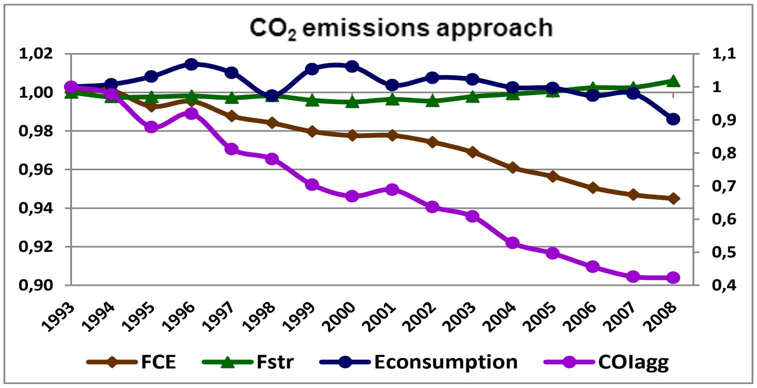
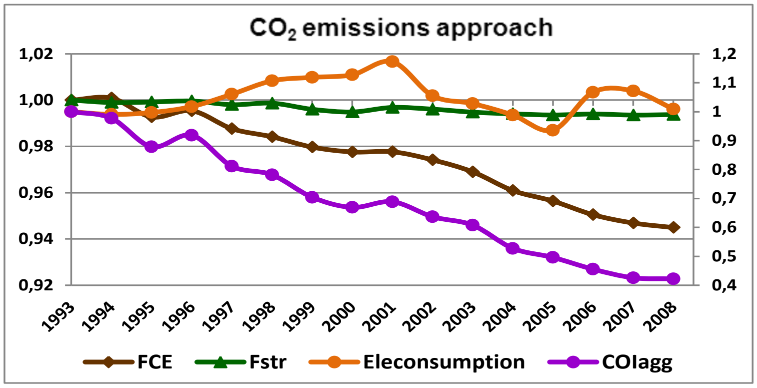


Fig. 2 The results of the decomposition analysis of aggregate energy intensity (*EIagg*), electricity intensity (*EIeIagg*) and fossil fuel intensity (*FFIagg*) into structural (*Fstr*) and intensity (*Fint*) effects for the Swedish manufacturing industries

The results should also demonstrate that the decrease in fossil fuel consumption has improved energy efficiency and decreased energy consumption through fuel substitution or a change in the mixture of fuels from inefficient, dirty or fossil fuels with a high carbon content (such as coal or several petroleum products) towards more efficient, clean or non-fossil fuels with a low carbon content (such as natural gas or hydroelectric energy); these trends are required for sustainable development. Moreover, achieving adequate fuel substitution to decrease the CO_2 emissions and energy consumption implies a change in economic conditions (fuel prices), a technological change (new technologies and innovation with adequate cost-benefits) and regulations that promote energy efficiency and clean production through the use of technologies that require less energy consumption and fewer pollutant-generating fuels[20-21].

CO_2 emissions approach. Figure 3 depicts the results of decomposition analysis from the CO_2 emissions approach. The results are similar to those obtained from the previous method, indicating the close relationship between the improvements in energy efficiency and the decrease of CO_2 emission intensity, which is consistent with several studies that have identified energy efficiency as a major energy issue because it is the most cost effective way of improving energy use and increasing both energy security and productivity and plays a role in the achievement of a carbon emission reduction target [22-23].





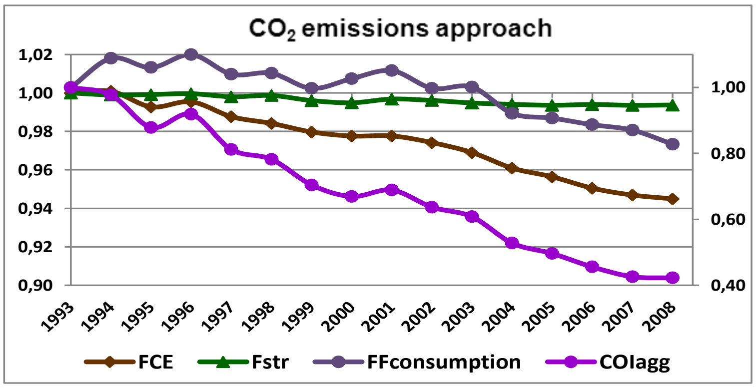


Fig. 3 The results of the decomposition analysis of CO_2 emissions for the Swedish manufacturing industries (structural effects (*Fstr*), energy carbon index changes (*FCE*), aggregate CO_2 emission intensity (*COIagg*), energy consumption (*Econsumption*), electricity consumption (*Eleconsumption*) and fossil fuel consumption (*FFconsumption*))

The results of the decomposition analysis from this approach indicate that the decrease in energy consumption has contributed to a lower aggregate CO_2 intensity. Similarly, structural and intensity effects had a minor role in the decrease in CO_2 emission intensity. These results highlight the fact that the Swedish manufacturing industry has increased its output while decreasing energy consumption, maintaining its production structure and decreasing its effects on climate change. Therefore, the results have demonstrated that clean production is possible within the framework of sustainable development.

3.3 Discussion of Results

Thus far, the results show that the Swedish manufacturing industries have decreased their energy consumption and output growth has not required higher energy consumption, making it possible to decrease energy and CO_2 emission intensity. The role of structural changes has been minor, and the trends of energy efficiency and CO_2 emissions were similar during the sample period. To understand the possible factors that have influenced these trends, we analyse the following issues: investments, inter-fuel substitution, energy price and energy taxes.

Investments. Multiple studies have demonstrated that higher investments generate higher energy efficiency or decrease energy intensity. Currently, investments in energy efficiency and clean energy are necessarily business decisions, and the greatest investment priorities are, in this case, based on regulatory requirements, decreased production costs or increases in productivity while maintaining or increasing product quality [24-25]. Moreover, the results of this study are consistent with several programs of the Swedish Energy Agency (SEA), which promotes investments to improve energy efficiency through standardised energy management systems and energy audits and identifies measures to decrease energy use and energy intensity. The Swedish long-term agreement program for energy efficiency in energy intensive industries (PFE), launched by the Swedish government in January 2005 and implemented and operated by the Swedish Energy Agency, has become a successful voluntary program. It has achieved an annual reduction in energy use of 2.909.33 TJ and a 2.5% increase in electricity intensity through the application of 872 measures and increased investments by companies [26-27]. Moreover, investments in clean technologies have grown significantly in the Swedish manufacturing industries, mainly in renewable electricity production, bio-fuels and techniques for increasing energy efficiency supported by different emission-reducing subsidies from the Swedish government [27]. This demonstrates that an adequate energy and climate change policy require government support and the interest of the industrial sector in improving environmental performance, pursuing increased productivity and economic growth with a goal of clean production with low carbon emissions.

Inter-fuel substitution. During the sample period, the manufacturing sector in Sweden increased its use of electricity and bio-fuels, whereas the use of other fuels has decreased (see Figure 4), indicating that, in this sector, electricity consumption has grown at a higher rate. However, fossil fuels declined during the sample period, demonstrating a shift in the structure of energy sources from lower efficiency or more polluting fuels (e.g., coal or petroleum products) to greater efficiency or cleaner fuels (e.g., electricity or bio-fuels). This is consistent with other studies [28-29] in the context of manufacturing industries. Moreover, the decline in the energy intensity in the manufacturing industries has been due to the ability to expand the use of higher quality fuels [30].

Energy prices. In the literature, it is accepted that energy efficiency becomes important during periods of high energy prices from a cost minimisation of outputs perspective. This may encourage improvements in the process and appropriate substitution of other inputs for energy [31]. Hence, increases in the prices of fossil fuels generated the substitution of these fuels for electricity and bio-fuels. Moreover, energy prices influenced energy efficiency results because decreases in aggregate energy intensity occurred during the years in which energy prices increased e.g., from 2000, Swedish manufacturing industries decreased the aggregate energy intensity while energy prices increased (see figures 2 and 5). Therefore, an increase in energy prices over time leads to a decrease in energy intensity, which concurs with [32-34].

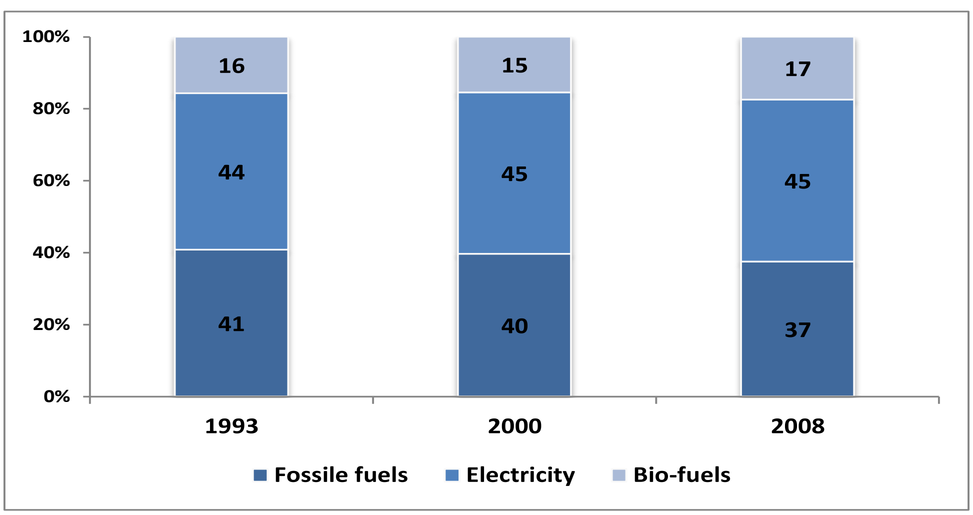


Fig. 4 Inter-fuel substitution in Sweden manufacturing industries (Source: SCB (Statistics Sweden)

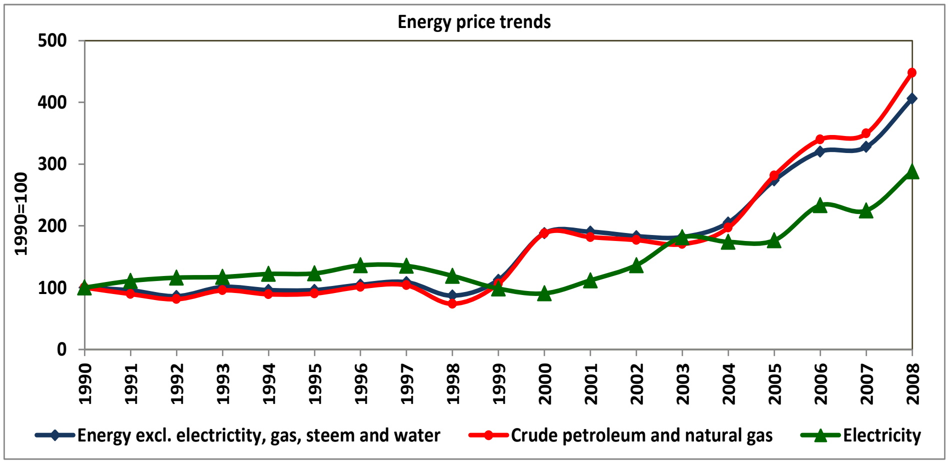


Fig. 5 Energy price trends (energy, electricity, crude petroleum and natural gas) in Sweden manufacturing industries (Source: SCB (Statistics Sweden))

Energy Taxes. Another factor analysed were the taxes, represented by energy and CO_2 taxes. This mechanism has been used in Sweden as both a fiscal tax source and as a policy instrument to motivate and strengthen incentives to save energy by increasing energy prices and carbon taxes. The taxes also make lower-carbon fuels substitutes. These taxes have been integrated with a variety of instruments and mechanisms that were designed to make them effective and maintain the competitiveness of Swedish manufacturing industries. A permanent substantial dialogue between all of the stakeholders, but mainly with industry, has generated higher applicability and effectiveness [35-36]. Moreover, results from decomposition analysis may demonstrate that adequate energy taxation reduces CO_2 emissions, improves the efficiency of energy use, promotes renewable energy production and use and provides incentives for sustainable development established by the green tax shift. Therefore, higher taxes should be applied to environmentally harmful activities to generate an increase in the use of biomass in district heating systems, investments in new technologies and the application of energy management systems and audits [37-38].

4. CONCLUSIONS

This study analyses the trends in energy consumption and CO_2 emissions in Swedish manufacturing industries between 1993 and 2008. This sector has achieved important advances in energy use, simultaneously increasing its output while decreasing its energy consumption. Similarly, energy and CO_2 emission intensity decreased during the sample period, demonstrating that it is possible to produce economic growth while using fewer energy resources and controlling the amount of CO_2 emissions.

The results of the decomposition analysis showed a decrease in aggregate energy intensity and aggregate CO_2 emission intensity, which was caused by a decrease in energy intensity and substitution fuels; the role of structural changes has been minor. Moreover, the growth in production did not lead to increases in aggregate energy intensity and CO_2 emission intensity, indicating that this sector produced more with less energy consumption and fewer emissions.

These trends could be explained by the energy policies and strategies applied in Sweden that include energy prices, energy taxes and technological change that encourage investments in new technologies, encourage fuel substitution and energy management in the manufacturing industries.

The findings of this study indicate that it is possible to achieve improvements in energy efficiency and decrease CO_2 emissions while increasing production and competitiveness through a suitable energy policy that encourages the importance of energy efficiency in the manufacturing process through technological change and policy strategies.

The results found in this analysis are a valuable source of information because they suggest several strategies to make significant improvements in the energy efficiency of manufacturing industries, especially in developing countries where it is very important to increase the efforts of industry and policy makers to achieve energy savings that contribute significantly to the reduction of greenhouse gas emissions.

Finally, the results of this study are particularly relevant for the formulation, development and strengthening of energy policies for manufacturing industries that are based on Swedish experience, where economic instruments (energy prices and energy taxes) and technical instruments have driven substantial improvements in energy efficiency and decreases in CO_2 emissions through clean technology investments and fuel substitution. These results demonstrate that it is possible to achieve economic growth and sustainable development through a steady advancement towards a low-carbon economy. Future research should scrutinise data on other sectors, countries and aggregation levels to improve the understanding of the trends of energy efficiency and CO_2 emissions.

6. ACKNOWLEDGMENTS

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Case study analysis of urban decentralised energy systems

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Abstract

The UK has set an ambitious plan to substantially cut its carbon emissions. In order to meet this 2050 target of 80% reduction, the UK is facing a significant challenge of restructuring its energy system, currently characterised by lock-in to centralisation. There is however potential to challenge this lock-in through the development of more decentralised energy systems - based not only on technological, but also on more innovative political, social and economic approaches. Examples of these unique approaches have already been successfully implemented in many cities worldwide, demonstrating that more decentralised energy systems can lead to enhanced carbon emissions reductions.

Using a multi-disciplinary framework, this work critically assesses several urban decentralised energy systems around the world through the assessment of exemplar international case studies.

Following semi-structured interviews, this work compares and critiques four diverse international case studies in order to demonstrate and contrast a variety of decentralised approaches. It emphasises the variety and inter-relationships of barriers and drivers involved in the implementation of such projects. Although it is believed that regulations heavily influence the implementation of decentralised energy projects, these projects are frequently driven and motivated by other factors such as reputation, profitability and the opportunity to show that "we can do it". The main non-technical barriers are not necessarily financial, as is often believed. Governance barriers - such as out-of-date regulations or unreliable partners - also play an important role in the success or failure of a project. Social barriers in the form of public apathy and misinformation regarding energy consumption can also be significant, which often affects the operation on the project.

Keywords: decentralization, energy systems, lock-in, renewable energy, carbon reduction, future scenarios, case study.

1. INTRODUCTION

The urban environment is responsible for significant amounts of greenhouse gas (GHG) emissions; at the same time, urban population and infrastructure are vulnerable to the effects of climate change, such as heat waves, sea level rises, and catastrophic climate event [1]. In order to reduce GHG emissions and save energy, the urban environment worldwide faces the challenge of transforming established energy systems based traditionally on the use of fossil fuels. A shift has to be made towards more sustainable and renewable forms of energy [2-4] and a number of towns, cities and communities are moving successfully towards those new models of energy generation and supply.

The UK has set an ambitious target of 80% carbon emission reductions by 2050, but to reach this target the significant challenge of restructuring the energy system has to be addressed. Currently, the UK energy system is characterised by a lock-in to centralisation [5; 2]. There is, however, a potential to challenge this lock-in through the development of more decentralised energy systems based not only on technological but also on more innovative political, social and economic approaches. Indeed, many cities worldwide have already pioneered unique and effective approaches to more decentralised energy systems leading to enhanced carbon emissions reductions. This paper critiques and compares some of these approaches in order to demonstrate a variety of potential decentralisation approaches.

In this paper, none of the case studies contain a thorough evaluation of the project impact and effectiveness with regards to their UK implementation; however, the diversity of the projects provides valuable information regarding decentralised urban energy systems and their ability to help address climate change and challenge urban energy systems lock-in. The case studies presented here cover only a small proportion of the decentralised urban energy projects that currently exist. The focus and motivation for selection of these case studies was their unique and original approach, together with their potential, yet unrealised, applicability within the UK context. To exemplify the multiplicity of pathways that potentially exist towards decarbonisation, it was intentional to present a range of energy resources, technologies, end users and types of project intervention.

2. DECENTRALISED URBAN ENERGY SYSTEMS

The shift towards more sustainable energy systems is extremely challenging and involves a range of complexities, choices and strategic decisions: there are various renewable energy technologies with different applications, technological and infrastructural needs and degrees of maturity; there are different scales at which technologies can be implemented; there are also issues of environmental impact and social acceptance, as well as powerful commercial and political lobbies [2].

Many European and other countries are beginning a transition from a centralized and largely fossil-fuel and nuclear-based power systems toward a more decentralized power system relying to a larger extent on small-scale generation from renewable energy sources and Combined Heat and Power (CHP) units, allowing greater active participation of consumers by becoming producers themselves and/or by smarter demand response management of their own energy use [6]. The main drivers for this transition are not only the necessity to reduce GHG emissions, but also to increase the share of renewables in the energy mix and to make the use of energy more efficient. Rising electricity demand and the price of fuel, liberalisation of the markets and increasing concern over energy security also play important roles in encouraging decentralisation of energy systems [6].

Various schemes exist which prove that it is possible to challenge lock-in in different economic, political and social contexts. One example is Barcelona's innovative policy framework – Solar Renewable Ordinance that started as a support tool for solar thermal and has now been extended to photovoltaic (PV). China also encourages the use of solar energy: according to Rizhao solar policy, it is mandatory for all retrofit programmes to install solar water heaters, while almost all the traffic and street lights and park illuminations are powered by PV cells [7]. Other examples include sustainable communities such as the Sustainable Urban District Vauban in Freiburg, Germany and Fossil Fuel Free Växjö in Sweden. The USA also encourages a variety of renewable energy projects from community-led wind farms to green gyms heated by the power created by gym users.

The concept of lock-in has originally been used as a characteristic of an economical assumption but is now frequently discussed in the context of high carbon energy systems [8]. The notion of lock-in does not just include technological aspects, but also includes financial (e.g. market rules), governance (e.g. institutional arrangements) and social aspects (e.g. social norms), all of which can present barriers to the changing of an energy system [9].

Decentralised energy systems are frequently claimed to be more resilient, reliable, efficient and environmental friendly, as well as more affordable and accessible whilst offering greater levels of energy security [9-12]. An emphasis on the potential benefits of a more localised and distributed pattern of energy generation and on the involvement of the community emerged in the UK in the late 1990s [2]. For example, Local Agenda 21 principles were called to be applied to local energy planning in 1999 by the Local Government Association [13]. Various parts of the 2003 White Energy Paper also relate to 'local' and 'community', stating for the first time in official energy policy a future of energy generation in a more local mode [14]. The UK is making efforts regards introducing policies that encourage new initiatives which may effectively challenge current lock-in [9], as well as contributing towards its energy targets. The UK has legally binding targets of delivering 15% of all energy from renewable sources by 2020, and reducing GHG emission by 80% by 2050, with a reduction of at least 34% by 2020 and a target to achieve 9% energy savings by 2016 [15]. A variety of policies have been introduced in recent years ranging from financial tools such as the Low Carbon Building Programme and Carbon Emission Reduction Target (CERT) to local innovative planning policies and subsidies for the installation of new technologies such as the Feed-in Tariff. A good example of policies that may help drive decentralisation is declaring that all new built residential and non-residential properties must be 'zero carbon' by 2016 and 2019, accordingly, thus require some way of generating energy on-site [3].

However, the development of decentralised systems in the UK is much slower when compared to similar developed countries such as Denmark, Germany, Sweden and others, partly explained by the fact that most of the UK policies are aimed at energy generation rather than demand (i.e. user-behaviour) [5]. In addition, there is frequently a lack of direct connection between personal behaviour and energy consumption: there is a mixture of economic, technical, cultural, behavioural and institutional barriers that often slow down the uptake of the installed technologies and the potential maximisation of energy savings and emissions reduction.

2.1 Challenging Lock-in through Urban Energy Systems (CLUES) project

In order to critically evaluate the pursuit of decentralised urban energy systems in the light of carbon reduction targets in the UK, the CLUES[14] project began in 2010, focusing on the potential scope for scaling up various individual examples of decentralised urban energy projects to a national level. One of the specific objectives is to undertake a comparative analysis of urban energy initiatives in the UK and internationally in order to understand the processes involved in transforming local exemplar cases to practices replicable at different scales and in different local contexts [4].

This paper discusses the international initiatives only: with the UK initiatives being discussed elsewhere [16]. As well as gathering and analysing the information regarding these innovative international urban decentralised energy projects, it is also important and valuable to identify the potential possibilities of their application and scaling up in the UK.

The four case studies discussed here are from the USA, the Netherlands, Germany and Sweden with the focus on the experience of the project's development, rather than on a critical evaluation of policy or the technical efficiencies of the projects. Indeed, these countries have already successfully pioneered a variety of unique and effective approaches to more decentralised energy systems leading to enhanced carbon emissions reductions. It could be hypothesised that some of the best practices of decentralised urban energy systems implemented in Europe and worldwide are potentially replicable in the UK. However, when discussing replicability, it is important to consider that together with available natural resources and the access to technology, aspects such as social and cultural embeddedness and political and financial context also need to be

[14] www.ucl.ac.uk/clues

considered. The definition of decentralised energy is much wider than just the physical technologies of heating, cooling and electricity generation; it is a concept that encompasses energy systems at different scales, with different institutional, policy, environmental, economic and social contemplations [17].

3. INTERNATIONAL CASE STUDIES

The four case studies presented in Table 1 were chosen due to their geographic diversity and their variety of financial and technical approaches, together with their potential, yet unrealised, applicability within the UK context.

Table 5 Comparison summary of four case studies

	Seawater district heating	**Morris Model**	**Energy Saving Partnership**	**Kungsbrohusen office building**
Location	The Hague, Netherlands	Morris County, New Jersey, USA	Berlin, Germany	Stockholm, Sweden
Technology/ area	Seawater heating	PV	Building retrofit	Eco-smart building
Focus	Heating and cooling	Financing	Financing	Profit
Date started	1999	2009	1997	2010
Scale	750 houses	19 municipal buildings; 3.2 MW	1,400 buildings	1 building, 27,000m^2
Investment	€10 m	\$30 m (in bonds)	No initial investment	€120 m
Funding body and instigating party	Vestia (housing corporation)	Morris County Improvement Authority (MCIA)	Berlin Energy Agency	Jernhusen
Energy / CO_2 reduction	50% of CO_2 reduction	51,500 MWh over 15 years	60,400 tonnes of CO_2/year	50% of energy consumption reduction
Aim	Sustainability	Financial savings		Profitability

3.1 Seawater district heating system: an example of The Hague (Scheveningen/ Duindorp)

The City of The Hague and Vestia Housing Corporation partnered with Deerns Engineering Consultancy to implement this energy source in the reconstruction of 800 highly energy efficient houses located within Duindorp - an area along the North Sea Coast.

The technologies involved are not new: the innovation lies in their combination that allows constructing a very efficient system for making seawater or surface water the source of energy for heating and cooling homes as well as heating water all year round [19]. The overall efficiency of the heat generation process with this system is more than 50% greater than conventional high-efficiency boilers, while the cost to the residents is the same [18].

The sea water heating plant is part of the city's plan to use more sustainable energy and is one of the steps being taken towards making the area 'climate neutral'. In 2009, the plant was awarded a Climate Star for their climate protection activities [18].

3.2 Morris Model: a new way of financing PV for municipal buildings

The Morris Model is a unique and cost effective method of financing municipal renewable energy projects for public facilities through low-interest bonds, traditional Power Purchase Agreements and federal tax. It allows local government to receive access to renewable energy at a price lower than they currently do, without any debt obligation. The Local Financial Board approved the MCIA bonds of up to $30 m. The MCIA issued $21.6 m of debt at a 4.46% net interest cost with a county guarantee to fund 19 solar projects with 3.2 MW capacities [20].

Traditionally, local governments had two ways of financing solar programmes: either with tax exempt bonds (local government-owned approach), or by entering into turnkey relationships with private solar developers. The Morris Model is a hybrid that incorporates these two approaches and takes advantages of both options, whilst minimizing drawbacks [20]. The project uses a turnkey approach but financing is provided at the lower cost of capital is obtained by government. This allows a cheaper financing for the solar development as well as preserving the utilities capacity to borrow from the private capital lending sources for other projects [21].

The MCIA has completed the first phase of its award winning renewable energy project, providing the County with 3.2 MW in clean energy and around $3.8 m in annual savings [20].The model has been replicated in Somerset and Union counties in New Jersey with several other counties in various stages of programmatic review [20].

3.3 Berlin Energy Saving Partnership (BESP): an innovative approach to commercial buildings retrofit

The BESP was first introduced by the State of Berlin in 1995. The concept was based on transferring energy management of state-owned properties to a partner, who uses private capital to self-finance the modernization of building infrastructure necessary to cut energy use and CO_2 emissions. In return, the partner guarantees annual energy cost savings for the state [22]. Implemented energy efficiency measures include refurbishment of heating and illumination, energy management as well as user motivation.

This model has proved to be a success in Germany and is now widely replicated in other European countries, such as Slovenia, Estonia, Bulgaria, Romania, as well as in China, Chile and other countries [22]. The next step in the development of BESP is “Energy Saving Partnership Plus”: its aim is to extend the focus of the partnership on insulation and windows replacement.

3.4 Kungsbrohusen Office Building: eco-smart office approach

Kungsbrohuset is a 27,000 m^2 property in the centre of Stockholm, near the Stockholm Central Station. The owner of the building – Jernhusen - wanted to prove that it is possible to build a sustainable office building using available market materials and mature technologies rather than sophisticated but – in their opinion - ‘risky’ innovations. The objective of the project was to create a development where the environment and energy-efficiency are central considerations. The building is advertised as being ‘eco-smart’, which includes three characteristics [23]:

- Eco-smart building: The building with energy efficient façade and environmentally adapted materials, combined with other innovative solutions that lead to three environmental certifications.
- Eco-everyday: Services and technical solutions that enable users to operate in an eco-friendly way.
- Eco-location: The building’s proximity to public transport makes travelling and transports easier and contributes to lower CO_2 emissions.

4. DISCUSSION

Rather than discussing drivers and barriers separately, this paper presents an aspect based analysis that reflects the variety of interconnections influencing the outcomes of the projects. Governance aspects include both structure and process, and involve public, public-private and private activities. By social aspects we understand not only the end-users in the discussed cases, but also those ‘affected’ by these project, such as communities living around schools, people living in the area where the construction takes place and those engaged in public consultations.

4.1 Governance aspect

The case studies represent three types of governance: The Hague system was initiated by a private company and was supported by the local government, Kungsbrohuset is fully run by a private company, and both Morris Model and BESP were initiated by local governments and implemented through a third party.

The Hague system was initiated by a combination of stakeholders – local government, the housing corporation, the engineering consultancy and the utility company - who wanted to prove that a '*carbon neutral future is possible*'. Vestia originated the idea of the district heating system for their newly renovated housing development, and the Deerns engineering company developed the innovative concept of seawater district heating: *"We have the sea here and there's a lot of energy in it and we can try to get this energy out of the sea and bring it into the houses so that we can reduce CO_2"*. This decision, however, led to the dropout of one of the initial stakeholders – the utility company – which did not believe that the proposed system would work; this undermined the success of the project. Vestia therefore took all the financial risks thereon in and the project was thus completed. Vestia's policy has always been aimed at energy waste reduction and sustainability: "*Vestia had the initiative to be energy efficient. They were miles ahead of regulations, miles ahead of what the municipality asked then and actually wanted*".

This initiative was supported by the City of The Hague, although at the time of the project introduction (1999) the City of The Hague had not yet developed their plan to become carbon neutral by 2050. The City of The Hague, Deerns and Vestia had previously been partners on a variety of projects such as housing renovation and ground source heat pump district heating systems. The City of The Hague supported Vestia's request for the planning permission to use Scheveningen Harbour since it was free after the container transporter moved to another harbour. This however was not straight forward: the harbour is a part of the coastal defence system against flooding, so the construction could not take place between October and April, as sand is not allowed to be moved over this period of time. It is also a nature reserve that attracts tourism from May to September, which again restricted and slowed construction of the houses and piping infrastructure. Planning permissions also greatly delayed the timing of the project.

The Morris Model has a very different governance approach. Due to the nature of the public-private partnership, governance is closely intertwined with the financial aspect of the model. Morris County is an AAA rated local government and one of the wealthiest counties in the USA. This is very important when implementing a programme like the Morris Model, as the low cost bonds issued by the MCIA are guaranteed by the County. New Jersey is one of 38 states that have introduced a Renewable Portfolio Standard (RPS) according to which energy producers have to produce a share of their energy from renewable energy sources. The Morris Model is also triggered by the national regulation: Washington's tax code gives 30% investment tax credit for PV along with 5 years accelerated depreciation. From 2009 the developer can also get a cheque for 30%

from the US treasury – this is a stimulus bill which was introduced to boost the economy and which expires in the end of 2011.

The idea of a hybrid funding mechanism was proposed by the MCIA in order to lower energy costs for the local government. This was possible by bringing together ('pooling') municipal buildings, as when pooled together, these buildings had enhanced purchasing power and were able to obtain an enhanced energy price from solar developers due to the increased scale: "[…] *if you're a solar developer and you're looking at where I'm going to deploy my assets and wares, I'm much more interested in an 8 MW project than I am in a 250 KW project*." Choosing a pool, however, was not very straightforward due to the costs of site pre-screening until the developer is chosen: *"they* [developers] *do a preliminary look. They look at the sites, but they don't do a true engineering test and notwithstanding the screen[ing] that we do, there have been in each of these deals typically some change in the final makeup of the sites*."

This financial model lowered the costs of energy dramatically and these savings were passed onto schools and municipalities. As one of the initiators of the project stated, "*everyone seems very happy with the final product. All of the stakeholders seem very happy. The developers make some money, the County has helped its local governments, the towns and schools have gotten renewable energy at a lower cost, so it truly has been so far a win-win for everyone"*.

The reason for developing BESP was to reach Germany's ambitious climate protection objectives, as well as to reduce energy costs. Its basic principle is simple: a private specialized energy service company (ESCO) - the contractor- brings its expertise and financial capacity into the project. The responsibility of the contractor is to ensure that by making adequate investments, the energy savings can be guaranteed. Both partners then share the cost reductions; profits are also shared between the client and the contractor, while energy consumption is reduced. BESP was initiated by the City of Berlin: "*…Berlin decided "Yeah, this is the right way for us to do energy refurbishment on buildings." And they were also really active to develop the model contract and so on and there was in these times a lot of strong, political back-up"*. The City of Berlin is now only slightly involved in the BESP, and its implementation is the responsibility of the Berlin Energy Agency (BEA), which confirms a building pool (the client) and organises tenders for the ESCOs. Buildings willing to take part in the programme have to fulfill a set of criteria. The minimum size of the project is also important and, similarly to the Morris Model, in order to allow smaller buildings to take part in the programme, BEA can create a 'building pool'. After the client is chosen, BEA organises a tendering process for the contractor, who then implements the energy efficiency measures. The successful implementation of the BESP largely depends on the careful planning and development of the project.

Kungsbrohuset office building is managed by Jernhusen, who built it as a replacement for the old unattractive office building. The idea of making the new building sustainable came after watching Al Gore's film 'An Inconvenient Truth' and the consequent realization that climate change presented a good business opportunity. Having purely financial profit as the main aim, Jernhusen also wanted to prove that it was possible to build a highly energy efficient building using only materials easily available on the current market as well as mature existing technologies: "*We had no research in this building. There's no special materials that you just can buy from the American government or something. This is all purely made with normal stuff that you can find everywhere. And put together in a very delicate way. Any technology, any method, anything that we have done here is found somewhere else in the world. We don't want to be first with anything because we don't want to take the risk, and thereby showing people that you can do it as well if you just put your effort in it*".

Because of the technologically challenging design and, the main problem experienced by the company during the project implementation was the coordination of the large amount of contractors; "*The main challenge is organisational I'd say. People who are not really… To get everybody on the train, to get everybody to co-work with these goals of getting it as energy efficient as we wanted, to work with the environmental situation. Some people just said "Why are we going to do this? Can't we do it like we've always done it? Why do you want to make energy calculations every 4 months? You're not going to earn many per cent on that," etc. etc. That kind of to persuade people and finally it comes to "Either you do as I tell you to do or we get rid of you." That was one of the hardest parts – to keep the line, to keep the focus on the target*".

Problems were also caused by the Stockholm Sky Line Group who petitioned against high-rise buildings, and the public planning consultations. Similarly to The Hague case, this delayed the projects construction; this, however, did not affect the project negatively.

The success and popularity of the Kungsbrohuset office building can be attributed not only to access to finance by the building owners: they have managed their risks with a good market understanding, active involvement and strong commitment into the construction and operation process, together with a precise matching of new technologies and products with customer needs.

4.2 Financial aspect

The total cost of The Hague system was €7.5mln, of which €7mln came from Vestia Housing Corporation and €0.5mln from the City of Hague. The price of the energy for the end users is similar to the previous conventional system; this however does not reflect the actual unit cost price – it is currently being subsidised by Vestia and is guaranteed to stay at the same level for 10 years.

Initially, the estimated payback period accounted for 20 years, however at the current rate this does not seem to be achievable due to one of the stakeholders leaving the project at its implementation stage. This caused a 25% gap in investment, which was later covered by Vestia as no other subsidy was found. The National Authority was asked to invest in the project, but they rejected this, as they did not believe that the project would be successfully implemented. However, 10 years later the same National Authority was awarded the Climate Star for the "Best Innovation". In order to make this project profitable, more houses than the original 750 have to be connected to the system. A Further 250 houses are planned to be connected in the nearest future. As this project is the first of its kind, and was experimental in nature, it was developed not for profit but to help raise the profile of the City of The Hague as a sustainable city and to support Vestia's belief in sustainability . Vestia stated that although financially this project is not yet mature, it also raised the image of Vestia: *"For the energy saving it is a success, and also for* CO_2 *reduction it's a success, and to learn about it for a lot of people is a success".*

In the Morris Model, the MCIA played a very important role in financing. In the first phase the saving were around 35% for the developers, and this lowered the cost of energy from US $0.15 or US $0.16 down to US $0.106. In essence, the private developer does not invest any of its own money. The main benefit of the model is that the County (through the MCIA) is fronting the money for the local towns, and instead of the private developer using their own private money from a bank, they go to the Improvement Authority acting as the bank to give them cheaper finance. The schools and others participating in the programme buildings do not have to invest anything, as all the installation and maintenance costs are covered by the developer. In addition, some of the participants needed a new actual roof as well, the price of which was also embedded into the project.

Morris Model gave a financial opportunity to install PV for those participants who would not be able to afford it otherwise. A good example is a Boonton School District: "*As a school district we had a big construction project that went out for referendum for our voters in 2007 and I believe it was almost a $25m referendum. It included the installation of solar panels and it was defeated. So when the solar panels were removed from the project and the project was scaled down a little bit the voters approved it. So this kind of came right at the right time when the community was not willing to pay for it"*. Now the School District has 728 PV panels installed and in 2011 they aimed at saving around US$18,000.

Unlike Morris Model, BESP did not have any initial investment and the Berlin government did not provide any financial support to the ESCO. All the financing was made by the contractor. When signing a contract with the client, the contractor guarantees a minimum level of energy savings – on average it was 26%. The contractor then receives his agreed earnings if the stated savings have been reached. At the same time, the client is able to save money through reduced heating and electricity consumption, itself achieved through enhanced energy efficiency measures. The investment carried out by the contractor is also refinanced through these savings. Any remaining savings are shared by the partners according to a ratio system agreed in the contract. The contractor is responsible for the maintenance and servicing of the system for the duration of the project (5 to 15 years), and the client only fully benefits from the complete savings once the contract has expired. In some cases, part of the refurbishment costs also come from the client, if the client wishes to implement additional energy efficiency measures that are not offered within BESP due to their high costs, such as windows replacement or renewable energy technologies installation.

The financing of the project may become a problem in the near future however: while the energy performance of the buildings is improving, the potential energy savings are decreasing, therefore there is an ongoing need for further energy saving measures, such as window replacement or insulation: "*We have the contract for this and we want to do this with some pilot projects, but still it's we still have to find a pilot case and we still have to find the financing because you need then some financing from subsidies or from other. The ESCOs cannot finance this*". This causes uncertainty among ESCOs, as energy performance contracting (EPC) may soon become more attractive to construction companies rather than ESCOs.

The construction of the Kungsbrohuset office building was financially driven and the project was fully financed by Jernhusen, the owner of the building: "*We want to build this product on solely an economical base. […]we had the land and we had the former building, so we had you could call it a business opportunity, but it's not* [about sustainability]. *It's mainly…to earn money*".

The concept of the building as being 'green' and 'user-friendly' as well as the central city location of the building allows the owner to charge higher rents: "*We earn money on the tenants because they pay us money to rent the letting. We don't earn the money on the energy efficiency. That's just a bonus kind of. We earn more money because its energy efficient, but we don't earn money only because it's energy efficient*". The construction of the energy efficient office building was not a core business for the company; however, it now is a part of the company's strategy. After the Kungsbrohuset attracted a lot of attention and brought higher than planned profit, Jernhusen is planning to construct similar building in other cities in Sweden.

4.3 Social aspect

Social aspects are crucial when discussing energy consumption reduction, particularly in building use, and introducing new low-energy initiatives does not necessarily mean rapid carbon reductions, as most of them require some form of human adjustment and change in behaviour.

In order for the seawater heating to work efficiently, for example, an understanding of how the system works is required from the end-users (occupants). To encourage the acceptance of the new heating system, Vestia organised information evenings for the occupants, as well as distributed information brochures; yet it took a long time for those living in the houses to accept some of the changes. The main challenge was the idea of the constant heating: when using seawater heating system, it takes about two days to warm up a house to the desired temperature, whereas with conventional gas heating, it is possible to obtain the required temperature within a few hours. Another barrier that slowed down the social acceptance was the fact that the system consisted of under floor heating, not wall-mounted radiators like the occupants' previous systems. Many did not appreciate that a particular type of carpeting must be used: otherwise the heat gets trapped and the temperature in a house does not increase efficiently. Again, this problem was being addressed through educational campaigns.

Vestia admits that the installation of the seawater district heating did not dramatically change end-user behaviour, partly due to the lack of interest and awareness: *'Because people with low income and low education, they… don't understand exactly how to use all this kind of stuff and they don't care about it. They care about other stuff – what the neighbours do and how to get beer or something. It is a social housing… It's a group where everyone knows each other. It's something like Coronation Street...*'. Although the change in end-user behaviour towards the acceptance of the seawater heating is slow, it does not dramatically affect the overall success of the project from a financial or efficiency point of view, and Vestia continues to run educational programmes in order to improve the awareness.

This raises the additional point of ensuring that any new type of renewable energy or energy saving system is designed with the end-user in mind, in order to work with the vagaries of occupant behaviour, and not against. The Kungsbrohuset building did exactly that: "*People don't want to change and they just want to have it the way that they've always had it and if they're going to change it has to be something better or easier or something. They don't want to do something that takes more time and they don't want to pay more money. They just want it to work anyway. So no, we have built this building so it kind of like helps them to save their energy*". In order to help the tenants save the energy without extra effort, the building is provided with energy efficient appliances, motion lighting, and the 'Green Button' that allows switching off of the electricity in the entire building (except for the computers). In addition, the energy monitor at the entrance hall of the building provides the occupants an opportunity to see how much energy has been generated and consumed.

Although behaviour change was not a part of the original idea, in order to maintain the 'green' reputation of the building, all the tenants in the building are supported by an expert who helps to minimize their impact on the environment. The building is also provided with a secure bicycle storage area, while the car parking space in purposefully limited. These factors, as well as the location of the building being close to the central railway station and bus terminals, encourage commuting: "*So there's 1800 people* [in the building] *and 100 car places. So that's 100 bosses who drive their cars. 400 go by bicycle and then it's 1300 who go by commuting I'd say*".

The Morris Model did not have behaviour change towards sustainability as its primary objective; however, the buildings particularly the schools participating in this programme, saw a good opportunity "*to show our community and our students that our school district was attempting to do something that would be positive for the environment and also positive for the taxpayers*". In order to encourage a better understanding of renewable energy, solar developers were required to include educational components, such as interactive kiosks and LCD monitors. Some schools have portable kiosks that can be moved from class to class: this allows students to generate graphs and charts to see how much energy is being produced at any given time. They provide informative campaigns for the community and the taxpayers, as many see the low costs of energy "*as too good to be true*".

Social aspect is an important part of the BESP. Every ESCO that carries out implementation of energy efficiency measures in the building is required to provide a user motivation programme, in the form of information distribution, workshops or others. This is particularly important in the current projects of the BESP, as the profit of the ESCOs depends on reaching the established energy saving target. There is a limit on how much savings the technical disruption can provide however, and in some cases the way users consume energy plays a crucial role, therefore it is in the interest of the ESCO to educate the end-user and hence, as a result to achieve higher energy savings. It is important to mention that user motivation is aimed not only at particular building staff such as estate officers, but rather at actual building users/occupiers, including even as far as kindergarten children. One of the companies involved in BESP commented: "*they* [users]*'re often very interested and very open to that, but the knowledge about energy saving, and also the ideas of what you can get as energy savings, is really far from reality. So there's a lot of lack of knowledge*". Workshops and awareness campaigns however, can sometimes cause problems: "*The expectations are often that high that they say "okay, we can replace the windows" like you said, or "Why can't we do some other things?"*". These measures go beyond the technical possibilities of ESCOs and hence can sometimes cause tension between the client and the contractor.

5. CONCLUSIONS

The four case studies presented here vary greatly not only in terms of their technology, scale and location, but also in terms of their governance and financial mechanisms. It was demonstrated that governance and social barriers rather than technical and financial ones constitute central problem areas in the adoption of decentralised energy approaches, indicating multi-dimensional complexity associated with organising and staging energy supply. Governance drivers play the most significant role, although not necessarily in the form of regulations, whereas financial drivers that are normally believed to be crucial were not viewed as such. Our discussion - although it does not exhaust the full list of potential drivers - offers useful hints regarding these, including regulations with legally-bound targets, and social drivers, such as word-of-mouth. Such a variety of drivers implies that there are different, and often inter-connected, pathways to decentralised energy development. All four projects have already been replicated or are planned to be replicated, in their own countries and abroad, including in two cases

(BESP and The Hague), the UK (although on a much smaller scale). Indeed, they have potential for replicating and scaling up in the UK and hence contributing to carbon reductions. Although the implementation of decentralised energy systems is facing various obstacles, it is important to remember that energy-related decisions made today will have long-lasting consequences not only in terms of investment but also in terms of their impact on society as well as wider global climate change.

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Energy Policy and Financing

Project funding for innovative research and development projects – a practical example in the field of renewable energy

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Abstract:

In order to guarantee sustainable economic growth and future-oriented jobs any government is in charge of providing the right framework conditions. An important lever is to support inventions as well as innovations all along the value chain. That applies for all fields of technology and for the field of renewable energies in particular.

Besides various national and regional specific funding programs the federal state of Lower Saxony (Niedersachsen), Germany, established a subsidization guideline mainly targeted at small and medium-sized companies (SME) to enable the implementation of research and development projects. Provided that the content-related and formal criteria of a project proposal meet the requirements of the guideline, the applicant may receive up to 50% sponsorship of the total project costs. This paper focusses on the process of project funding with respect to a practical example in the field of renewable energy, beginning with the relevant network activities and ending with the evaluation scheme applied to decide whether the proposal qualifies or not.

The practical example chosen deals with the application of a PEM fuel cell-system to be installed in a wind energy plant in order to maintain emergency functions during power failure or while the assembly phase is still ongoing.

Keywords: Innovation framework, evaluation scheme, technology transfer, renewable energy

1. INTRODUCTION

Drivers of innovation processes can mainly be divided into four groups: science, economy, consumer and policy. The interaction of these groups can be illustrated by considering the innovation supply potential over the innovation demand potential (Fig. 20). Evidently, the supply potential of science and economy is high as well as economy and consumers provide a high demand potential. This way two driving trends can be observed. One is the technology trend with its origin at science towards economy (e.g. micro- and nanotechnology, bio- und gene technology, automation), second one is the consumer trend (e.g. mobility, health, communication). Consequently, new innovative products are introduced to the market for the benefit of the consumer.

Unfortunately, the introduction of clean energy technologies to the market is the best example that the economic system not always works this way. Although there is a certain interest in a product on the demand side there might still be too many obstacles that prevent the development on the supply side. The exceptions to the rule can often be subsumed under market failures. If desirable products within the range of clean technology on the one hand show outstanding figures on the carbon footprint but on the other hand cannot guarantee functionality to a reasonable price that is already state of the art in comparable products they will not find many customers. High technological and economic risks very often keep the industry from making further progress despite promising market situation, so that only innovations would change this attitude. In order to enable the development of these products the fourth driver of innovations – policy – therefore should set up appropriate framework conditions.

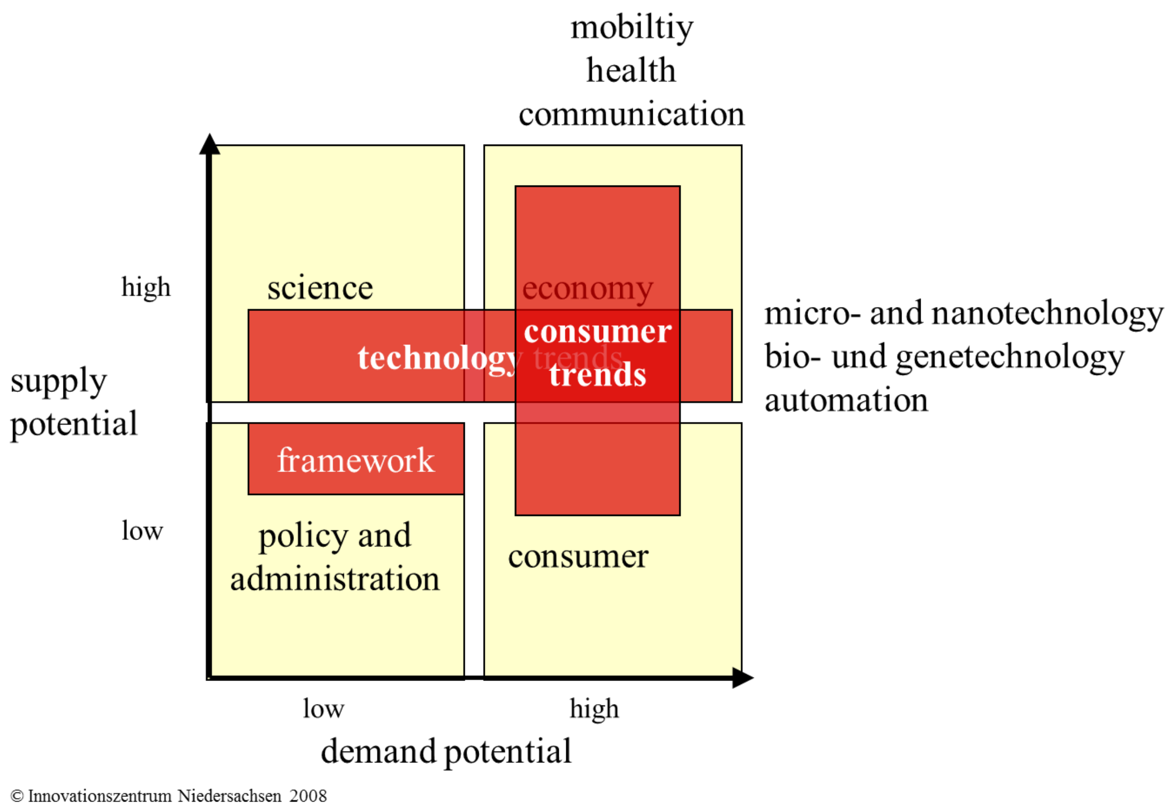

Fig. 20: Drivers of innovation

2. FRAMEWORK FOR INNOVATION AND TECHNOLOGY TRANSFER

There is no patent solution regarding a framework for innovation. Policy of any country or region is responsible to set up a system that fits to the individual requirements.

2.1. Technology site of Niedersachsen

This paper reflects on the individual requirements of Niedersachsen (Lower Saxony), a federal state of Germany. Its technology site maintains a key priority for adjusting a framework for innovation and technology transfer by taking into account that strengthening the virtues of a site finally leads to prospects of the future. Regarding companies and research institutes that belong to leading entities with respect to a certain field of technology an overview of the technology site of Niedersachsen is derived (Fig. 21). Three classifications can be made to distinguish the level of a technology branch from its national and international competitors. Focusing on wind energy and vehicle manufacturing the economy in Niedersachsen belongs to the top worldwide among others. Therefore, a practical example for supporting the innovation process within the framework was chosen from the interaction between renewable energy (wind energy) and drive technology (fuel cell).

Niedersachsen installed 6.8 GW wind energy (June 2011) which is approximately one quarter of current installed capacity in Germany. The energy strategy of Germany aims at covering at least 80% of gross electricity consumption from renewable energy sources by 2050 while consecutively taking off-line nuclear power plants by 2022 [1]. Despite the high degree of wind turbines in Niedersachsen the expansion and implementation of wind energy is still ongoing. The importance of the energy issue leads to the decision to create an own energy strategy for Niedersachsen [2]. Aligning to milestones Niedersachsen plans to cover 80 % of the gross power consumption from renewable energy – including offshore wind energy roughly 140 % are theoretically possible. Wind energy is therefore a key position to meet the targets. The energy strategy of Niedersachsen proposes the following regulatory framework concerning onshore and offshore activities (Table 6):

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Fig. 21: Technology site of Niedersachsen

Table 6 Regulatory framework for wind energy in Niedersachsen

Onshore wind energy	Offshore wind energy
Reducing the regulatory limitation of height of the wind turbine	Enabling port infrastructure
Instead of setting up strict distance limits individual decision for appropriate areas are allowed	Defining areas for required power lines for connecting offshore wind farm
Simplifying the admission of wind turbines	Initiating part time degree courses for employees
Repowering	Defining test areas to study wind energy within the 12 miles zone
Establishing an repowering platform for owners of old wind turbines and investors	
Regional policy supports the activities on a national level	

Nevertheless, apart from a regulatory framework there are still several technological challenges that need to be solved by an interaction between science and companies such as increasing the power outcome per asset, fluctuating electricity feed in, setting up of load-bearing structures, improving weather forecasts, grid expansion and European integration of energy markets.

Volkswagen as one of the world largest vehicle manufacturer is making great efforts in research and development of low-carbon drive technologies on the basis of biomass and synthetic fuels as well as electric mobility. The development of next generation batteries and fuel cells is still subject to national and international research. Just considering the broad field of fuel cells there is an enormous need for development concerning all components in terms of reducing costs, extending lifetime and simplifying the system, so that an intensive level of innovative activity is required (Table 7).

Table 7 Technological challenges for developing fuel cells

Material technology of stack components	MEA technology (MEA = diaphragm electrode unit)	Fuel/air-supply
Bipolar plate	New coatings	Integration of motor, motor driver electronic and compressor
Resistivity against corrosive media, high temperature and mechanical load	Zero-carbon electrode substrates	Process stability for vehicle-specific features during operating conditions
Sufficiently high electric potential and conductivity	Platinum free catalytic converter	Design and production of pressure regulation
Cost-effective materials and automated manufacturing.	Proton conducting membrane electrolytes	Investigations of life cycle and corrosion
Power electronics and control systems		
Test engineering		

2.2 Innovation framework of Niedersachsen

A sustainable climate and energy policy and the competitiveness of the companies at the site both are decisive factors for an innovation framework in Niedersachsen. The next section provides the means of knowledge- and technology transfer in order to introduce innovations despite technological challenges named above and refers to the actors that contribute to the value added chain of innovation (Fig. 22).

An institutional funding of universities and scientific research institutions provides the basis to guarantee the interaction of several faculties necessary for investigating the complex subject of climate change and energy topics. Therefore, the government of Niedersachsen established research institutes that work together across locations. The energy research center of Niedersachsen (EFZN) was founded to ensure an interdisciplinary analysis regarding the complete energy chain. Furthermore, the center for wind energy research (ForWind) bundles wind energy research activities from the universities Oldenburg, Hannover and Bremen into a broad spectrum within the areas of physics and engineering. The German wind energy institute (DEWI) is one of the leading international consultants in the field of wind energy, offers all kinds of wind energy related analysis for industry, wind farm developers, banks, governments and public administrations.

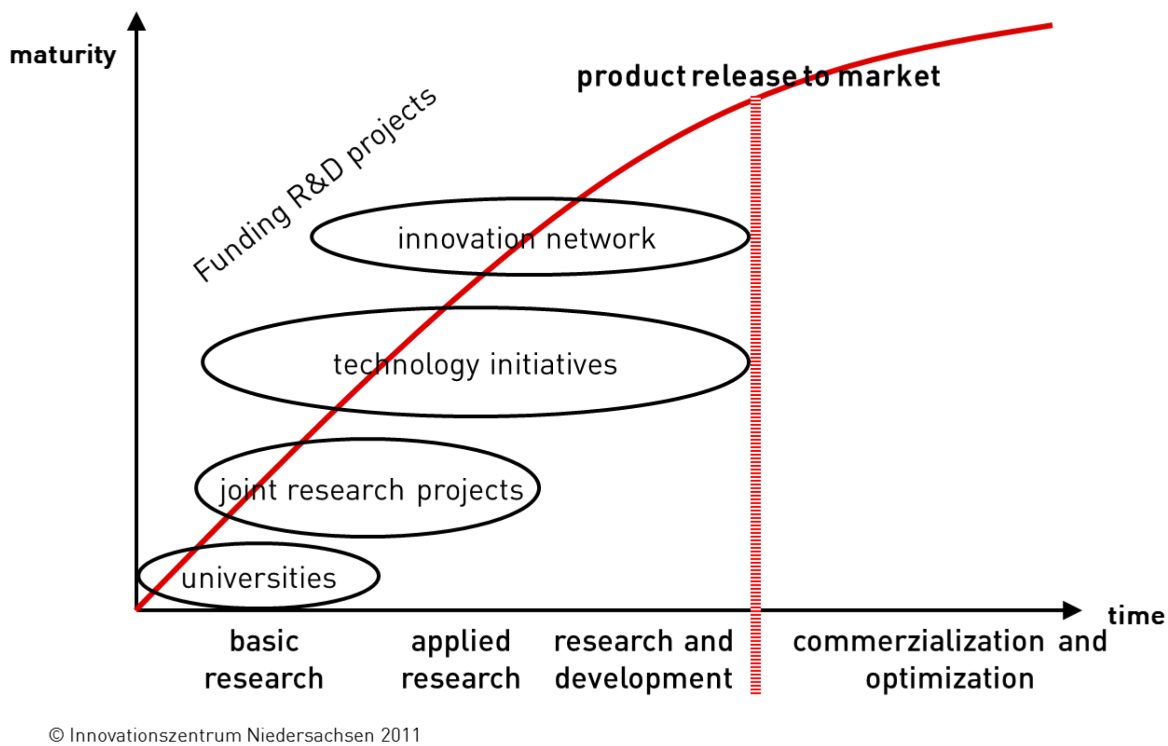

Fig. 22: Partners of value added chain of innovation

Funding joint research projects on energy topics enable the knowledge transfer mainly among research itself. Second task is to provide a competent contact point for companies that are already interested in basic research. At this stage the cooperation among research respectively research and companies not only increases quality of research and teaching but may also result in far advanced products or services. There are presently three joint research projects in Niedersachsen dealing with decentralized energy systems, sustainable use of biomass energy between conflicting priorities of climate protection, landscape and society and the consequences of climate change for costal protection, animal and crop production, forestry and land-use planning.

The further research and development advances on the time scale the higher product maturity is achieved. Technology initiatives aim at intensifying the knowledge and technology exchange between companies respectively companies and research institutes. Technology initiatives set up networks providing a trans-technologically and interdisciplinary communication platform. This network supports research institutes and companies (preferably SME) in order to develop innovative products, processes and services resulting in increasing innovation capabilities within the companies and contributing in increasing or securing jobs. Currently, the technology initiatives nano and material innovations, life science, aviation, maritime cluster, information technology and fuel cell/electric mobility convey innovations. The main tasks of a technology initiative are described in Fig. 23.

- Establishing trans-technologically and interdisciplinary networks
- Initiating innovative projects between science and companies. Therefore, need for development has to be linked to the competences of the companies on site
- Aquiring national and international funding
- Effective presentation using different media
- Supporting the government in Niedersachsen

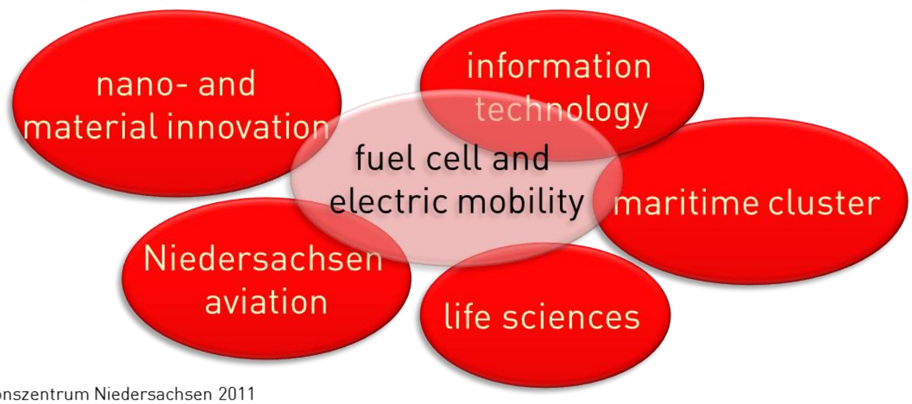

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Fig. 23 Main tasks of technology initiatives in Niedersachsen

3. FUNDING RESEARCH AND DEVELOPEMENT

Along the value added chain of innovation different guidelines support the funding of research and development. The guidelines set up rules that have to be followed by the project partners in order to achieve non-repayable subsidies. The following section shows the subsidization guideline especially developed for Niedersachsen along with the evaluating scheme for independent experts and ends up with a practical application of the guideline on a research and development project in the intersection of fuel cells and wind energy.

3.1 Innovation guideline of Niedersachsen

After all relevant players were brought together on the technical side, national and international funding programs have to be considered that are suitable. Niedersachsen offers a guideline open to all types of technology to especially support research and development of small medium enterprises that deal with high technological targets and risks [3].

Before notice of granting can be delivered, so that the project can start, certain steps have to be carried out carefully.

First of all, the project consortium has to prove that the formal aspects such as liquidity and solvency are sufficient for the proposed project. Then, an evaluation of the quality according to the innovative topics is matched with the criteria of the guideline. The guideline is certified by the European Union. Table 8 shows the criteria that have to be evaluated by the expert committee.

Table 8 Quality criteria for innovation funding based on Niedersachsen guideline

Features	Guideline for innovation funding
Quality criteria	1. Derived product, process or service is either new or a significant improvement to the German market. 2. Project approach is clarified in detail 3. Project approach promises success 4. Derived product, process or service is marketable 5. Project contributes to the performance of industry situated in Niedersachsen 6. Jobs are ensured or created 7. Project contains high technical risk 8. Project contains high economical risk 9. Use of resources is done most efficiently 10. Environment and Sustainability is taken under account 11. Gender aspects are guaranteed
General notice	12. All quality criteria have to be fulfilled 13. Evaluation of quality criteria is carried out by independent experts
Deadline	None
Rejection	In case of rejection the applicant receives the negative evaluation

3.2 Evaluation scheme

In order to evaluate the quality criteria a scheme has to be applied to enable a comprehensible and reproducible assessment for the expert. Table 9 shows a scheme that is used to evaluate research and development projects based on Niedersachsen guideline.

Table 9 Evaluating scheme

Features	Evaluating scheme
Innovation	1. Product, process or service has a definable task. Compared to other products this task is achieved with a higher ideality: A higher ideality results from dissolving the connection between added functionality and added disadvantages (major restraint of growth). The connection between added functionality and added disadvantages is dissolved by application of at least one of one of the following: miniaturization, automation, integration, and self-organization. 2. Product, process or service … improves functionality introduces new technologies from other disciplines extends the area of utilization by integrating new functions extends the area of utilization by integrating formerly unknown functions consists of a new technical system 3. Product, process or service … is new to the German market is an adaptive development
Market	4. Target market Commercial customers (B2B, customer (B2C), public sector 5. State of development Mature market, growing market, future market 6. Consumer trend Mobility, communication, health, sustainability 7. Number of branches targeted at 8. Benefit for the customer

	Usability, time to market, anticipated price
Resources	9. Knowledge resources Within project consortium, external service supply, network, applied research, basic research 10. Personnel resources No change, safe jobs on a long scale, create new jobs 11. Added value in Niedersachsen
Competence	12. Degree of competence within the consortium
Overall impression	13. Technical risk 14. Economical risk

3.2.1 Initiating a research project in the intersection of fuel cells and wind energy

The application of the Niedersachsen guideline can be illustrated on a research and development project in the intersection of fuel cells and wind energy. As the first step, the technology initiative for fuel cell and electric mobility generated the issues on the supply side.

The supply side confirmed that all relevant components of forced-air ventilated low temperature PEM fuel cells are introduced to the market. Still the suitable configuration is to be determined and to be optimized for an industrial application. Then, the technology initiative fuel cell/electric mobility linked the producer of fuel cells with several potential users on the industrial side. Finally, a producer of wind turbines agreed to participate in a combined project. The application of PEM fuel cells within a wind turbine could be a new innovative solution to maintain important emergency functions during power failure or while the assembly phase is still ongoing.

An application was submitted on basis of the Niedersachsen guideline. All research and development projects have in common that once it is applied for time to start has to be as short as possible. Therefore, the evaluation of the formal and innovation criteria has to compromise between accuracy and short processing time. With respect to the practical example independent experts stated that all quality criteria were fulfilled and in case there is no liquidity problem granting could be delivered to the consortium.

4. CONCLUSION

An innovation guideline should take into account the individual structure and potential of the situated companies and research institutes on a site. This paper illustrated the means for regulatory and innovative framework according to a practical example in the intersection of two technology fields of clean energy technologies. Focusing on the process of initiating and funding a research and development project the Niedersachsen subsidization guideline and its evaluation scheme was taken as a basis. Funding innovative projects that else would not be considered by industry is one measure against market failure and one step towards a sustainable economic growth with future-oriented jobs in the field of renewable energy.

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Sustainable Energy Development in the Pacific – the Evolution of Energy Frameworks and National Policies

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Abstract:

The Pacific Island Countries and territories (PICTs) face a number of common energy challenges. One of these is the lack of indigenous fossil fuel resources This leaves these nations with no option but to import the required fuel from abroad at great expense. The remoteness of these island nations imposes further costs and introduces supply chain issues.

Over the past decades, the region has been actively engaged in finding ways in which these challenges could be addressed and solutions found that reduced the region's reliance on imported fuels. The earliest thinking relied heavily on the possible use of renewable energy to substitute for fossil fuel. Over the years however, there has been a gradual evolution of thought, with the consequence that recent energy strategies at both the national and regional levels have realized the limitations of this one-pronged approach. It is realized that some energy use sectors will continue to depend on fossil fuels for a long time. The importance of energy efficiency and effective energy policies and plans is also acknowledged. Another important development has been the use of the whole-of-the-sector approach to the solution of energy problems.

This paper traces the development in energy policies that have taken place in the Pacific over the last decade, and critically assesses the key elements of the new thinking in the energy planning for the region. After deliberating on the needs for energy policies in general, it examines the features of the Pacific Island Energy Policy and Plan (PIEPP), and discusses the possible reasons why it was unable to deliver its expected outcomes. The importance of the whole-of-the-sector approach as well as other considerations that

are now thought to be essential tools for energy planning and implementation in the Pacific region is discussed. The present status of development of a regional energy strategy, as embodied in the Framework for Action on Energy Security in the Pacific (FAESP), is then outlined.

Keywords: Sustainable energy development, Energy policy, Energy Efficiency, Pacific Island Countries (PICs), National Energy Policy, FAESP

1. ENERGY CHALLENGES OF THE PACIFIC

The Pacific Island countries and territories (PICTs) comprise 22 island nations and territories stretching from the Northern Marianas to the North West of the Pacific to French Polynesia and Pitcairn Islands to the South East. They include American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn Islands, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis and Futuna Islands. The total population that inhabits these 79 million square kilometers of the mid-Pacific region is about 10 million. However, when the population of 7 million belonging to Papua New Guinea alone is ignored, the true picture of a sparsely populated region of nations separated by vast distances emerges.

The PICTs are faced with many energy challenges because of their remoteness, sparse populations and their geological nature. Because of their general lack of indigenous oil reserves (except for Papua New Guinea) they are heavily dependent on imported fossil fuels for their energy needs. Almost all of this is required for their power generation and transportation needs, with 25% of the imports going towards the former sector and 75% towards the latter [1]. Imported petroleum is responsible for more than 80% of power generation in the PICTs. The Cook Islands, Kiribati, Nauru, Solomon Islands and Tonga, are entirely dependent on imported fuel for their power generation [1]. Figure 1 indicates the large contribution imported fossil fuel makes to the power generation mix of selected PICs.

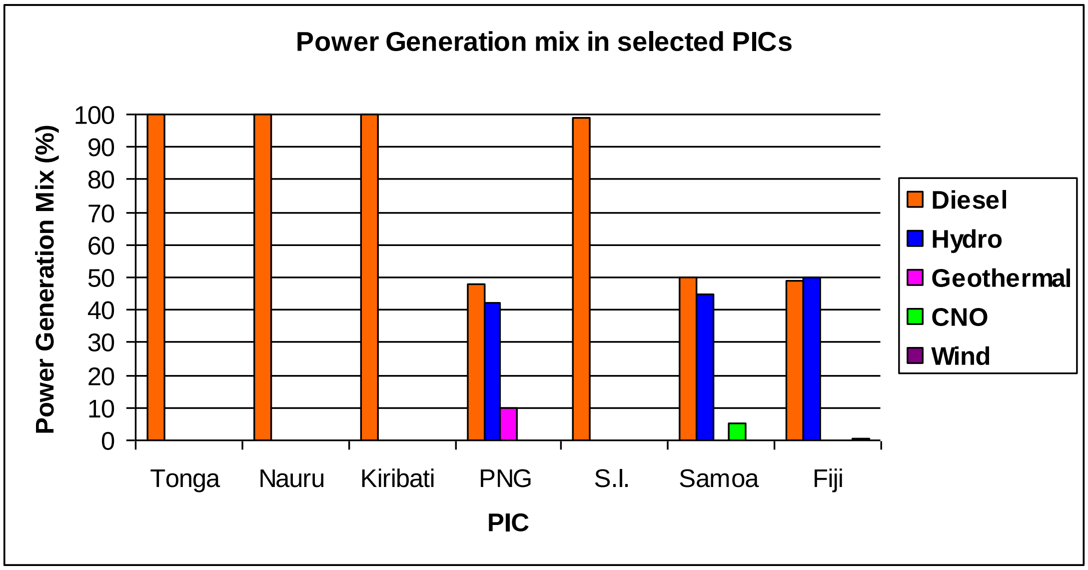

Figure 1. Comparison of imported fossil fuel and other primary energy sources for power generation – selected PICs (source: [2])

A matter of great concern to all PICs is that fuel import costs as a percentage of their GDP have more than doubled between 2002 and 2008. In the case of Fiji, the ratio of fuel import costs to GDP increased from 5% in 2002 to 12% in 2008, while this ratio increased from 12% to 25% between the same years for Kiribati [3]. Because of the almost total dependence of the PICs on imported fuels for power generation and transportation, a rise in fuel prices contributes to inflation, deterioration in balance of payments and lower real incomes in these countries [1]. Some experts have predicted that the situation is currently (2012) developing towards another fuel price crisis for these countries. As global fuel prices have nearly doubled over the last two years (2010, 2011) an oil price shock to the PICs comparable to that of 2008 is imminent.

These economic ramifications of imported fuel prices has made the region well aware of the need to reduce, if not eliminate its imported fuel dependency. Ways that come to mind are substitution of imported fuels by indigenously-sourced energy supplies, the most obvious of which is renewable energy. Import bills can also be reduced by reducing the landed price of imported fuels, and by making more efficient use of this commodity through energy efficiency measures.

In working towards a viable solution to the fuel import issue, the region is faced with several challenges. These include the small, isolated nature of most PICs, the limited and varied availability of indigenous renewable energy resources, and the lack of human and institutional capacity to meet these challenges [4].Acrucial first step to developing solutions to these energy challenges is the formulation of energy policies, both at the regional and national levels. This paper outlines the attempts that have been made over the last decade towards the achievement of such aims.

2. EARLY ATTEMPTS AT A REGIONAL POLICY

The PICs differ vastly in their demography, geography and geology. They range from low-lying coral atolls to mountainous volcanic island states, and from populations of a few thousands to several millions. There are also many social and cultural differences, including language differences. Apart from English and French, the region boasts a rich diversity of indigenous languages. Geological differences between the volcanic islands and coral atolls mean the availability of energy resources such as hydropower and biomass resources is not even across these island nations.

While the PICs have many energy issues in common, there are also many differences in their energy needs and their ability to satisfy them. Each nation thus needs an energy policy that is tailor-made to suit its own requirements. But there are also challenges it shares with other PICs, a notable example being the fossil fuel supply problems to remote small island states. There is therefore a need for regional policies to cater for such common requirements. These small nations also need guidance in the development of their individual national energy policies.

The first regional energy policy to be attempted was the *Pacific Island Energy Policy and Plan* (PIEPP) [5]. It was developed in 2002 by the *Energy Working Group* (EWG) of the *Council of Regional Organizations of the Pacific* (CROP) and was to act as a "guideline for a regional organization energy policy and for developing PICT national energy policies" [6]. This Plan was revised in 2003 to strengthen the renewable energy (RE) component and presented to the *Regional Energy Ministers' Meeting* (REMM) in Oct/Nov 2004 [6].

The PIEPP consists of 6 themes and 4 cross-cutting issues, collectively labeled as the 10 sections. The six themes were *Regional Energy Sector Coordination*, *Policy and Planning*, *Transportation,Renewable Energy*, and *Petroleum*. *Rural and Remote Islands*, *Environment*, *Efficiencyand Conservation*, and *Human and Institutional Capacity* comprised the four cross-cutting issues.

The nature of a section was defined via a statement of goal. For each section, policies were stated, a strategy or strategies adopted for its implementation, activities stipulated for the implementation of the strategies, and indicators of success (i.e. key performance indicators) identified for assessing the outcomes of each activity. The goal, policies and strategies of a typical section (Theme 5, Renewable Energy) are listed in Table 1.

The task of ensuring that each strategy was properly implemented was allocated to a specific regional organization, called the "lead agency". In 2004, the overall administrative responsibility for energy was given to the *Pacific Islands Applied Geoscience Commission* (SOPAC). There were also assumptions associated with each strategy that had to be clearly recognized, and a timeframe to indicate the expected time of completion.

Table 1 The goal, policies and strategies of PIEPP corresponding to theme 5 (Renewable Energy) (source: [5])

Theme	**Goal**	**Policies**	**Strategies**
5. Renewable Energy	5. An increased share of renewable energy in the region's energy supply	5.1 Promote the increased use of proven renewable energy technologies based on a programmatic approach	5.1.1 Implement a regional RE programme
			5.1.2 Ensure access to information and training materials in RE
			5.1.3 Assess RE potentials in PICs
			5.1.4 Assist PICs in obtaining funding

			for RE projects
			5.1.5 Carry out feasibility studies of RE technologies in the PICs
		5.2 Promote the effective management of both grid-connected and stand-alone renewable-based power systems	5.2.1 Support the establishment of stand-alone power systems by the utilities
		5.3 Promote a level playing field approach for the application of renewable and conventional energy sources and technologies	5.3.1 Remove biased barriers to application of RE technologies
		5.4 Promote public-private partnerships and mobile external funding for RE	5.4.1 Implement externally-funded projects through public-private partnerships

All these features are exemplified for the case of the renewable energy strategy 5.1.1 in Table 2 below.

In December 2004, the PIEPP was separated into two complimentary documents - the *Pacific Islands Energy Policy* (PIEP) which was a policy document only, and the *Pacific Islands Energy Strategic Action Plan* (PIESAP) which was the associated working document [4]. The two documents were endorsed by Senior Energy Officials at their Regional Energy Meeting held in December 2004 in Madang, Papua New Guinea [4].

3. INADEQUACIES OF THE PACIFIC ISLAND ENERGY POLICY AND PLAN (PIEPP)

Possible problems with the PIEPP became evident as early as 2004 [6] when it was observed that the division of responsibilities for the implementation of the Plan would be a major difficulty. The Plan was the responsibility of the Energy Working Group (EWG) of the Council of the Council of Regional Organizations of the Pacific (CROP) and was administered by SOPAC. However, the EWG seemed to have an "unclear mandate, outdated terms of reference, and … no budget for its meetings" [6]. It is also obvious that while the EWG had the overall responsibility for the Plan, the themes were apportioned to several different regional organizations each of which had an interest in energy.

Table 2 The organizational features of the RE strategy 5.1.1 of PIEPP (source: [5]).

Strategy 5.1.1 Design and implement a regional programme to promote the widespread and sustainable utilisation of proven renewable energy Technologies				
Activities	Lead Organization	Indicators	Assumptions/Risks	Time Frame
Install 10,000 solar water heaters in schools, hospitals and community based premise	SOPAC	Number of installed systems [Regional programme reports]	Resources (financial and TA) available	2012
Install 20,000 solar modules in rural	SOPAC	Number of installed systems		2012

electrification projects		[Regional programme reports]		
Install 5 wind power projects with a combined capacity of 5 MW	SOPAC	Number of installed systems [Regional programme reports]		2012
Install 1pilot micro-hydro project	SOPAC	Number of installed systems [Regional programme reports]		2012
Support the use of bagasse and wood chips where feasible	SOPAC	Energy Mix statistics [Energy Sector annual report]		2012
Plant 0.5 million fuelwood seedlings in atoll countries	SOPAC	Energy Mix statistics [Energy Sector annual report]		2012

In a review of the Plan carried out in 2010 [7], it became clear that there were several underlying flaws that presented serious barriers to its successful implementation. The two main objectives of the Plan were to coordinate the regional energy sector planning and programmes of regional organizations, and to offer guidelines in the planning of National Energy Policies and Plans of individual PICTs. It was essentially found that while the Plan was largely successful in its second objective, it was unable to carry out its first objective with any effectiveness. The main reason for this failure seemed to lie in the lack of a clear vision for the regional energy programme, as well as uncertainty in the role the lead agency assigned to this task (SOPAC) was supposed to play. But there were several other serious failings pointed out by the review committee. Among these were

- The objectives of the Plan were vague, and lacked focus
- There were no guiding principles for the energy sector development
- No proper timeframes had been set
- There were no clear allocations of responsibility
- There was no mechanism mentioned for the monitoring and evaluation of the success of the activities
- The Plan did not emphasize that the region would be dependent on imported fossil fuel for a long time to come, and subsequently that fuel pricing and supply issues should be addressed as a priority
- The importance of data on energy in decision-making was not stressed

At the Pacific Energy Ministers' meeting (PEMM) at Nuku'alofa, Tonga in April 2009, it was resolved that the lead role for energy in the region was to be given to SPC. It then became evident that PIEP and PIESAP had to be revised if SPC was to succeed in its new role. This was brought to the notice of the Pacific Leaders at the Pacific Islands Forum Meeting in Cairns, Australia in August 2009. The ministers agreed on the need to review the PIEP and its associated Action Plan (PIESAP). The key priorities to be addressed in the review included strengthening coordination of regional services and donor assistance, and the delivery of energy services to the region through one agency (the SPC) and through one programme [8].

The ministers also called for [8]

- Human capacity development to support national and regional energy programmes
- Strengthening national capacity in collection and analysis of energy data and information
- Support for the regional bulk procurement initiative
- Facilitation in investment in sustainable renewable energy technologies, energy efficiency and energy conservation

The document that resulted from this decision was the *Framework for Energy Security in the Pacific (FAESP)* [8] and its associated implementation plan, which were endorsed by the Pacific leaders in 2011.

4. NEW THINKING IN REGIONAL ENERGY PLANNING

A novel feature of FAESP is its use of the "whole-of-sector-approach" (WOSA) in problem-solving. It is also based on a "many partners, one team" philosophy, which acknowledges that energy solutions for the region require input from many stakeholders who should be accorded equal status, and considering energy the sector in its entirety rather than focusing only a limited aspect. So what is the whole of sector approach?

This new approach to energy planning was used for the first time earlier in the formulation of the *Tonga Energy Roadmap* (TERM), the new national energy policy for Tonga by the several development partners and other stakeholders involved in the exercise [9]. The essential features of WOSA are described in a paper delivered by the World Bank at the Forum Energy Ministers Meeting (FEMM) in Brisbane Australia on 21 June 2010 [10]. According to this paper, a successful WOSA at the national level requires that the government coordinates the activities of all relevant stakeholders involved in the planning, and allows access to all relevant energy information to the team members. In addition, the development partners should fund and coordinate the technical assistance required for the planning process.

The other features of this approach include

- A least cost approach to meeting the overall objectives
- Risk management through, for instance, the development options to meet demand, especially for electrical demand
- Assurance of financial cost-effectiveness of the task
- Environmental and social sustainability of the outcomes
- Clear delineation of the roles of the government, utilities and the private sector

The WOSA is not a new problem-solving methodology. It is a well-understood principle used in the past, that includes [10]

- The need for high level leadership of National Energy Policy and Strategy development, with alignment across line departments.
- Energy to be treated as an integrated sector in the overall infra-structure development of the nation
- The realization that tasks should be realistic, time-bound, costed, and lead to measurable outcomes
- Renewable Energy should be considered for all its perceived benefits, including economic benefits, improving energy access, and its environmental and social impact
- Energy plans should be linked to national energy budgets
- The role of the private sector must be recognized.

5. FEATURES OF THE FAESP

The FAESP starts with the following clear statements of vision, goal and expected outcomes

Vision - An energy secure Pacific

Goal - Secured supply, efficient production and use of energy for sustainable

development

Outcomes - i) Access to clean and affordable energy

ii) Optimal and productive use of energy

The framework is based on eleven guiding principles [8], and the following seven themes which embody the principles:

1. Leadership, governance, coordination and partnership
2. Energy planning, policy and regulatory frameworks
3. Energy production and supply
    3.1. Petroleum and alternative liquid fuels
    3.2. Renewable Energy
4. Energy conversion
5. End-use energy consumption
    5.1. Transport energy use
    5.2. Energy efficiency and conservation
6. Energy data and information
7. Financing, monitoring and evaluation

These statements of policies are realized via an implementation plan (called the *Implementation Plan for Energy Security in the Pacific – IPESP*) [11] that assigns actual activities to the policies, apportions responsibilities and institutes a system of monitoring and evaluation. The overall structure of FAESP is depicted in Figure 2 Below.

The FAESP has learnt from the lessons provided by the PIEPP example, and is a product of an analysis and development process involving the cooperative efforts of many stakeholders, including regional agencies, development partners and country beneficiaries, that took two years and several stages of vetting and approval by Pacific energy officials and leaders.

It is a well-structured document which has a clearly stated vision, goal and expected outcomes. It is based on clearly-stated guiding principles that provide the basis for the rational development of the framework. Responsibility for the activities are unambiguously assigned, and metrics for determining the successful achievement of outcomes are clearly stated. It is a pragmatic document that learns from previous experiences and includes new thinking in the formulation of strategies

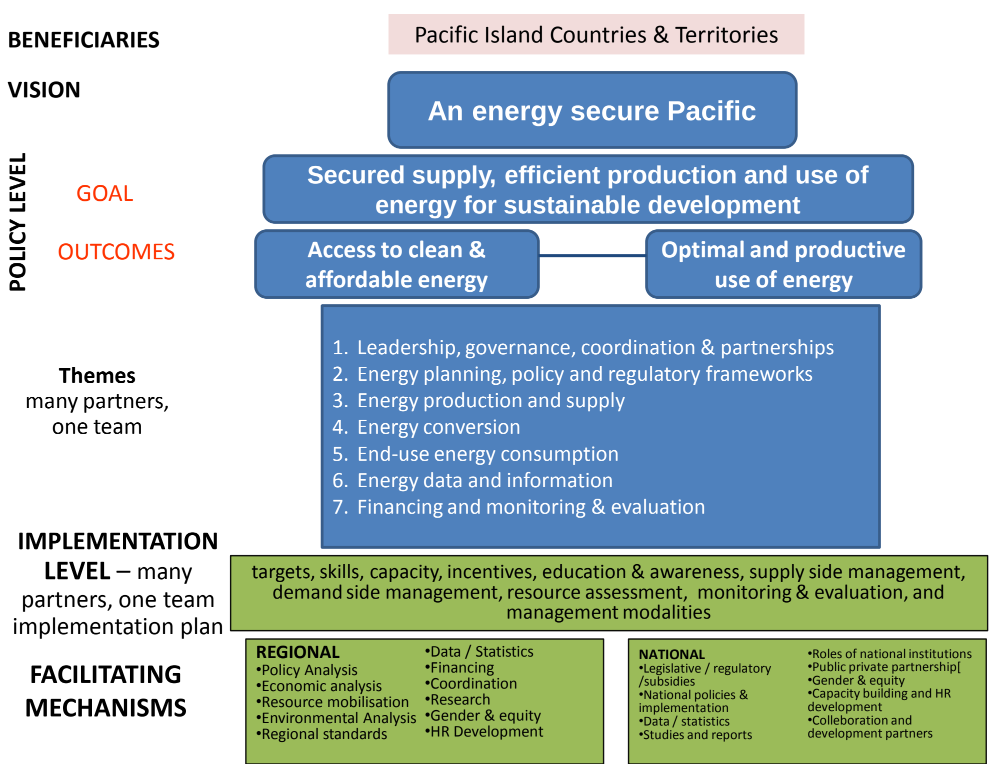

Fig 2 – Structure of FAESP (source – SPC Division of Energy)

Some of the obvious differences between the PIEP and FAESP are outlined in Table 3 below.

There are three notable new elements that FAESP introduces to regional energy planning. Firstly, it is based on the whole-of-sector approach. Secondly, it is sensitive to issues of sovereignty when it acknowledges the primacy of national energy policies over regional ones. And lastly it formalizes the need for inclusiveness in the "many partners, one team" philosophy it embraces.

6. NATIONAL ENERGY POLICIES

All PICTs have some form of a national energy policy or energy document that acts as a guide to national energy activities. The comprehensiveness of these documents varies from country to country. Over the past decade, national energy priorities have rarely changed as compared to current initiatives with the focus still on energy security as outlined at the regional level and more specifically on the reduction in the use of fossil fuels.

Table 3 – Comparison of features of PIEP and FAESP

	PIEP	FAESP
1.	It has no clear allocation of responsibilities	SPC is the lead agency responsible for FAESP
2.	It has no guiding principles	It is based on eleven clearly-stated guiding principles
3.	Its objectives are vague and lack focus	It has seven themes, each with a rationale, expected outcomes, long-term objectives and key priorities
4.	Has no clearly-specified timeframes for its activities	The activities are assigned clearly-defined timeframes in the associated IPESP
5.	The importance of energy data	The importance of energy statistics is

	(statistics) for decision-making is ignored	clearly acknowledged in Guiding Principle 8 and is re-iterated in Theme 6 of FAESP
6.	It has no formal status	It was endorsed by the Pacific Energy Minister's Meeting in Tonga in April 2009 and at the Pacific Islands Forum meeting in Cairns Australia in August 2009. Or Vanuatu in Aug 2010. Brisbane ministerial meeting was in June 2010.
7.	No monitoring and evaluation framework	Has an M&E framework in terms of the IPESP and the development of the energy security indicators
8.	No specific budget	Has an itemized budget which tallies to US$20m (excluding personnel costs) for a 5-year timeframe.

The challenge has always been on the availability of resources for the implementation of the energy plans. More specifically, it has been to obtain these resources through national budget allocations. Generally speaking, these policies have not been realized in practical terms, as many countries are yet to have specific energy regulations and legislations enacted to support their policy statements.

7. CONCLUSIONS

Will FAESP work?

It is too early to make a definitive statement. But no plan is ideal, and FAESP is bound to have problems that will only appear over a period of time. Considering the complexity of the situation, with such a diversity of people and their needs and the heterogeneity of available energy resources, it will be very surprising if FAESP will have succeeded in meeting all its requirements on its first application. Further reviews will therefore almost certainly be in order.

Perhaps a more appropriate question to ask is what the situation would have been in the absence of FAESP. There can be no doubt that, having learnt the lessons of the past, this new regional energy plan will be a significant improvement over the last.

It must be noted in passing that FAESP and its Implementation Plan have been designed to be administered by the CROP agencies. It will therefore be appropriate if all the CROP agencies coordinated their efforts by putting together their annual work plans in one document where it could be centrally monitored. There can be no doubt that FAESP has already brought about a noticeable improvement in cooperation within CROP members as compared to the PIEPP, with the result that there are some joint activities now are taking place. However, a combined work plan will bring about a vast improvement in the collaborative efforts of these Pacific organizations.

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Past and Present Green Economy Initiatives, and Capacity Building and Financial Mechanisms for the Future Development of the Barbados Energy Sector

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Abstract:

As with most Small Island Developing States (SIDS), imported fossil fuels make up the majority of Barbados's primary energy requirements, including electricity generation. As well as using up valuable foreign exchange, this import bill makes the island highly vulnerable to the ever more volatile international energy market. Sustainable development has long been present in the islands ideological mind-set and in 2010 the Government of Barbados signalled its commitment towards becoming "the most environmentally advanced green country in Latin America and the Caribbean". This paper first describes the island's present fossil fuel dominated energy sector, as well as past and present green economy related initiatives. It then discusses two key areas of energy sector reform necessary to promote sustainable development: capacity building and finance, highlighting the role that innovative financing mechanisms could play in decreasing the countries reliance on fossil fuel imports.

Keywords: Small Island Developing States, green economy, renewable energy, financing mechanisms

1. INTRODUCTION

Imported fossil fuels (~9,000 barrels/day) cover most of Barbados's primary energy requirements, including electricity generation. This import bill makes the island highly sensitive to the volatile international energy market (Fig. 1). In 2010 imported oil for electricity generation cost the country some US$300 million (7.5% of GDP). With few possibilities of expanding its own limited production of fossil fuels (the Barbados National Oil Company extracts ~1000 barrels/day), the most effective method of increasing energy security is to (1) contain demand growth by increasing energy efficiency, and (2) expand production from alternative energy sources [1]. Although much progress is now being made, neither of these two areas has an established policy/regulatory framework for the promotion of public or private investments [2].

The share of renewable energies in total primary energy supply has remained constant at slightly over 7 per cent over the last decade [3]. The source of renewable energy in the primary energy mix originates mainly from the use of solar water heaters and bagasse co-generation during the sugarcane-harvesting period (approximately 50-50 share between the two). The electricity generated from bagasse co-generation is all used in the sugar refining process/factories and there is currently no utility-scale renewable energy on the island. However, a 10MW wind farm has been held at the planning stage for over six years with installation now expected by 2014. There are also plans for a 13.5MW waste-to-energy plant, and a 17.5MW biomass co-generation plant.

The two largest consumers of the fuel imported onto the island by far are electricity generation (50 per cent) and transport (33 per cent). Of the total electrical energy generated in 2010 (1,036 GWh), domestic consumption was the major user at 31 per cent (see Fig. 2). The commercial sector was the second largest consumer with 22 per cent. Tourism, which includes hotels and numerous tourist attractions, was a close third with 17 per cent. In addition, a notable user of electricity is the water sector with most potable and irrigation water being either pumped from aquifers or via a 30,000 m^3/day reverse osmosis desalination plant. Barbados is classed as a water scarce island due to it being a relatively flat island with few rivers thanks to it consisting of predominantly permeable coral limestone.

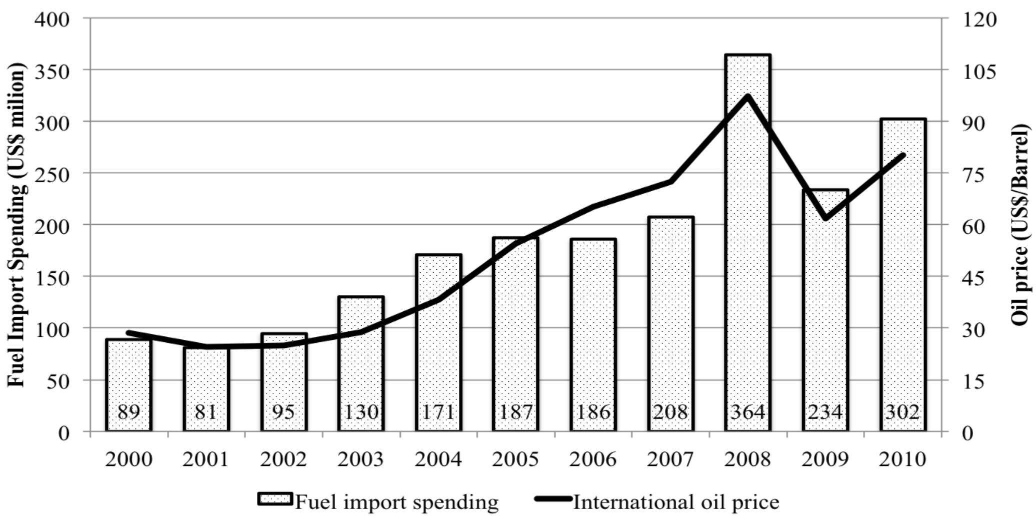

Fig. 1 Fuel import spending for electricity generation (Ministry of Finance and Economic Affairs)

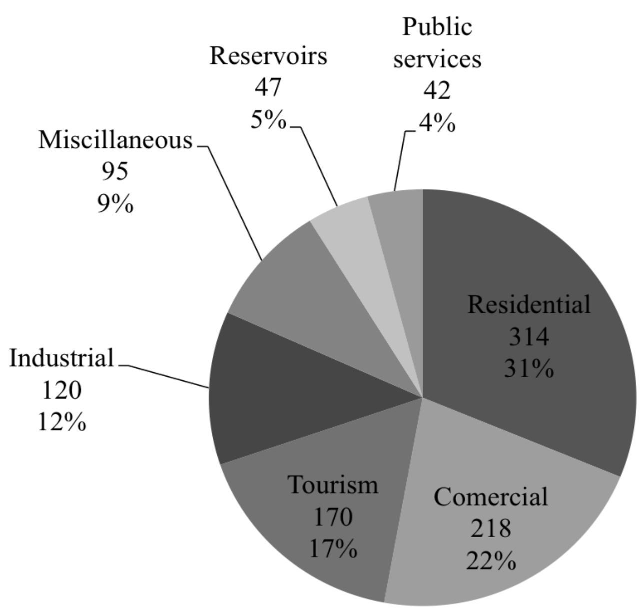

Fig. 2 Electricity consumption by sector for 2010 (GWh)

Fig. 3 shows that there has been a steady increase in electricity generation in recent years, with an average annual increase of 2.7% over the last 11 years. However, the electricity consumption per customer (commercial and residential) peaked in 2007 and has been slowly decreasing since. When the consumption is broken down between commercial and domestic customers (see Fig 4.), it is clear that the commercial customers are the main cause of this decrease. A steep increase in domestic electricity consumption was seen up until around 2005, since then consumption per customer has levelled. This levelling off coincides with the increase in energy prices, which occurred at the same time. The number of customers has increased by 19% since 1999 levels.

Electricity generation on the island is produced by Barbados Light & Power (BL&P). Most of the generators they use for producing the islands electricity are diesel-electric units that run on heavy fuel oil. Some gas turbines are kept in reserve for peak loads and emergencies. Total installed capacity for the island is 240MW whilst the peak load for 2010 was 168MW.

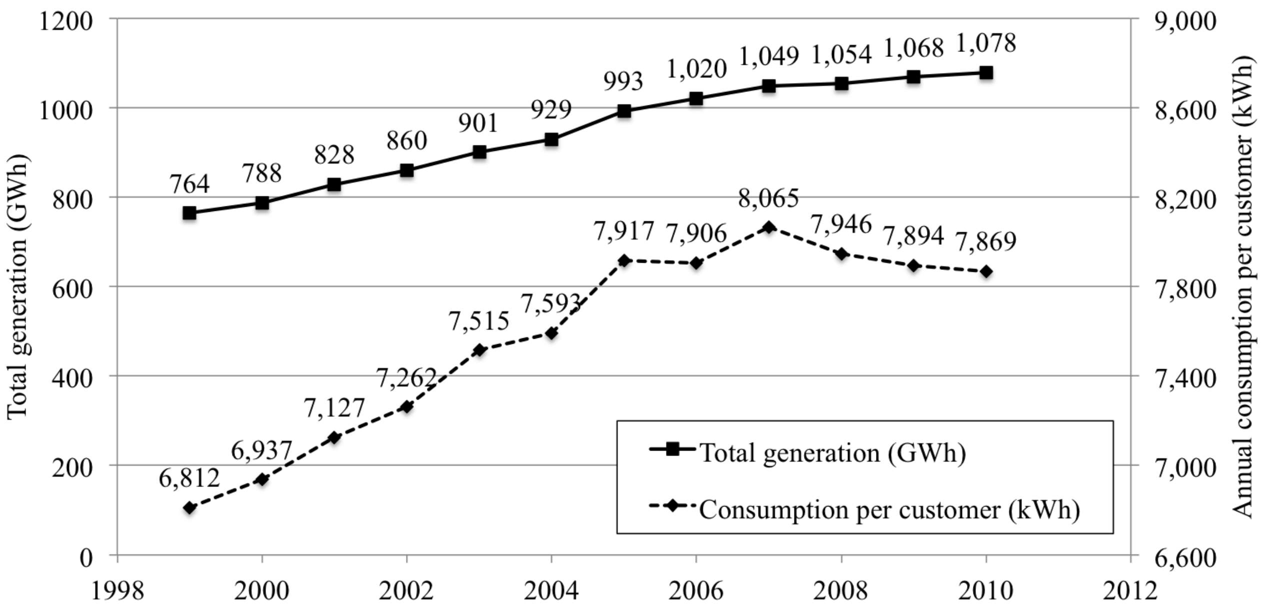

Fig. 3 Electricity generation and consumption per customer [4]

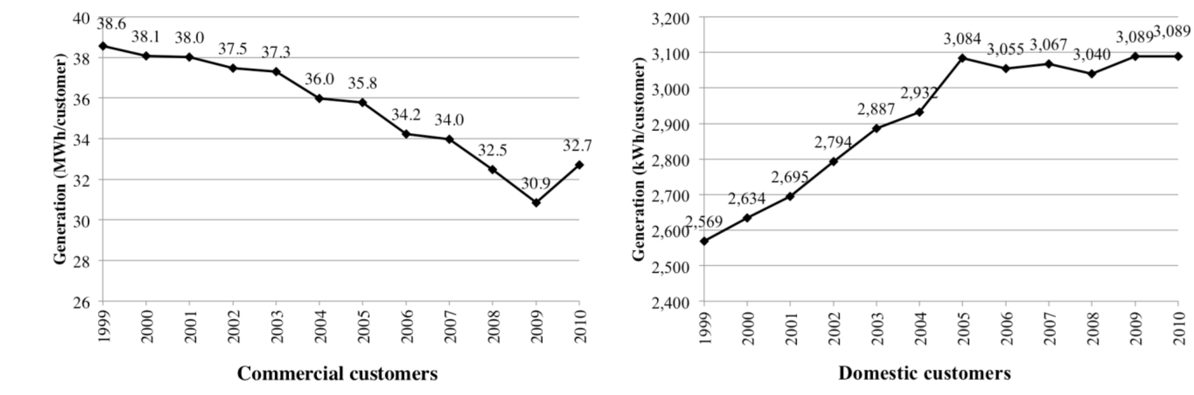

Fig. 4 Electricity consumption for commercial and domestic customers [4]

2. GREEN ECONOMY

The transition of Barbados towards a green economy was first proposed in the 2007 Statement of Economic and Financial Polices [5]. The Statement describes the green economy as:

"The practice of green economics recognises that because everything on earth is connected, synergies and linkages can be created within and between sectors often with resulting substantial increases in efficiency and productivity."

Past and present green economy initiatives for Barbados are described in the following sections.

2.1 Past Green Economy initiatives

With the exception of the widely acknowledged success of the Barbados solar hot water heating industry [6], which originated and grew from the 1970s global energy crisis, green economy related initiatives in Barbados are mainly confined to recent history. The National Sustainable Development Policy (NSD Policy) was published in 2004 with the aim of providing a clear outline as to what would be required in order to make the island more sustainable [7]. The policy is targeted at all persons, corporations and decision-makers. Its recommendations to the energy sector focus on conservation as well as the promotion of alternative renewable energy sources, in particular; support for Independent Power Producers (IPPs), the articulation of standards for energy efficient technologies, the encouragement of utility-scale use of renewable energy technologies, capacity building in education establishments (primary, secondary, tertiary and vocational establishments), and cooperation with the wider Caribbean region. Following this report various administrations adopted a number of green economy-related initiatives. The 2007 Statement of Economic and Financial Policies was the most broad-based to date outlining initiatives in the areas of energy, water, waste management, coastline protection and other policies to elicit behavioural change. For example, all businesses in Barbados can now write-off 150 per cent of the cost incurred to obtain international environmental certification. Since the 2007 budget, most of the public policy initiatives focused on energy, largely due to the impact that high oil prices have on the economies of small states. For example, all alternative energy systems are now exempted from import duty and households and businesses are allowed to write-off the costs of conducting energy audits and retrofitting their homes/buildings. A detailed list of some of the main historical green economy-related initiatives can be found in the Green Economy Scoping Study (GESS) [1] and the Sustainable Energy Framework for Barbados (SEFB) [2].

2.2 Present initiatives

The Government of Barbados (GoB) has begun to introduce measures designed to increase the share of renewable energy supply and energy conservation measures, reflecting concerns about the GHG emissions and the terms-of-trade risks from fuel import costs. In an effort to utilise the island's favourable wind and solar resources, BL&P together with the island's independent regulator, the Fair Trading Commission (FTC), introduced a 2-year trial known as the Renewable Energy Rider (which is effectively a Feed-in-Tariff) to lower the costs of renewable generation. The current payment is 1.8 times the fuel related element of the electricity tariff (currently US$0.24 per kWh) or US$0.158 per kWh, whichever is higher. This measure has no direct fiscal impacts since the costs are passed on to consumers by BL&P (although there may be indirect effects for example on receipts from income and profit taxes). If this system were continued and expanded then the increase cost passed onto the consumer could eventually have repercussions on poorer sections of society; options would need to be explored to ensure that this does not occur.

To improve energy Demand Side Management (DSM), BL&P are trialling a time-of-use tariff, whereby commercial customers can benefit from a lower electricity price during off-peak hours, and an Interruptible Service Rider for commercial customers who agree to have their supply interrupted thus reducing the reserve generating capacity required [4].

In addition, a Smart Energy Fund, financed through a loan from the Inter American Development Bank, has been established to promote renewable energy and energy conservation: of the US$10 million total funding envelope, US$6 million is set to be allocated to loans for energy auditing, energy conservation programmes and renewable energy technologies, while the remainder is to be used for grant finance, including for LED light bulbs and more efficient air conditioning units.

The 2011 Statement of Economic Policies continued to promote the use of energy conservation and alternative energy with initiatives aimed at helping homeowners, businesses, farmers and the vulnerable groups of society. The budget also included the submission of draft RE and EE policies, as well as draft legislation to facilitate the generation of RE systems and the sale of electricity to the grid.

3. DISCUSSION

Although the nation of Barbados has made progress in transitioning toward becoming a greener economy, there are still obstacles to its continued transition, in particular in the areas of financial and capacity enhancement. These obstacles are discussed in this section.

3.1 Capacity enhancement

As suggested in the 2007 Statement of Economic and Financial Polices [5] (see section 2), the importance of education, training, research, communication and sensitization to the green economy is paramount. The principals and benefits of a green economy need to be understood and practiced by all sectors of society in order to ensure its success.

To date, the sentiment often found in Barbados among businesses, farmers, householders and hotel owners is that there is a willingness to explore green economy initiatives (increasingly so as the cost of energy rises), however there is a significant 'skills gap' in meeting the needs for the green economy [1]. There is a need to put appropriate education and training arrangements in place. Training would need to focus on trade schools, universities, and on-the-job training in the workplace [8]. Solid R&D,

engineering, and manufacturing capacities are a critical aspect of building green industries and jobs. Indeed, some occupations in the renewables sector or in energy efficiency require highly educated and even quite specialized personnel, including a variety of technicians, engineers, and skilled trades. Green employment is not limited to high-end skills. There are many positions that demand a broad array of skills and experience levels, especially in installation, operations, and maintenance.

There is evidence that this process has already begun; with solar PV installation courses taught by experts, being arranged by BNOC and the GoB's Energy Division, renewable energy modules and programmes are now being offered at undergraduate and postgraduate level at the University of the West Indies, and the DIREKT [9] and INEES [10] projects at the UWI are encouraging renewable energy knowledge transfer between other SIDS and developed countries.

Elsewhere, evidence of private sector capacity building is evident, the Barbados Renewable Energy Association (BREA) was formed in the spring of 2011, and is a non-governmental association promoting the application of RE and EE technologies in Barbados. There are currently around twenty companies offering RE and EE solutions on Barbados. They serve both the public and private sector and their activities include; energy auditing; solar PV and solar thermal installation; small-scale wind installation; system design; biodiesel production; and consultancy. The association is committed to national development through ongoing lobbying for appropriate alternative energy policies and frameworks that benefit all energy users in Barbados and it will provide a collective voice to these RE and EE companies.

While access to RE and EE training has developed considerably in recent years, it is still a fundamental component of sustainable development and capacity-building for the long term, and would need to continue to expand, both in the current channels mentioned in the previous paragraph, and also in the area of public awareness and the workplace. As noted in the Barbados National Assessment Report 2010 [11],

"communicating sustainable development to the general population is a challenge. For effective education, a variety of messages have to be transmitted to a number of different publics in differing formats. The resources required to adequately provide the volume of information required in the appropriate format have been ad hoc and information is usually provided in response to various situations. The approach to public education and information require streamlining and coordination and will be bolstered by the requisite information for decision-making".

There are still more areas that require urgent capacity enhancement. There is a requirement for increasing the amount of renewable energy positions in key areas, most notably the energy division's renewable energy unit. Given the importance that renewable energy and energy efficiency will have in energy policy for a green economy, the employment of additional renewable energy qualified staff is required. Another sector requiring capacity enhancement is the Government Electrical and Engineering Department (GEED), here currently the requirement is for training of existing employees in the certification of the installation of renewable energy technologies (namely solar PV and wind), rather than an increase in staff numbers [1].

3.2 Options for financial incentives

Although the costs of technical components have been declining, the investment in RE and some EE technologies are still expensive and to date, this has discouraged their deployment. High costs limit diffusion and create a negative reinforcing effect, which prevents the economies-of-scale that are needed to generate cost decreases. In addition, most of the RE technologies are new and not market-mature in Barbados, which creates high risks for investors, as their performance cannot be guaranteed. Nonetheless due to the high cost of electricity on the island some forms of renewable energy technologies are already economically viable. The SEFB highlights wind energy, waste-to-energy, solar water heating, hybrid PV/Thermal and biomass cogeneration as RE technologies that are already commercially viable, with several other technologies close to becoming viable if oil prices continue to rise [2].

Although many technologies are already viable, financial constraints (i.e. limited access to capital) are currently limiting the uptake of RE technologies, and this issue is being experienced across the private, public, and third sectors (i.e. voluntary, non-government and community sectors). Particular aspects of this barrier are the timescales of securing funding, the risks for investors, particularly with regard to the timescales involved, the difficulty of finding funding for feasibility and bidding stages of projects, and the lack of funding for paying person hours (revenue as opposed to capital). These constraints, particularly in the public sector, also include the issues of what they can borrow and whom they can lend to. Possible financing solutions to reduce this financial burden are the subject of the remainder of this discussion section and concentrate on innovative Hybrid Private-Public partnerships (PPP) and Energy Performance Contracting (EPC).

3.2.1 Hybrid private-public partnerships

Usually, governments have two ways of financing a solar programme; either with tax-exempt bonds (government-owned approach), or by entering into turnkey relationships with private solar developers. In the case of the local government-owned approach, government issues debt that typically has to be repaid over the useful life of the project. Also under this approach the government owns the system as well as retains all the benefits of the ownership other than the federal tax benefits; however, the debt adds to the burden of government and requires a procurement process to design, acquire and install the solar project. In this case the financing can be obtained at tax-exempt rates, and the government could receive revenue from selling the electricity to the power utility in order to lower the overall costs of the solar project [12,13].

The turnkey solar developer-owned approach is typically used when the government lacks knowledge or experience in solar project development. In this case the government engages a private developer to build and own the project: the private developer gains access to the roof of the local government buildings through a license and access agreement. The private developer designs, finances, installs, operates, and maintains the solar system and then sells the renewable energy back to the local government through a Power Purchase Agreement (PPA) [11,12].

These two approaches can be incorporated together: by doing so, the PPP takes advantages of both options, while minimizing drawbacks [14]. The idea of the hybrid approach is that the government provides the financing through a bond issuance. Normally a third party – such as an Energy Agency or an Improvement Authority- is introduced in order to act as a facilitator between the government, the solar developer and the sites where the technology is to be installed. This third party issues bonds supported by the credit of the government and, therefore, significantly lowers the costs of capital for the projects. The project then uses a turnkey approach, with the difference that the financing being provided at the lower cost of capital is obtained by government.

This allows a cheaper financing for the solar development community as well as preserves the developer's capacity to borrow from the private capital lending sources for other projects [12].

One example of this approach is the Morris Model implemented in New Jersey, USA [15]. The programme started in 2009 and the Local Financial Board approved the Morris County Improvement Authority (MCIA) bonds of up to $30 mln [13]. The MCIA issued $21.6 million of debt at a 4.46% net interest cost with a county guarantee to fund 3.2 MW of solar projects. The MCIA has completed the first phase of its award winning renewable energy project, installing 13,629 solar panels at locations in 5 school districts and several county government facilities throughout the county. These installations provide the county with 3.1 MW of clean energy and around $3.8 mln in energy savings, and approximately 7,000 tonnes of carbon dioxide equivalent (CO_2e) emissions.

3.2.2 Energy Performance Contracting

While PPPs are used for financing renewable energy technologies, EPC can be used for energy efficiency projects, such as building retrofits. EPC, or energy service performance contracting, is a mechanism to deliver energy efficiency products. It is a financing mechanism that includes energy savings guarantees and associated design and installation services provided by the Energy Service Companies (ESCOs) [16]. EPC can be broadly defined as a contract between ESCO and a client involving an energy efficiency investment in the client's facility, the performance of which is guaranteed by the ESCO, with financial consequences for the ESCO [17]. Under EPC, ESCO provides finance for a specific set of measures for energy efficiency retrofit, such as planning, building, operation & maintenance, optimisation, fuel purchase, (co-) financing and user behavior motivation.

The contract between the ESCO and the building owner contains guarantees for cost savings and takes over financial and technical risks of the implementation and operation for the entire project duration (typically 5 to 15 years). The EPC service is paid by realised energy cost savings [18].

EPCs were originally introduced in the 1970s in North America due to the oil crisis. Currently ESCOs have successfully been implemented in many countries, such as Chile, China, the UK and almost all EU countries. One of the most well known programmes is the Berlin Energy Saving Partnership (BESP) [14], which is described in detail here. The State of Berlin first introduced the BESP in 1995. The concept is based on transferring energy management of state-owned properties to a partner, who uses private capital to self-finance the modernization of a building's infrastructure necessary to cut energy use and CO_2e emissions. In return, the partner guarantees annual energy cost savings for the state [19].

Among refurbished buildings under the current BESP there are schools, nurseries, office buildings, leisure centres, theatres, universities and other municipal buildings. The general details of current contracts are presented in Table 1. To date, implemented energy efficiency measures include refurbishment of heating and illumination, energy management as well as user motivation. User motivation is particularly important in this programme as building energy consumption often rises back once the projects are finished, therefore it is important to make building user aware of the energy consumption patterns and affect their energy use so the efficiency becomes habitual rather than behavioral.

Table 10. BESP results

Number of contracts	24 pools (~1,400 buildings)
Guaranteed savings (all contracts)	US$14.9 mln/year (including US$3.6 mln/year savings in Berlin public budget)
CO_2 reduction	67,900 t/a
Investment (all contracts)	US$64.6 mln

The process of the BESP is the following: Firstly, the Berlin Energy Agency confirms a building pool (the client). Buildings willing to take part in the programme have to fulfill the following criteria [20]:

- Secured ownership for at least 10 years;
- Steady use of the building and constant energy consumption in the past 3 years;
- Consumption of connected buildings (under-supply) is measurable;
- Modernisation and replacement of the central heating, ventilation and cooling devices are possible (no restrictions in supply contracts, devices owned by building owner);
- Minimum project size (baseline);
- If parts of the building are rented to third parties – allocation of the costs/savings has to be checked.

The client is responsible for the uptake of various buildings and is bound by contract to the utility company. In order to reduce its energy consumption, the client runs a competitive tendering process to transfer the financing, planning, implementation, and monitoring of energy saving measures to a private energy saving partner – the contractor. The main criteria for the contractor are specialist know-how (references), effectiveness and creditworthiness. The successful contractor undergoes a tendering process. While the contract between the client and the utility company is not affected by the project, the contractor, however, agrees on the necessary technology and supply with the energy supplier. When signing a contract with the client, the contractor guarantees a minimum level of energy savings – around 25%. The contractor only receives his agreed earnings if the stated savings have been reached. At the same time, the client is able to save money through reducing heating and electricity consumption achieved through energy efficiency measures. The investment carried out by the contractor is also refinanced through these savings. Any remaining savings are shared by the partners according to a ratio system agreed in the contract. The contractor is responsible for maintenance and servicing of their system upgrades for the duration of the project (5 to 15 years), and the client fully profits from the full savings one the contract has expired [20]. This programme is not limited to large buildings with high-energy consumption: a group of smaller buildings can create 'a building pool' which allows less unprofitable buildings to be integrated in the project.

4. CONCLUSIONS

This paper has outlined the current status of Barbados's energy sector, highlighting the green economy related initiatives that are currently being explored. Building capacity in the RE and EE sector will continue to play a vital role in the islands transition towards a green economy. For a country such as Barbados, which has limited access to funding and is 'locked-in' to a fossil fuel based energy economy, financing mechanisms such as the hybrid Private-Public Partnerships and Energy Performance Contracting offer realistic opportunities for increasing its RE and EE capacity. Barbados has a number of energy use sectors that could significantly benefit from the financial initiatives described here. In particular Energy Performance Contracting is capable of providing substantial energy and emissions savings in its hotel and tourism sector, its government sector (including the Barbados Water Authority), the island's education establishments and its manufacturing sector.

5. ACKNOWLEDGEMENTS

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International Norms and Documents regarding Technology Transfer and Renewable Energy.

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Abstract:

One of the key responsibilities imposed on state parties to any International Convention on Environment is sustainable development, development that meets the need of present generation without compromising the ability of future generation to meet their needs. In this context, it is mandatory to look into international documents while organizing any discussion on Technological transfer in the field of renewable energy. Almost all the documents advocate transfer of such technology either free of cost or at minimum cost to developing countries, also advocate for renewable energy as need of the hour to meet growing demand of the energy by present generation. In this research paper an attempt is made to study and focus on all the state responsibilities as to Technology transfer in the field of renewable energy. All international bodies and their role are also likely to be studied in depth to arrive at specific conclusion and suggestions as to modalities of such transfer with fulfillment of international obligations.

Rational: It is therefore necessary to study the international Documents regarding Renewable energy and Technology transfer.

Objectives: To study international documents regarding, sustainable development, Renewable energy, technological transfer etc.

To study the functioning of various international bodies established by United Nations in the field of renewable energy.

To suggest the state responsibility, manner and method of technology transfer in the field of Renewable energy.

Key Words: Sustainable development, Renewable energy, Technology transfer, International Documents, International Bodies and State responsibility.

The renewable energy as a clean and sustainable energy come on world forum only after awakening of the world to the concept of Sustainable development adopted at world Human environment conference in the year 1972, since then many conferences conventions, organizations, and specialized bodies are established for research and development in the field of renewable energy, in this paper an attempt is made to enlist and study the working and efforts made by various regional and global bodies in this regard.

Following are the major conventions and bodies working in the field of Renewable energy.

1. United Nations Conference on the Human Environment, 1972

2. International Union for the Conservation of Natural Resources, 1980

3. Ten years after, Stockholm, 48th plenary of the General Assembly in 1982

4. World Commission on Environment and Development, 1983

5. Rio Declaration on Environment and Development, 1992

6. Commission on Sustainable Development, 1993

7. Programme for the Further Implementation of Agenda 21, 1997

8. Ten Years After Rio: Successes and Failures, 2002

9. World Summit on Sustainable Development in Johannesburg

10. International Renewable Energy Agency

11. World Future Energy Summit

12. World Sustainable Energy Conference

13. Ban Ki-Moon: Powering Sustainable Energy for All

14. *Renewable Energy* in Africa: Prospects and Limits - *United Nations*

15. Increasing Global *Renewable Energy* Market Share - *United Nations*

16. The Intergovernmental Renewable Energy Organization (IREO)

17. UN-Energy,

1.. United Nations Conference on the Human Environment, 1972

The **United Nations Conference on the Human Environment** (also known as the **Stockholm Conference**) was an international conference convened under United Nations auspices held in Stockholm, Sweden from June 5–16, 1972. It was the UN's first major conference on international environmental issues, and marked a turning point in the development of international environmental politics.[i]

When the UN General Assembly decided to convene the Stockholm Conference, at the initiative of the Government of Sweden, UN Secretary-General U Thant invited Maurice Strong to lead it as Secretary-General of the Conference.[ii]

The conference was opened and addressed by the Swedish Prime Minister Olof Palme and secretary-general Kurt Waldheim to discuss the state of the global environment. Attended by the representatives of 113 countries, 19 inter-governmental agencies, and more than 400 inter-governmental and non-governmental organizations, it is widely recognized as the beginning of modern political and public awareness of global environmental problems.

The meeting agreed upon a Declaration containing 26 principles concerning the environment and development; an Action Plan with 109 recommendations, and a Resolution.

Some argue that this conference, and more importantly the scientific conferences preceding it, had a real impact on the environmental policies of the European Community (that later became the European Union). For example, in 1973, the EU created the Environmental and Consumer Protection Directorate, and composed the first Environmental Action Program. Such increased interest and research collaboration arguably paved the way for further understanding of global warming, which has led to such agreements as the Kyoto Protocol.

2. International Union for the Conservation of Natural Resources, 1980

The **International Union for Conservation of Nature and Natural Resources** (**IUCN**) is an international organization dedicated to finding "pragmatic solutions to our most pressing environment and development challenges."[1] The organization publishes the IUCN Red List, compiling information from a network of conservation organizations to rate which species are most endangered.[iii]

The IUCN supports scientific research, manages field projects all over the world and brings governments, non-government organizations, United Nations agencies, companies and local communities together to develop and implement policy, laws and best practice. IUCN is the world's oldest and largest global environmental network - a democratic membership union with more than 1,000 government and NGO member organizations, and almost 11,000 volunteer scientists in more than 160 countries. IUCN's work is supported by more than 1,000 professional staff in 60 offices and hundreds of partners in public, NGO and private sectors around the world. The Union's headquarters are located in Gland, near Geneva, Switzerland.[iv]

IUCN's stated vision is "a just world that values and conserves nature." Its mission is to "influence, encourage and assist societies throughout the world to conserve the integrity and biodiversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable."[v]

3. Ten years after, Stockholm, 48th plenary of the General Assembly in 1982

Ten years later, at the 48th plenary of the General Assembly in 1982, the WCS initiative culminated with the approval of the World Charter for Nature. The Charter stated that "mankind is a part of nature and life depends on the uninterrupted functioning of natural systems".

4. World Commission on Environment and Development, 1983

Brundtland Commission

Formally known as the World Commission on Environment and Development (WCED), the Brundtland Commission's mission is to unite countries to pursue sustainable development together. The Chairman of the Commission, Gro Harlem Brundtland, was appointed by Javier Perez de Cuellar, former Secretary General of the United Nations, in December 1983. At the time, the UN General Assembly realized that there was a heavy deterioration of the human environment and natural resources. To rally countries to work and pursue sustainable development together, the UN decided to establish the **Brundtland Commission**. Gro Harlem Brundtland who was the former Prime Minister of Norway and was chosen due to her strong background in the sciences and public health. The Brundtland Commission officially dissolved in December 1987 after releasing the Brundtland Report in October 1987. The organization, Center for Our Common Future, was started up to take the place of the Commission. The Center for Our Common Future was officially started in April 1988.

The organization aims to create a united international community with shared sustainability goals by identifying sustainability problems worldwide, raising awareness about them, and suggesting the implementation of solutions. In 1987, the

Brundtland Commission published the first volume of "Our Common Future," the organization's main report. "Our Common Future" strongly influenced the Earth Summit in Rio de Janeiro, Brazil in 1992 and the third UN Conference on Environment and Development in Johannesburg, South Africa in 2002. Also, it is credited with creating the most prevalent definition of sustainability, as seen below.[2]

5. Rio Declaration on Environment and Development, 1992

The **United Nations Conference on Environment and Development** (UNCED), also known as the **Rio Summit**, **Rio Conference**, **Earth Summit** (Portuguese: ***Eco '92***) was a major United Nations conference held in Rio de Janeiro from 3 June to 14 June 1992.

172 governments participated, with 108 sending their heads of state or government.[1] Some 2,400 representatives of non-governmental organizations (NGOs) attended, with 17,000 people at the parallel NGO "Global Forum" (a.k.a. Forum Global), who had Consultative Status.

The issues addressed included:

- systematic scrutiny of patterns of production — particularly the production of toxic components, such as lead in gasoline, or poisonous waste including radioactive chemicals
- alternative sources of energy to replace the use of fossil fuels which are linked to global climate change
- new reliance on public transportation systems in order to reduce vehicle emissions, congestion in cities and the health problems caused by polluted air and smog
- the growing scarcity of water

An important achievement was an agreement on the Climate Change Convention which in turn led to the Kyoto Protocol. Another agreement was to "not carry out any activities on the lands of indigenous peoples that would cause environmental degradation or that would be culturally inappropriate".

The Earth Summit resulted in the following documents:

- *Rio Declaration on Environment and Development*[vi]
- *Agenda 21*[vii]
- *Forest Principles*

Moreover, two important legally binding agreements were opened for signature:

- *Convention on Biological Diversity*[viii]
- *Framework Convention on Climate Change (UNFCCC)*.

Critics, however, point out that many of the agreements made in Rio have not been realized regarding such fundamental issues as fighting poverty and cleaning up the environment.

6. Commission on Sustainable Development, 1993

The United Nations **Commission on Sustainable Development** (**CSD**) was established in December 1992 by General Assembly Resolution A/RES/47/191 as a functional commission of the UN Economic and Social Council, implementing a recommendation in Chapter 38 of Agenda 21, the landmark global agreement reached at the June 1992 United Nations Conference on Environment & Development/Earth Summit held in Rio de Janeiro.

CSD 1

CSD 1, the Organizational Session of the CSD.1[ix] was held in June 1993. The Organizational Session focused on a broad range of organizational and administrative issues, reflected in topics of the Commission's documents:

- Budget implications of draft decisions
- Establishing a provisional agenda & a multi-year programme of work
- National reporting on implementation of Agenda 21
- Information exchange: UN System & Donors
- UNCED follow up: international organizations & UN Coordination
- Coordination of development data
- **Progress in environmentally sound technology transfer**
- Initial financial commitments & flows
- Government information on financial commitments
- Urgent & major emergent issues
- United Nations Conference on Trade and Development & Agenda 21 implementation
- UNEP & Agenda 21 implementation
- Issues relating to future work of CSD
- Guidelines for national reporting
- Multi-year programme of work
- Financial commitments & financial flows
- Integrating sustainable development in the UN System

7. Programme for the Further Implementation of Agenda 21, 1997

Agenda 21 is an action plan of the United Nations (UN) related to sustainable development and was an outcome of the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in 1992. It is a comprehensive blueprint of action to be taken globally, nationally and locally by organizations of the

UN, governments, and major groups in every area in which humans directly affect the environment.

Development of Agenda 21

The full text of Agenda 21 was revealed at the United Nations Conference on Environment and Development (Earth Summit), held in Rio de Janeiro on June 13, 1992, where 178 governments voted to adopt the program. The final text was the result of drafting, consultation and negotiation, beginning in 1989 and culminating at the two-week conference. The number 21 refers to an agenda for the 21st century.

Rio+5

In 1997, the General Assembly of the UN held a special session to appraise five years of progress on the implementation of Agenda 21 (Rio +5). The Assembly recognized progress as 'uneven' and identified key trends including increasing globalization, widening inequalities in income and a continued deterioration of the global environment. A new General Assembly Resolution (S-19/2) promised further action.

The Johannesburg Summit

The Johannesburg Plan of Implementation, agreed at the World Summit on Sustainable Development (Earth Summit 2002) affirmed UN commitment to 'full implementation' of Agenda 21, alongside achievement of the Millennium Development Goals and other international agreements.

8. Ten Years After Rio: Successes and Failures, 2002

In 2002, ten years after the Rio Declaration, a follow-up conference, the World Summit on Sustainable Development (WSSD) was convened in Johannesburg to renew the global commitment to sustainable development. The conference agreed on the Johannesburg Plan of Implementation (JPOI) and further tasked the CSD to follow-up on the implementation of sustainable development.

On 24th December 2009 the UN General Assembly adopted a Resolution (A/RES/64/236) agreeing to hold the United Nations Conference on Sustainable Development (UNCSD) in 2012 - also referred to as 'Rio+20' or 'Rio 20'. The Conference seeks three objectives: securing renewed political commitment to sustainable development, assessing the progress and implementation gaps in meeting already agreed commitments, and addressing new and emerging challenges. The Member States have agreed on the following two themes for the Conference: green economy within the context of sustainable development and poverty eradication, and institutional framework for sustainable development

Since UNCED, sustainable development has become part of the international lexicon. The concept has been incorporated in many UN declarations and its implementation, while complex has been at the forefront of world's institutions and organizations working in the economic, social and environmental sectors. However, they all recognize how difficult it has proven to grant the environmental pillar the same recognition enjoyed by the other two pillars despite the many calls by scientists and civil society signalling the vulnerability and precariousness of the Earth since the 1960s.

9. World Summit on Sustainable Development in Johannesburg

In 2012 the United Nations will convene the **United Nations Conference on Sustainable Development**, also known as **Rio 2012** or **Rio+20**, hosted by Brazil in Rio de Janeiro, as a 20-year follow-up to the historic 1992 United Nations Conference on Environment and Development (UNCED) that was held in the same city. The conference is organized by the United Nations Department of Economic and Social Affairs.

The decision to hold the conference in 2012 in Rio de Janeiro was made by UN General Assembly Resolution A/RES/64/236 on 24 December 2009.

Rio+20 is a key milestone in a series of major United Nations conferences, in which the 1992 Earth Summit / United Nations Conference on Environment and Development was the centerpiece, putting sustainable development as a top priority on the agenda of the United Nations and the international community.

The conference has three objectives.

1. Securing renewed political commitment to sustainable development.
2. Assessing the progress and implementation gaps in meeting already agreed commitments.
3. Addressing new and emerging challenges.

Conference Themes

The conference has two themes agreed upon by the member states.

1. Green economy within the context of sustainable development and poverty eradication.
2. Institutional framework for sustainable development.

10. International Renewable Energy Agency

The proposal for an international agency dedicated towards renewable energy was made in 1981 at the United Nations Conference on New and Renewable Sources of Energy in Nairobi. The idea was further discussed and developed by major organisations in the field of renewable energy, in particular Eurosolar.

Since then, the global interest in renewable energy has been increasing: Several international meetings such as the World Summit for Sustainable Development 2002 in Johannesburg (WSSD) or the G-8 Gleneagles Dialogue addressed renewable energy, and the 2004 Bonn International Renewable Energy Conference in Bonn, as well as the 2005 Beijing International Renewable Energy Conference were a response of Governments towards the increasing demand for further international cooperation on renewable energy policies, financing, and technologies.

It is important to recall that the International Conference for Renewable Energies in Bonn 2004, supported by the International Parliamentary Forum on Renewable Energies called for the establishment of the International Renewable Energy Agency (IRENA) in its concluding resolution. Only a few years later, and through combined efforts of Governments across the world, the idea had come to life.

11. World Future Energy Summit

World Future Energy Summit is the world’s foremost annual meeting committed to advancing future energy, energy efficiency and clean technologies by engaging political, business, finance, academic and industry leaders to drive innovation, business and investment opportunities in response to the growing need for sustainable energy.

Now approaching the 5th edition, World Future Energy Summit continues to provide the leading platform for international policy makers, innovators, business decision makers and investors to explore global energy challenges with the view to creating real and sustainable solutions.

In 2012, WFES will bring together more than 150 eminent thought leaders to reveal the latest innovations and discuss the burning issues surrounding future energy. This is your opportunity to hear cutting-edge information, gain first hand knowledge, and discuss with international colleagues the challenges and solutions for achieving clean, secure and sustainable energy for all.

This year’s Summit program has been designed to address the theme *Powering Sustainable Innovation*. As the global demand for energy continues to escalate, it is innovation which will transform our traditionally fossil fuel based energy into a diverse mix featuring renewable and sustainable energy sources. It is innovation which will enable the development of advanced clean energy technology and continue to make huge leaps forward in improving energy efficiency.

Throughout the four days of the Summit, the underlying theme of innovation will be seen across the framework of policy, business, technology and finance with ground breaking presentations from industry leaders, frank discussions among senior representatives from key players and valuable insights from respected analysts.

12. World Sustainable Energy Conference

World Sustainable Energy Conference 2012-Geneva

In order to promote one of the most dynamic research areas, raise awareness on current global issues, meet renowned representatives of the most authoritative world organisations in the field, **InTech** has become an official participant, exhibitor and contributor to the **World Sustainable Energy Conference to be held in Geneva, January 10th-12th.**

Other participants include the likes of UNESCO, WHO, WTO, Greenpeace, Greencross, ISEO, just to name a few, all gathered in one place to set a sustainable energy agenda that might just change all of our lives. How?

Sustainable energy provides energy to meet the needs of the present without endangering the provision of energy sources for future generations. All renewable energy sources are valid assets to provide sustainable energy and include:

- Hydroelectricity
- Solar Energy
- Wind Energy
- Wave Power
- Geothermal energy
- Bio Energy
- Tidal Power

Among other, sustainable energy solutions and their implementation tools by energy type, quantity, annual investment and cost from now until 2050 and beyond will be thoroughly discussed at the conference, proving also the positive impact of such energies on economies, the environment and the overall health of us all. All issues discussed, conclusions and recommendations for governments and active parties engaged in subjects related to sustainable energy will be forwarded as input to the next **Rio + 20 Summit** (United Nations Conference on Sustainable Development) to be held on June 20-22, 2012, in Rio de Janeiro, Brazil.

InTech has been raising environmental care awareness through its publications many times and by having been invited to this year's Geneva conference, the stakes are about to be raised not only for InTech as a publisher pushing forward for a greener earth promoting authors passionately engaging in environmental issues, but to our global audience of researchers, scientists and lay readers too, all heavily interested in being on top of the latest news and developments regarding this specific field of study and its implications for all the stakeholders: each Earth's inhabitant included.

Our Earth in Unsustainable Numbers

Looking at some of the **latest stats** on what has actually been going on for the last few decades in relation to energy supplies, consumption and dangerous emissions, it comes as no surprise we have drained our home, planet Earth. In fact we're killing it.

To remind ourselves from time to time how impoverished our Earth is of all its natural resources (coal, petroleum, mineral gas), just take a look at some of the stats below clearly portraying the rapid growth of demand for energy and the consumption of sky high amounts of natural resources for its production through the past few decades.

13. Ban Ki-Moon: Powering Sustainable Energy for All

UN Secretary-General calls for Action to Achieve Sustainable Energy for All by 2030

The Secretary-General's objectives are to expand energy access, improve energy efficiency and increase the use of renewables, all critical elements for powering sustainable development

Abu Dhabi -- In his keynote address today to the World Future Energy Summit, UN Secretary-General Ban Ki-moon called on governments, the private sector, and civil society to make significant commitments to action in support of his Sustainable Energy for All Initiative. His call to action underscores the importance of energy to sustainable development, and contributes to the global launch of 2012 as the International Year of Sustainable Energy for All.

"This is the right time for this Initiative," said the Secretary-General. "Across the world we see momentum building for concrete action that reduces energy poverty, catalyzes sustainable economic growth, and mitigates the risks of climate change. Achieving sustainable energy for all is both feasible and necessary. My Initiative will help us meet these objectives simultaneously. It can be a triple win for all."

The Secretary-General's participation in the World Future Energy Summit marks his first visit abroad during his second term of office and highlights his commitment to sustainable energy as the key to powering sustainable development. The Secretary-General has designated sustainable development as his top priority for his next five year term.

Globally, one person in five lacks access to modern electricity and twice that number, three billion people, rely on wood, coal, charcoal or animal waste for cooking and heating. In developed countries the problem is a substantial waste of energy.

The Secretary-General articulated three complimentary objectives, all to be achieved by 2030.

First: to ensure universal access to modern energy services.

Second: to double the rate of improvement of energy efficiency.

Third: to double the share of renewable energy in the global energy mix.

The World Future Energy Summit serves as the global launch of 2012 as the International Year of Sustainable Energy for All, which was mandated by the UN General Assembly. The Secretary-General's Initiative contributes to the International Year of Sustainable Energy for All by mobilising action from a range of key actors.

The Secretary-General has appointed a High-level Group of eminent global leaders from business, finance, government and civil society to mobilize action commitments that will help drive change on the ground, in corporate board rooms, and in policy portfolios around the world.

In Abu Dhabi, the Group met and produced a Framework for an Action Agenda, which proposes several high-value actions at the national and international level, including action to expand energy access, promote efficiency standards and policies, and strengthen investment in renewables.

Towards the UN Conference on Sustainable Development (Rio+20) in June, the Secretary-General will officially launch the Action Agenda, publicizing the commitments made by all stakeholders to the Initiative.

14. *Renewable Energy* in Africa: Prospects and Limits - *United Nations*

The developing nations of Africa are popular locations for the application of renewable energy technology. Currently, many nations already have small-scale solar, wind, and geothermal devices in operation providing energy to urban and rural populations. These types of energy production are especially useful in remote locations because of the excessive cost of transporting electricity from large-scale power plants. The application of renewable energy technology has the potential to alleviate many of the problems that face Africans every day, especially if done so in a sustainable manner that prioritizes human rights.

Background

Mean surface temperature anomalies during the period 1995 to 2004 with respect to the average temperatures from 1940 to 1980

Africa is the largest and most populous continent in the world after Asia. Covering 20.4% of the available land area world wide, it is home to over 900 million people distributed within 53 countries. Approximately one-third of the estimated 1.6 billion people living without access to electricity worldwide live in Africa. It is estimated that, with the exception of Libya, South Africa and Egypt, the majority of African countries are only able to provide direct access to electricity to 20% of their peoples. This number is as low as 5% in some countries. Most of the existing power plants and transmission equipment were constructed in the 1950s & 1960s, and in the absence of proper maintenance have deteriorated over the last several decades; the degradation has forced many utilities to operate at small fractions of their installed capacity.[x]

Access to energy is essential for the reduction of poverty and promotion of economic growth. Communication technologies, education, industrialization, agricultural improvement and expansion of municipal water systems all require abundant, reliable, and cost-effective energy access.[xi]

Renewable energy resources

Hydro-electric, wind and solar power all derive their energy from the Sun. The Sun emits more energy in one second (3.827×10^{26} J) than is available in all of the fossil fuels present on earth (3.9×10^{22} J), and therefore has the potential to provide all of our current and future global energy requirements. Since the solar source for renewable energy is clean and free, African nations can protect their people, their environment, and their future economic development by using renewable energy sources to this end they have a number of possible options.[xii]

15. Increasing Global *Renewable Energy* Market Share - *United Nations*

Renewable energy commercialization involves the deployment of three generations of renewable energy technologies dating back more than 100 years. First-generation technologies, which are already mature and economically competitive, include biomass, hydroelectricity, geothermal power and heat. Second-generation technologies are market-ready and are being deployed at the present time; they include solar heating, photovoltaics, wind power, solar thermal power stations, and modern forms of bioenergy. Third-generation technologies require continued R&D efforts in order to make large contributions on a global scale and include advanced biomass gasification, biorefinery technologies, hot-dry-rock geothermal power, and ocean energy.

16.The Intergovernmental Renewable Energy Organization (IREO)

In the year 2000, the United Nations was looking for a way to go from spending the majority of its time reacting to existing problems…to preventing those problems from happening in the first place. The U.N. reasoned that, if we get a few important things right…our planet and its people will be much better off.

These important actions were articulated as the United Nations Millennium Development Goals (MDGs). Taken together, the U.N. Millennium Development Goals offer a prescriptive remedy for the future of the human race. Of these goals, Number Seven, "ensure environmental sustainability" has become the founding principle of the Intergovernmental Renewable Energy Organization (IREO).

17. UN-Energy,

the United Nations' mechanism for inter-agency collaboration in the field of energy, was established in 2004 to help ensure coherence in the United Nations system's multidisciplinary response to the World Summit on Sustainable Development (WSSD), and to support countries in their transition to sustainable energy. The core fields of access to energy, renewable energy and energy efficiency - UN-Energy's clusters - have garnered major attention and experienced rapid growth in investments and policy-related focus with an ever-growing number and variety of players involved.

UN-Energy aims to promote system-wide collaboration in the area of energy with a coherent and consistent approach, as there is no single entity in the United Nations system that has primary responsibility for energy. Its role is to increase the sharing of information, encourage and facilitate joint programming and develop action-oriented approaches to co-ordination. It was also initiated to develop increased collective engagement between the United Nations and other key external stakeholders. UN-Energy brings together members on the basis of their shared responsibility, deep commitment, and stake in achieving sustainable development.

Conclusion remarks:

In order to make this event successful and realistic on the part of implementation of whatever is outcome, all the international bodies and organization working in the field needs to be invited for partnership and active co-operation, without which this conference will not be able to achieve its objective.

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