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Low-carbon measures for Fiji's land transport energy system

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ABSTRACT

Road transport in Fiji is fully dependent on petroleum fuels. This study is a first for Fiji where fuel demand for land transport is studied under some clean transportation strategies. Long-range Energy Alternatives Planning (LEAP) tool is used with 2016 as the base year and 2040 as the end year. In 2016, approximately 337 million litres of fuel was used with an associated GHG emission of around 864 Gg of CO_{2e}, which increases to 1158.4 Gg by 2040 in Business as usual (BAU) scenario. Several measures are explored to reduce the fuel consumption in the land transport sector in Fiji.

1. Introduction

Almost 20% of the world energy consumption is by the transport sector, Fig. 1 and the sector is heavily dependent on motor gasoline and diesel fuels, Fig. 2. For Fiji's case, the transport sector accounts for 60% of the total petroleum consumption in the country (ECA, 2013). Fiji being an island country with around 900000 population is committed to reducing its fossil fuel consumption as noted in its Nationally Determined Contributions (NDC) to GHG reductions (GoF, 2015). Fiji's transport sector is growing as evidenced by the increasing number of vehicles, number of passengers and tonnes of goods transported, Fig. 3.

To the best of authors' knowledge, there has not been any study conducted in Fiji on the current and future projects on energy consumption of land transport. A number of studies have been done globally, nationally and regionally to study how different strategic interventions are affecting fossil fuel consumption and GHG emissions. It was noted by Sadri et al. (2014) that energy-environment planning for transportation requires extensive data for energy carriers, production, consumption and vehicle technologies. While (Liu et al., 2015) mentions that emission reduction measures for urban passenger transport in Beijing can be divided into two categories (i) a clean vehicle strategy which encompasses technical improvement in vehicle or fuel and (ii) a mobility management strategy which reduces traffic volume through a variety of measures.

For Delhi city, the passenger transport fuel demand and environmental emissions were studied using scenario analysis in LEAP by Bose and Srinivasachary (1997). They have discussed strategies of improving efficiency of buses and how to reduce congestion of roads. China's freight transport sector's energy demand and GHG emissions was studied by Hao et al. (2015) where they concluded that China needs aggressive efforts to reduce GHG emissions by almost 30% compared to BAU scenario. In addition, road freight transport for heavy goods vehicle in Spain was studied by Andrés and Padilla (2015) for its energy intensity and concluded that alternative mode of transport such as rail would achieve higher energy efficiency.

Recently, Dhar and Shukla (2015) had studied low carbon scenarios for transport in India using ANSWER MARKAL from 2010 to 2050 and found that although vehicle fleet efficiency increases in BAU scenario, rapidly increasing transport demand, population and income levels tend to overwhelm the energy savings from efficiency measures. ANSWER MARKAL is a Microsoft Windows interface specifically developed for working with IEA/ETSAP's MARKAL energy system model (NS, 2018). Dhar and Shukla (2015) recommended that low carbon policies such as CNG, battery electric vehicle, hybrid gasoline, hybrid diesel, fuel cell electric vehicle, ethanol-gasoline blended, bio-diesel blended vehicles tend to reduce emissions.

A similar study has been done for Thailand for the same time horizon but a different tool AIM/Enduse is used, (Selvakkumaran and Limmeechokchai, 2015). They have studied emission taxes and low carbon society scenarios. These researchers (Dhar and Shukla, 2015; Selvakkumaran and Limmeechokchai, 2015) also discuss about co-benefits of low carbon society (an economy with minimum GHG emissions). The co-benefits are necessary to look at because technology to reduce GHG emissions require huge capex investments. The co-benefits include energy security for a country and better air quality (Selvakkumaran and Limmeechokchai, 2015).

Yeh and Sperling (2010) in their paper conclude that reducing transportation fuel use and GHG emissions require a portfolio of

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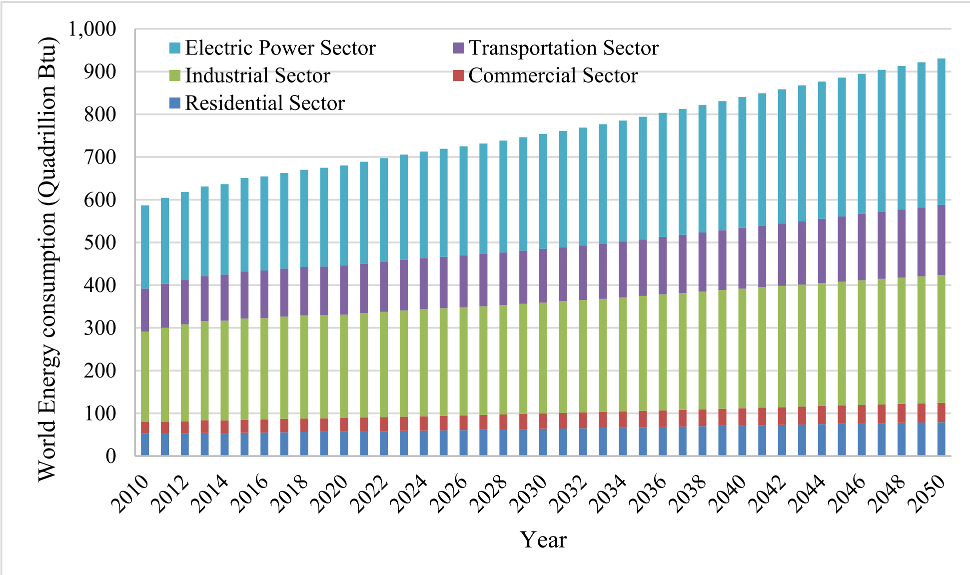

Fig. 1. World energy consumption by different sectors.
Data Source: (IEA, 2017).

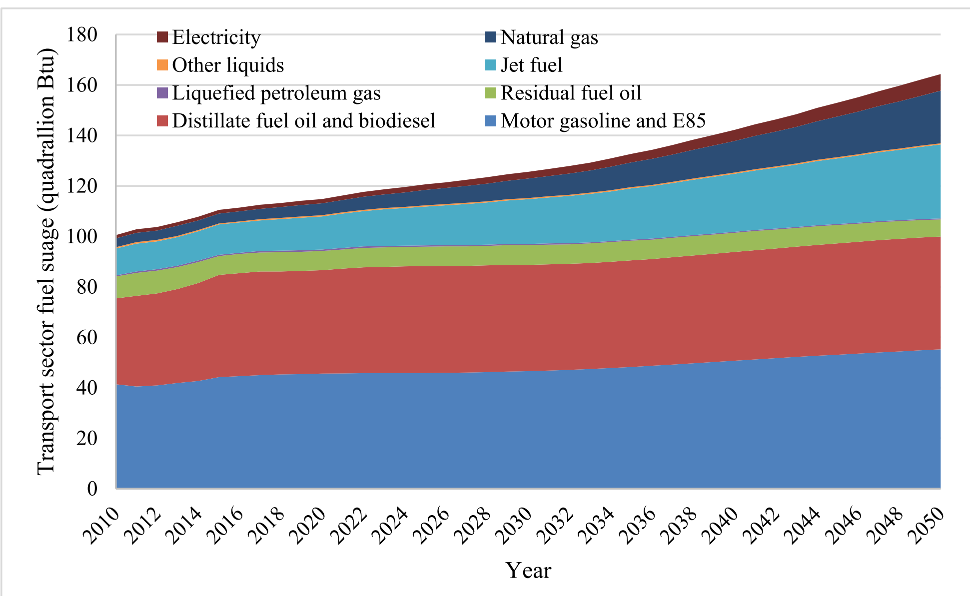

Fig. 2. World transport sector energy consumption in reference case.
Data source: (IEA, 2017).

policies and programs. This is supported by Guttikunda and Mohan (2014) who emphasize that policies should not be implemented in isolation but be supplemented by providing high quality fuel, stringent fuel efficiency standards and enforcing them to reduce pollution levels. Improvement in traffic management, vehicle pollution checking procedures and promotion of behavioral change to use more public and non-motorized transport are also some additional actions to be undertaken to reduce pollution (Guttikunda and Mohan, 2014).

In addition, Mraihi et al. (2013) in their study of factors affecting energy consumption for road transport found that vehicle fuel intensity (energy demand per vehicle), vehicle intensity (number of vehicles per GDP), per capita GDP, urbanized kilometers and national road network are principal drivers of the change in road transport related energy consumption.

The present study aims to study different low carbon measures in Fiji's land transport for the period 2016–2040. Two types of strategies as mentioned by Liu et al. (2015) are studied for Fiji's case; clean vehicle strategy and mobility management strategy to explore path to sustainable land transport. The aim of this study is to quantify fossil fuel consumption as a function of strategic interventions and its related GHG emissions in land transport sector using LEAP tool.

Next section of this paper presents an overview of Fiji's land transport system. Section 3 presents the method and model framework used in this study followed by result presentation. Section 5 discusses policy implications of low carbon strategies studied in land transport. Finally, some conclusions are made.

2. Fiji land transport

There has been almost 70% increase in total number of vehicles over the past 15 years reaching 101,425 registered vehicles in 2015

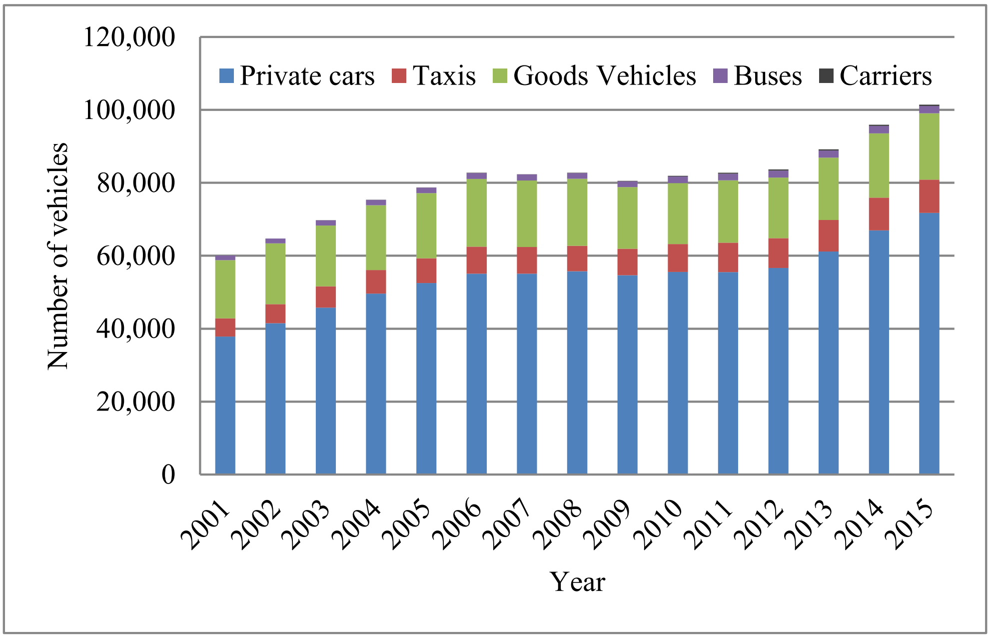

Fig. 3. Number of vehicles[1] over the past years in Fiji.
Data Source: (FBoS, 2018).

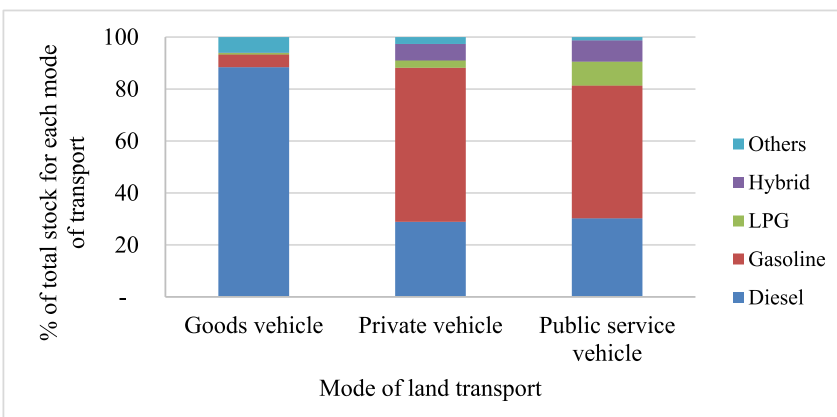

Fig. 4. Different types of land transport in Fiji as on 9 March 2017[2].
Data Source: (Khan, 2017).

compared to 60,071 in 2001. On average, the number of vehicles on Fiji roads has been increasing at a rate of 3.87% annually. In the past two years, private vehicle numbers have increased quite significantly indicating society's need for individual transportation with growth in economy and affordable prices of vehicles.

According to Fiji Land Transport Authority (LTA) data, in March 2017, there were 55,112 gasoline vehicles, 43,752 diesel vehicles, 3448 LPG vehicles and 6158 hybrid vehicles (Khan, 2017). Goods vehicles (freight) had the highest share of diesel vehicles while private vehicles and taxis are mainly fueled by gasoline, Fig. 4. All buses in Fiji are fueled by diesel. As seen in Fig. 5, there are some very old (50 years) vehicles registered while majority of vehicles are less than 30 years old.

The per capita ownership of private cars in Fiji is still lower than many of high income and some middle-income countries. The per capita registered private cars ownership in Fiji is 8 per 100 people, compared to 80 in the United States, 61 in Canada, 59 in Japan, 52 in United Kingdom, 27 in Russia and 16.5 in Thailand (Guttikunda and Mohan, 2014). Using estimated population data obtained from Fiji Bureau of Statistics and GDP at constant basic price in FJD, the vehicle intensity has been calculated as seen in Fig. 6.

To determine how population and GDP affects number of vehicles, linear regression was made. The general form of regression model is given in eq. (1).

$$LTV = \beta_o + \beta_1 Pop + \beta_2 GDP + \varepsilon \tag{1}$$

Where LTV is the number of land transport vehicles, Pop is the population, GDP is the gross domestic product at constant basic price (FJD million), β_o is the constant term, β_1 and β_2 are the coefficients of Pop and GDP respectively and ε is the error term.

Using error term and adjusted R^2 values as the factors for choosing the best model, Model 2, which just considers GDP, is estimated to be the best for estimation of increase in the vehicle numbers, Table 1. When on average, GDP at constant base price increases by 2.7% annually, vehicle numbers would increase by 3.4% per annum. With this

[1] Private cars include private cars, government vehicles and other vehicles while the taxis include taxis, rental and hire cars.

[2] Public service vehicles are taxis and buses. Others denoted in the legend of the chart refers to number of vehicles with unknown fuel type designation.

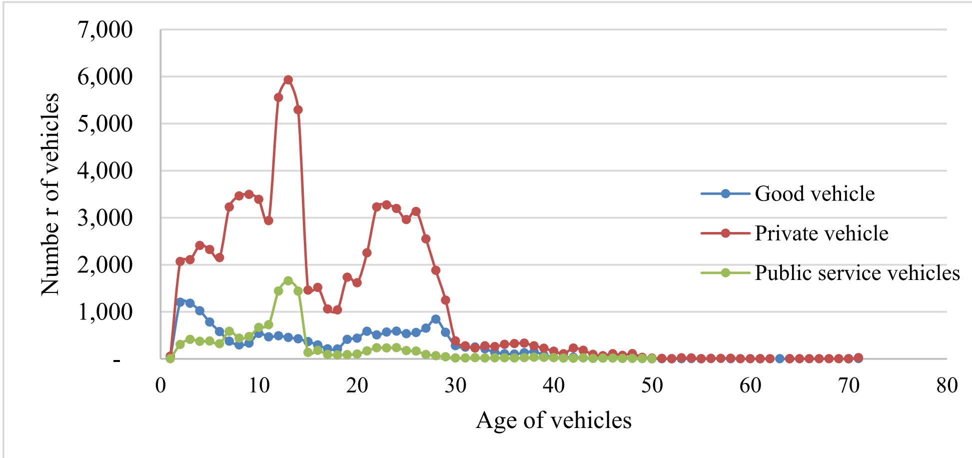

Fig. 5. Age of vehicles for Fijian vehicles as at 9 March 2017.
Data Source: (Khan, 2017).

increase in vehicles numbers in future years, road transport passenger activity increases by 1.3% and freight activity increases by 1%, Fig. 7.

3. Method and model framework

3.1. Data collection

LTA provided data on registered vehicle number in terms of the type of fuel used and age of vehicles. Number of vehicles registered over the past years was obtained from Fiji Bureau of Statistic (FBoS, 2018).

No data has been recorded for passenger and freight activity for land transport by FBoS or LTA. Hence, questionnaires were developed for drivers to provide information on number of passenger travelled per trip, number of trips taken in a day or year, fuel used per trip, type of fuel used, model of vehicle, and other information. Altogether 320 drivers were surveyed randomly at various service stations and at their work places during February and March 2017 at Suva, Lautoka and Labasa, Fig. 8. This data was used to calculate the fuel economy of different fuel type for different mode of vehicles.

3.2. LEAP framework

3.2.1. Land transport energy model structure

The LEAP tool was used for scenario analyses. It is a widely used tool for energy systems and its emissions analyses. The base year of study is 2016 and end year is 2040. This study uses **A**ctivity, **S**tructure, **I**ntensity → **F**uel use (ASIF) methodology which is also used by International Energy Agency (IEA) (Cazzola and Teter, 2016). In this study, transport activity is measured in passenger kilometers (pkm) for passenger transport or tonnes kilometers (tkm) for freight transport, Fig. 7. To convert transport activity to energy consumption eqs. (2)–(4) are used.

$$A_t = \sum N_{ijt} \times DT_{ijt} \times OR_{ijt} \tag{2}$$

Where A is the vehicle activity measured in pkm or tkm in a given year, t. i is the vehicle type and j is the fuel type. N is the number of vehicle in a given year t, DT is the average annual distance travelled by a vehicle (km/vehicle) and OR is the occupancy rate or load factor measured in number of passengers carried per vehicles or average load carried per vehicle respectively. Average annual distance for each type of vehicle was calculated

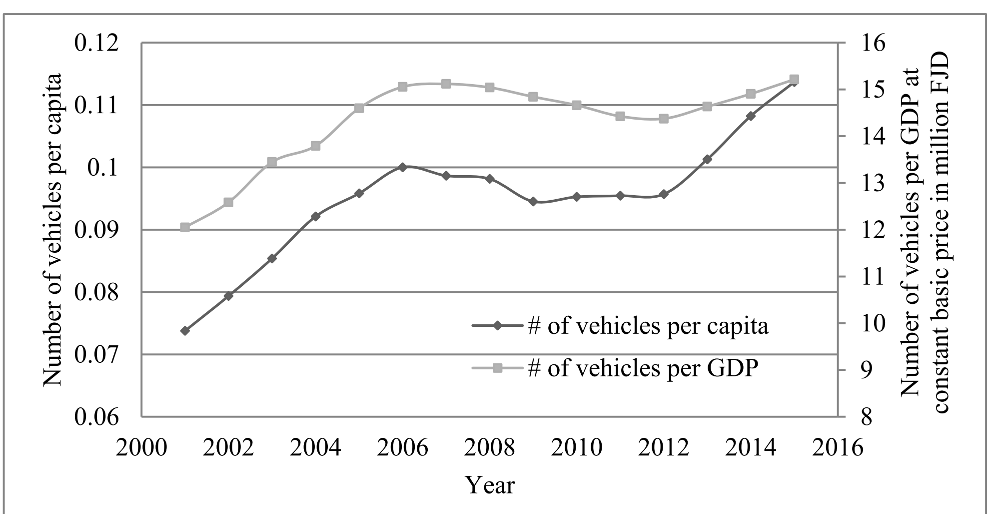

Fig. 6. Vehicle intensity for Fiji.
Data Source: (FBoS, 2018; WB, 2017).

Table 1
Regression models for number of vehicles (p-value is given in brackets).

Model	Parameters considered	β_0	β_1	β_2	ε	Adjusted R^2
1	Pop	−195461.069 (0.001)	0.326 (0.000)		5667.292	0.718
2	GDP	−39671.596 (0.008)		21.412 (0.000)	3939.126	0.864
3	Pop and GDP	−53328.117 (0.320)	0.025 (0.788)	20.027 (0.004)	4087.11	0.853

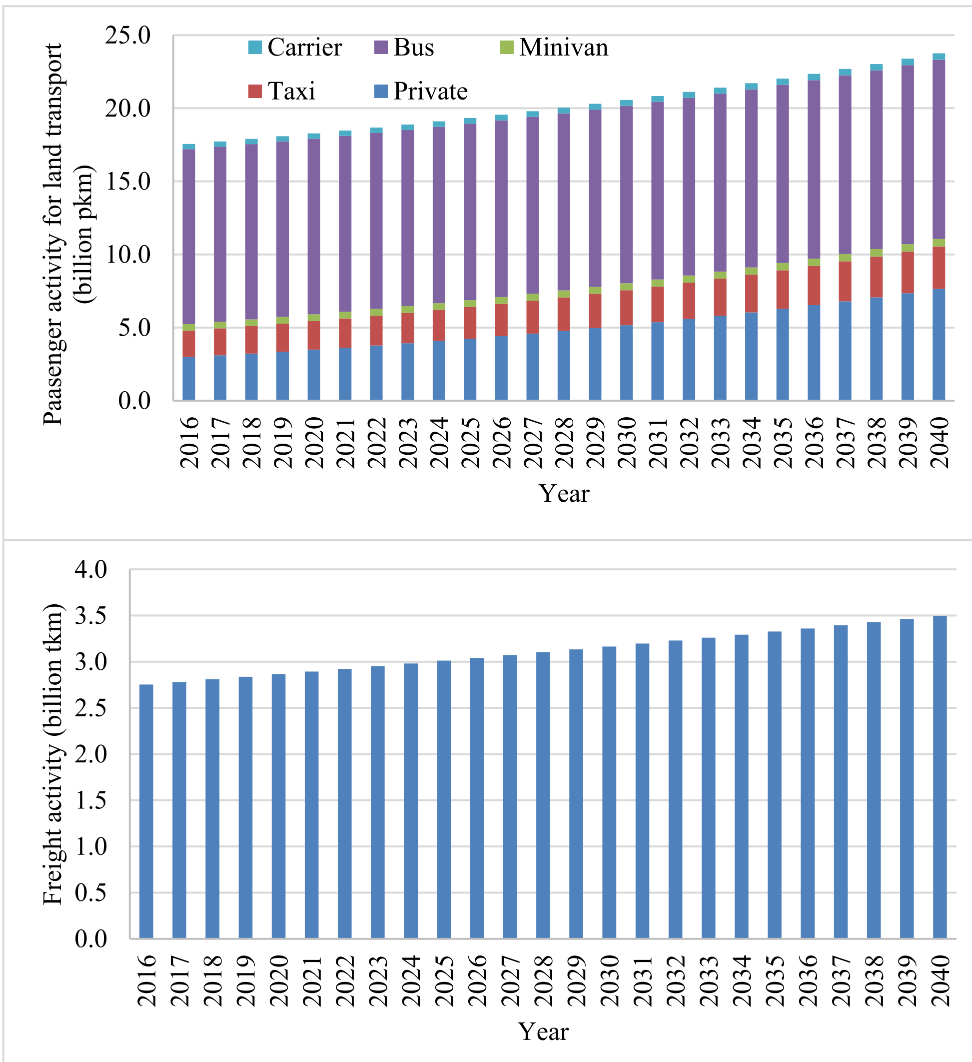

Fig. 7. Passenger and Freight activity for land transport in Fiji in future years.

using the annual distances travelled by individual vehicles for different modes of transport as collected during the survey.

For Structure, percentage of transport activity (pkm or tkm) is used for different mode of transport and fuel type of vehicles. The fuel economy data input in the structure are average values obtained from survey, Table 2. Land transport structure, Table 2, was first made in Excel, to calculate the pkm or tkm for each type of mode of transport with different fuels using number of registered vehicles, average number of passenger or load carried per trip, and annual distance travelled by vehicle.

Energy intensity, *EI*, is the product of fuel economy and occupancy rate/load factor, eq. (3).

$$EI_{ij} = FE_{ij} \times OR_{ij} \tag{3}$$

Where fuel economy, *FE* is the distance travelled in per litre of fuel (km/l). The fuel economy of land transport used in this study is discussed in sub-section 3.2.3.

The energy consumption in a given year, E_t, from different road transport vehicles and different fuel type is the product of transport activity and energy intensity, eq. (4).

$$E_t = \sum A_{ijt} \times EI_{ij} \times EC_j \tag{4}$$

Where *EC* is the energy conversion factor for fuel type *j* in (GJ/l). Table 3 gives the EC of fuels used in this study.

3.2.2. Emission factors

LEAP tool has environmental database linked to it so for each fuel type emission factors were assigned which lead to calculation of total emissions (*EM*), eq. (5).

$$EM_{ijkt} = E_{ijt} \times EF_{ijk} \tag{5}$$

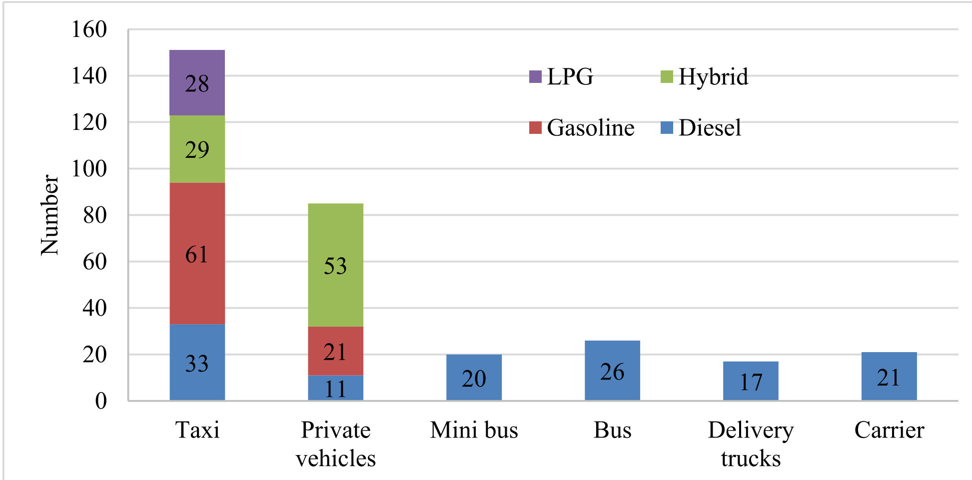

Fig. 8. Number of vehicles participated in survey.

Table 2
Parameters of land transport vehicles used in LEAP tool.

Mode of transport with fuel type	Registered vehicles in 2016	Avg. annual distance (km)	Load factor (# of passengers per vehicle) or (load per vehicle)	Fuel economy (km/litre) *Italics are assumed values*
Private (cars, gov, diplo, driving)				
Diesel	24828	14800	2.5	*10*
Gasoline	48322	14800	2.5	8.52
LPG	2262	14800	2.5	*13*
Hybrid	5182	14800	2.5	19.78
Electric		14800	2.5	*5.03* km/kWh
Biodiesel B5		14800	2.5	*10*
Ethanol E10		14800	2.5	*8.18*
Public (Taxi& rental or hire)				
Diesel	1399	69400	3	10.42
Gasoline	5259	69400	3	11.95
LPG	1073	69400	3	13.25
Hybrid	956	69400	3	26.77
Mini van				
Diesel	350	89800	12.5	7.10
Gasoline	50	89800	12.5	*10*
Buses				
Diesel	1396	142800	60	2.52
Electric				*0.75* km/kWh
Carriers				
Diesel	374	71800	13	10.30
Gasoline	2	71800	13	*10*
Good vehicles				
Diesel	16149	32200	5	7.20
Gasoline	841	32200	5	*10*
LPG	113	32200	5	*11*

Where k is the type of emission based on the fuel's chemical composition, EF is the emission factor (kg/GJ).

For emission factors of fuels used in model, environmental database in LEAP was used. IPCC Tier 1 emission factors were chosen for diesel, gasoline and natural gas for land transport.

For correct calculation of emissions and reducing double accounting in emissions, diesel and gasoline emission factors were considered for B5 and E10 fuels respectively. Once, the emissions were calculated, results were scrutinized by individual branches by different fuels. For emissions from E10 and B5 fuels in different mode of transport in road transport, these emissions were multiplied by factor 0.9 and 0.95 respectively. This is because IPCC informs that due to unavailability of emission factor for biofuels in individual country for a specific blend of biofuel, one option is to use the emission factor of fossil fuel as a percentage of fossil fuel addition in the biofuel concerned (Garg and Pulles, 2006). In addition, biofuel are considered as carbon neutral fuels as the carbon dioxide used during photosynthesis are used during production of biofuel and use of biofuel in vehicles or electricity generation (Lopes et al., 2016).

Table 3
Energy content of fuels used in transport analysis.

Fuel	Energy content (GJ/metric tonne)	Reference
Diesel	43.330	LEAP tool
Gasoline	44.800	LEAP tool
Ethanol	26.744	LEAP tool
Biodiesel (from coconut oil) B100	40.37	(Hossain et al., 2012)
Biodiesel B5	43.182	Calculated based on ratio [(5% of 40.37) + (95% of 43.33)]
Bioethanol E10	42.994	Calculated based on ratio [(10% of 26.744 + 90% of 44.8)]

3.2.3. Fuel economy of vehicles

From the results of land transport questionnaires, taxi, carriers and private diesel vehicles have fuel economy of around 10 km/l while minivan and good vehicles has fuel economy of around 7 km/l of diesel, Table 2. All buses in Fiji run on diesel fuel with an average fuel economy of 2.52 km/l. Results from questionnaire also showed, private gasoline vehicles have fuel economy of 8.52 km/l while gasoline taxi's fuel economy was 11.95 km/l. Hybrid vehicles have higher fuel economy. Questionnaire results show private hybrid vehicles have fuel economy of approximately 20 km/l while hybrid taxis have approximately 27 km/l. For B5 fueled vehicles, this study assumes that their fuel economy would be the same as diesel vehicles. This is because (USDOE, 2017) reports that low blend of biofuel in diesel does not significantly affect fuel economy of diesel vehicles but E10 fueled vehicles have reduced fuel economy compared to gasoline vehicles because of its lower energy content. Fuel economy of E10 vehicles is calculated as gasoline vehicle fuel economy divided by ratio of energy content of gasoline to E10. It has to be noted that fuel economy obviously depends on the road conditions, maintenance of vehicles, age of vehicles, and behavior of drivers.

3.2.4. Model verification

In Fiji, land transport fuel usage is not recorded explicitly. The only data available was the fuel import and re-export data from FBoS. This data was then used to calculate the retained fuel import, Fig. 9.

The retained amount of diesel and gasoline is used in land transport

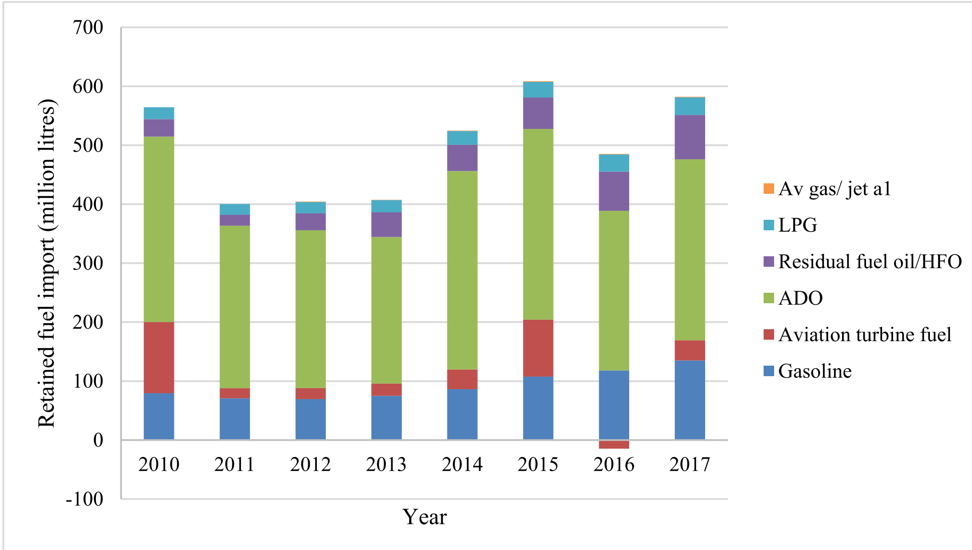

Fig. 9. Retained fuel import in Fiji from 2010 to 2017.
Data Source: (Miller, 2018).

Table 4
Modelling results for land transport sector and retained import of selected fuels.

Fuel	Unit	Modelling Results		Retained fuel import	
		2016	2017	2016	2017
Diesel	Million litres	204	207	271	307
Gasoline	Million litres	124	126	118	135
LPG	Million kg	4.61	4.67	29	30

as well as for domestic maritime transport. Similarly, LPG retained import includes usage in land transport as well as domestic, commercial and industrial use. Hence, no comparison can be made between modelling results and actual consumption in land transport. It can only be noted that the difference between our transport fuel modelling results and the retained import (FBoS) represent the amount of fuel used by other sectors in Fiji Table 4.

3.3. Low carbon measures considered in analysis

A number of measures were studied to reduce fossil fuel consumption in transport sector in land transport Fiji, Table 5. All low carbon measures have the same annual growth rate as Business as Usual (BAU) but there are changes in sub-sector activity and fuel economy depending on the strategy studied.

4. Results

For land transport, 12 PJ of fossil fuel was consumed in 2016 which increases to 16 PJ in 2040 in BAU scenario. Regarding different modes of road transport, buses are the major consumer of diesel followed by goods vehicle and then private vehicles, Fig. 10. For gasoline, private vehicles followed by taxi are major consumers.

Several individual measures plus one combination of some individual measures are studied in order to reduce fossil fuel energy demand and consequently a reduction in fuel import bill. Combination scenario (Combo) includes private hybrid & electric, taxi hybrid & electric, electric bus, modal shift and public transport measures.

The energy demand for different measures considered for reducing fuel demand ranges from 12-16 GJ in 2040 as shown in Fig. 11. Combination of measures is seen to have the largest impact on the fuel energy demand with a reduction of 25% relative to BAU.

We wanted to see how the volume of fuel demand would change in future when different measures are taken. This can be visualized in the results plotted in Fig. 12. In 2015, fuel consumption was 337 million litres with 63% diesel, 37% gasoline and 3% LPG. Fig. 13 shows the volume of fuel consumed in 2040 under different measures. In this graph for B5 and E10 measures, diesel and gasoline consumption includes fossil fuel component in B5 and E10.

As expected, Combination of measures has the lowest fossil fuel consumption of diesel, gasoline and LPG of around 223, 100 and 10 million litres respectively by 2040. Considering, Fig. 12, biofuel consumption is increasing significantly in future, but this biofuel is made up of 95% diesel for B5 fuel and 90% gasoline for E10 biofuel. Biofuel introduction in land transport has 233 million litres of B5 standard biodiesel consumed in 2040, which means that 11.65 million litres of pure locally produced biodiesel will be needed. Similarly, for ethanol E10 introduction in vehicles, 148 million litres of E10 fuel is needed in 2040, which implies that 14.8 million litres of pure ethanol need to be produced locally. So even though, biofuel usage has increased but actual fossil fuel used in these scenarios decrease by 8.8% for diesel and 6.3% for gasoline, Figs. 12 and 14.

Freight drivers applying eco-driving techniques have the potential to reduce diesel fuel consumption by 3.4% in 2040, Fig. 14. Use of hybrid and electric vehicles for private and taxi would have the potential of reducing diesel by 8.3% and gasoline by 15.5% in 2040. Cycling and walking can reduce diesel consumption by 0.13% while gasoline consumption reduction is very minute.

Land transport GHG emissions are steadily increasing for all measures compared to 2016 except combination of measures emissions, Fig. 15. When BAU emission in 2040 is compared with “Combo”, there is 25.5% reduction in emissions, Fig. 16. It is seen that electric vehicles (private, taxi and buses) and hybrid vehicles (private and taxi) have a combined GHG reduction of almost 16% in 2040 compared to BAU emission in the same year.

5. Discussions and suggestions for policy makers

IPCC special report on emission scenarios forecast global emissions from fossil fuel use to range from 7.8-14.7 GtC/yr[3] in 2020, 8.5–26.8

[3] GtC means gigatonnes of Carbon which is equivalent to 3.67 gigatonnes of carbon dioxide (IPCC, 2000b).

Table 5
Measures taken for reduction in fuel consumption in transport sector in Fiji.

Scenarios	Change in model	Reason
BAU	1.3% annual growth in passenger activity and 1% annual growth in freight activity, Fig. 7.	This scenario assumes present trends of vehicular growth in Fiji and fuel intensity, occupancy rate, modal split to remain unchanged in future.
Electric vehicle	2020 0.5% of private vehicles and taxis are electric 2030 2% private vehicles and taxis are electric 2040 5% of private vehicles and taxi are electric	Assuming 1000 electric vehicles in 2020 with assumed annual growth of 20% (this increases the number of electric vehicles to 38,000 by 2040), share of electric vehicle passenger activity increases from 0.5 to 5% from 2020 to 2040.
Hybrid vehicles	From 2020 16.1% of taxis are hybrid vehicles From 2030 28.6% of taxis are hybrid In 2040 37.6% of taxi are hybrid Private vehicles From 2020 13.7% of private vehicles are hybrid From 2030 20.2% of private vehicles are hybrid In 2040 32.2% of private vehicles are hybrid	Government is supporting hybrid vehicles import by having no duty charged, encouraging consumers to purchase hybrid vehicles and electric vehicles
Electric buses	In 2020 3% of buses are electric which increases to 10% in 2030 and increases to 20% in 2040.	One bus company in Fiji is considering purchase of electric buses for its fleet. This scenario is explored to study its effects on diesel consumption. (Eudy et al., 2016) presents that battery electric bus have fuel economy of 2.15kWh/mile. This was used as fuel intensity for electric bus in Fiji.
Modal shift to non-motorized mode of travelling	Using the assumption given in reason section (on the right), by 2020 0.01% are using non-motorized mode of transport, by 2030 it increases to 0.03% and by 2040 it increases to 0.2%.	Cycling and walking are promoted by government. Infrastructures are built to support this initiative. It is assumed that 300 people are walking and 300 people are cycling for their daily transport instead of taking motorized transport in 2020. This number increases annually at a rate of 20% reaching 11500 people walking and 11500 cycling by 2040. 3 km daily for walking and 6 km daily for cycling was assumed using (Dhar and Shukla, 2015) assumption of 1.6 km average trip for walking and 3 km average trip length for cycling.
Eco-driving of goods vehicles (freight)	Taking 10% improvement in fuel economy, heavy goods vehicles fuel economy improves from 7.2 km/l to 8 km/l.	Eco-driving is promoted for heavy goods vehicles. In Fiji, 94% of good vehicles are diesel while the remaining are run on gasoline and LPG. (Park et al., 2013) reports from experimental analysis that eco-driving can achieve 8–16% reduction in fuel consumption in heavier vehicles while (Barkenbus, 2010) reports that fuel economy can improve as much as 25% while conservatively fuel savings can be between 5 and 10%.
Carless days [Promotion of public transport]	Initiative to start in 2020, with all private cars number coded. The number of private vehicle on road would reduce by factor 0.5 and this would mean that the share of private passenger vehicle would reduce from current 17% to 10%, taxi share would increase from 10% to 11%, minivan share to increase from 2.6% to 2.8% and bus share to increase from 68% to 73.8%.	Color code or number code private passenger vehicles. For example, on registration plates of private vehicles, there is "6" written on some vehicles and "3" written on other vehicles. Vehicles with "6" can only run on road on Monday, Wednesday and Friday while "3" would run on Tuesday, Thursday and Saturday. This would encourage vehicle owners to look for other means of transport (carpooling, bus travel, etc.)
Combination of measures		This combines the measures of private hybrid, taxi hybrid, electric bus, modal shift, and public transport
Biofuel use in vehicles (B5 standard)	This scenario takes 10% of diesel vehicles to be introduced with B5 standard biofuel in 2020, which gradually increases to 90% of diesel run vehicles by 2040.	Fiji has B5 standard (has 5% biodiesel and 95% diesel to be blended) for use. B5 standard has been chosen for use in scenarios because its feasibility report has been done by World Bank and this standard has been found to be technically and economically feasible considering the availability of coconut oil by taking out the use for food (LMCInternational, 2008b). (USDOE, 2017) reports low-level blend of biofuel such as B5 are ASTM approved to be used in any compression-ignition diesel engine. It further states that B20 can also be applied to diesel engine without any significant impact (the drop in fuel economy is unnoticeable) on fuel economy.
Biofuel use in gasoline vehicles (E10 standard)	This scenario takes 10% of gasoline vehicles to be introduced with E10 fuel in 2025 which gradually increases to 90% of the vehicles by 2040. All types of vehicles consider E10 use except buses.	E10 standard has 10% ethanol to be blended with gasoline (Singh, 2011). E10 standard has been passed in cabinet to be used in gasoline engines. It has been reported that the best feedstock for ethanol production in Fiji is molasses that is currently being produced by FSC. (TERNZ, 2006) reports that vehicles can adapt to E10 without any risk to damage. In addition, vehicular emission is observed to reduce by as much as 30% (Veal). The fuel economy of vehicles is bound to reduce because net energy content of ethanol is much lower than gasoline. This is calculated based on the energy content of gasoline and the fuel economy of different mode of transport. [1l gasoline = 44.8 MJ while 1l E10 = 43 MJ, therefore, to have the same power in gasoline vehicles running on E10 it would need more E10 fuel compared to gasoline to run the same distance. Hence, (44.8/43) 1.0419l of E10 would have 44.8 MJ of energy. So for taxi, gasoline taxi have 11.95 km/l, E10 taxi would (11.95/1.0419) 11.468 km/l]

GtC/yr in 2050 and 3.3–36.8 GtC/yr in 2100 by studying 40 scenarios with different 4 different story lines (IPCC, 2000a; b).

Section 4 presented fossil fuel consumption and its related emissions due to different low carbon measures applied to land transport. At present, Fiji is trying to reduce its GHG emissions in transport sector as evident in existing tax policies in Fiji with respect to vehicles, Table 6. These measures support Fiji's NDC and Green Growth Framework aspirations (GoF and GGGI, 2017). estimates total emission in energy sector (electricity, industry and transport) in base year 2013 to be 1500 Gg of CO_2 which increases to 1800 Gg of CO_2 by 2030 in BAU scenario. NDC targets 30% reduction in emission by 2030 where 10% of reduction is unconditional by using the available resources in Fiji while remaining 20% is conditional based on external funding (GoF and GGGI, 2017).

For achieving this target, NDC reports that going 100% renewable grid electricity generation will reduce 20% of BAU emissions by 2030 while 10% of emission reduction is achieved through energy efficiency measures in transport, industry and demand-side sub-sectors. To

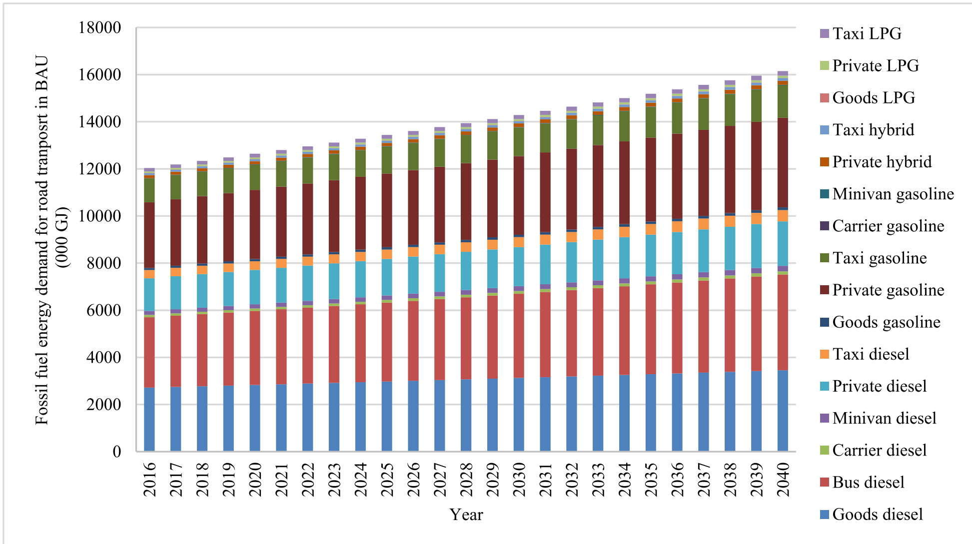

Fig. 10. Road transport fossil fuel energy demand in BAU.

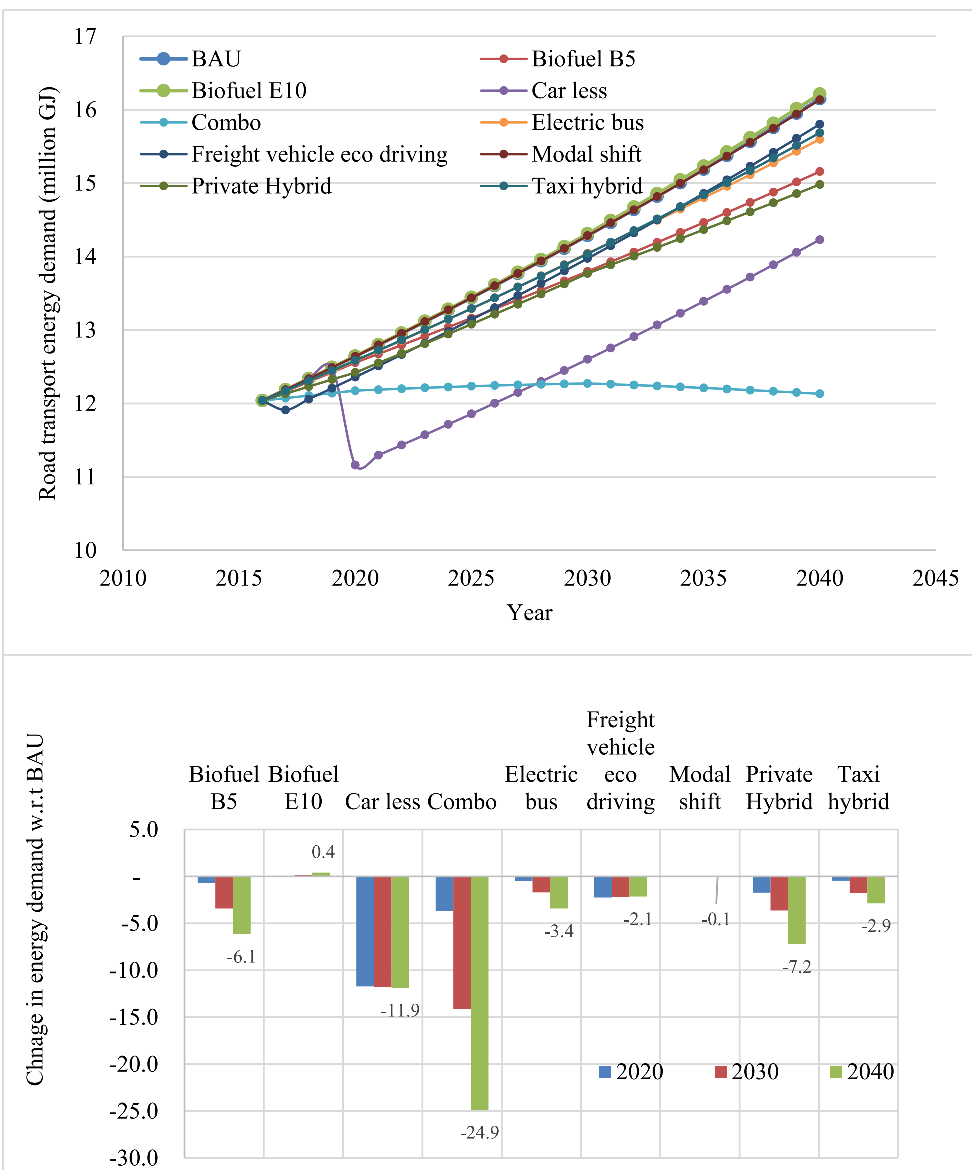

Fig. 11. Road transport energy demand growth for different measures.

achieve emission reduction target for land transport (GoF and GGGI, 2017), report that short-term (2018–2020) mitigation action plan involves improving fuel economy of private cars, buses and taxis by having Euro norm fuel standards, age limit on vehicle importation and incentives to increase the share of hybrid vehicles. Medium-term (2021–2025) mitigation action plan is to replace all diesel fuel usage in land transport with B5 biofuel from 2021. NDC further recommends Fiji to focus its attention on improving public transportation system and also encourage non-motorised transport like cycling.

In addition, Green Growth Framework (GGF), developed in 2014 is a “living document” which discusses 3 pillars (environment, social and economic) with 10 thematic areas in restoring balance in development that is sustainable for our future (GoF, 2014). Sustainable transportation is one on the thematic areas in this document. For sustainable transportation in Fiji, it is recommended that Fiji considers electric and hybrid cars, promotion of public transportation and non-motorized transport, and alternative fuels such biofuels in long-term. Present study, supports Fiji's NDC's and GGF for sustainable transportation. Below is a discussion on the policy implications of the strategies mentioned in section 3.3 and 4.

Introduction of biodiesel in transport sector will reduce volume of diesel consumption by 8.8% in 2040 relative to BAU. Analysis reveals that when land transport activity increases annually at 1.3% then total annual volume of biodiesel B100 increase from 1 million litres in 2020 to almost 12 million litres in 2040, Table 7. A study by the World Bank in 2008 revealed that with the current resources in coconut plantations

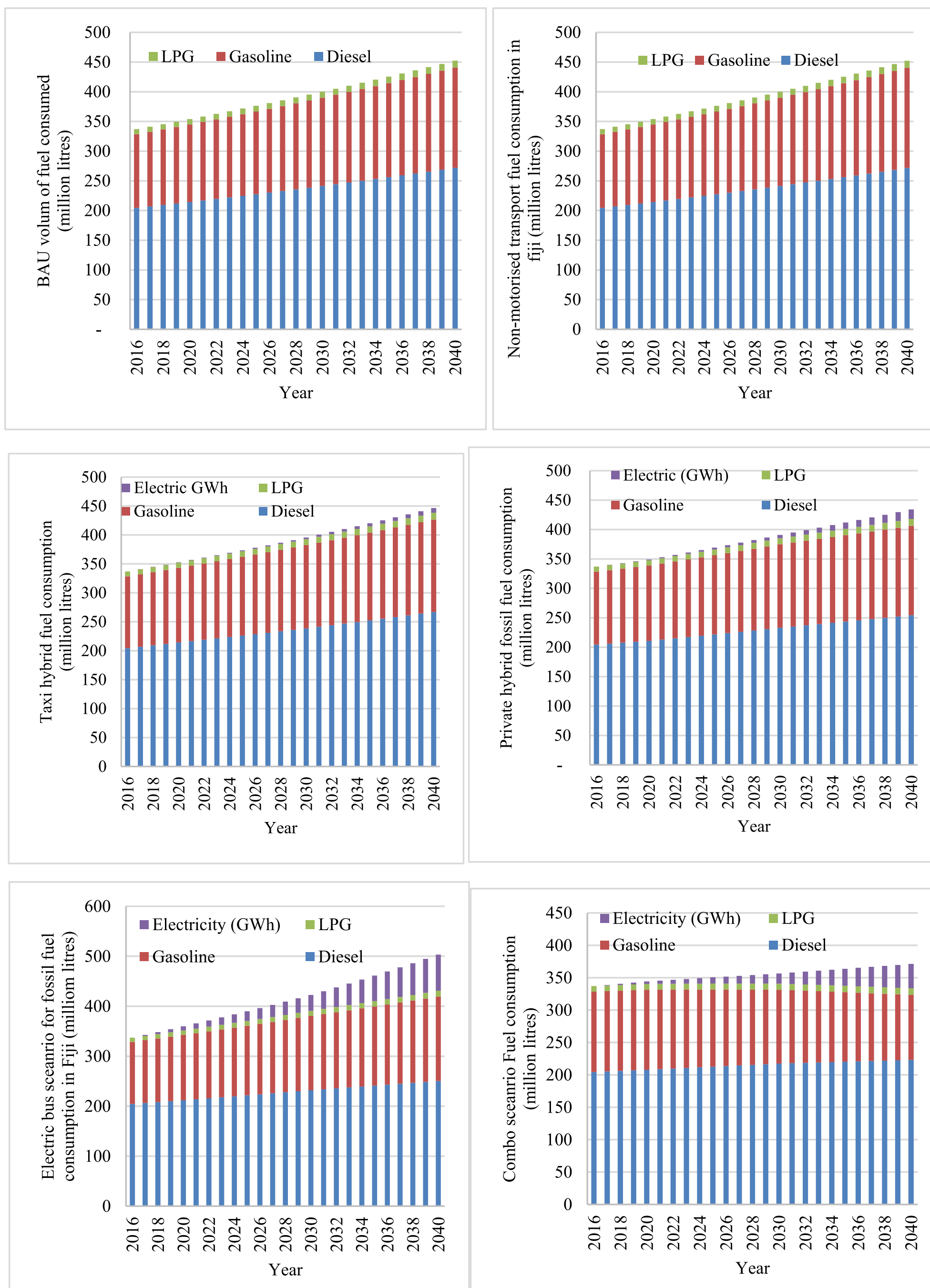

Fig. 12. Annual fuel consumption for different measures studied.

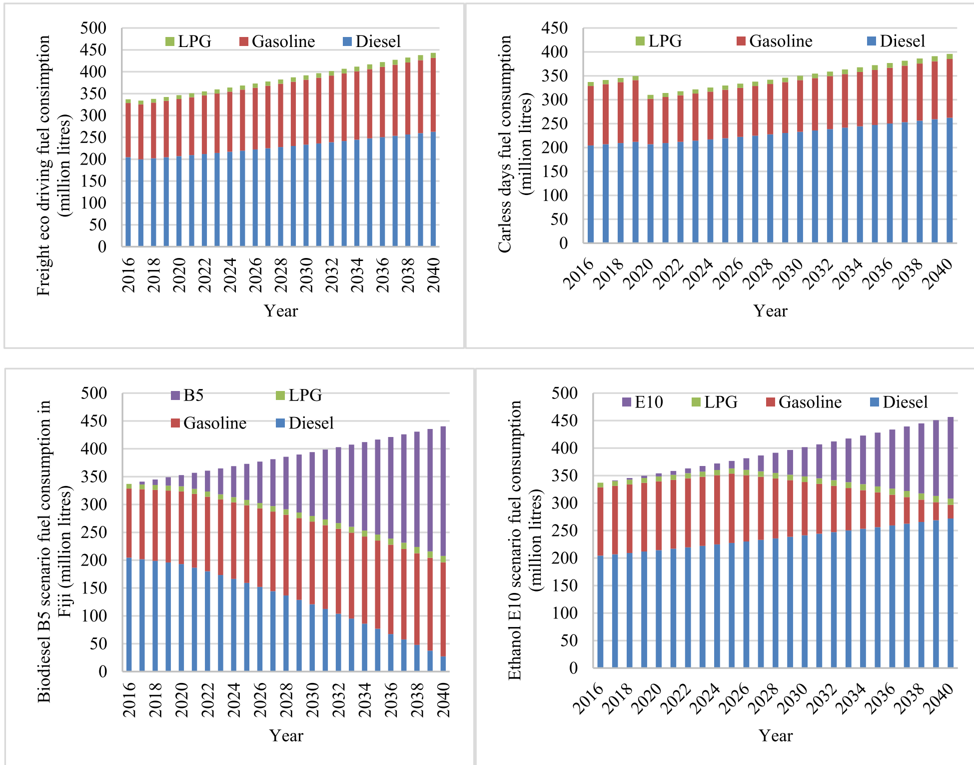

Fig. 12. (*continued*)

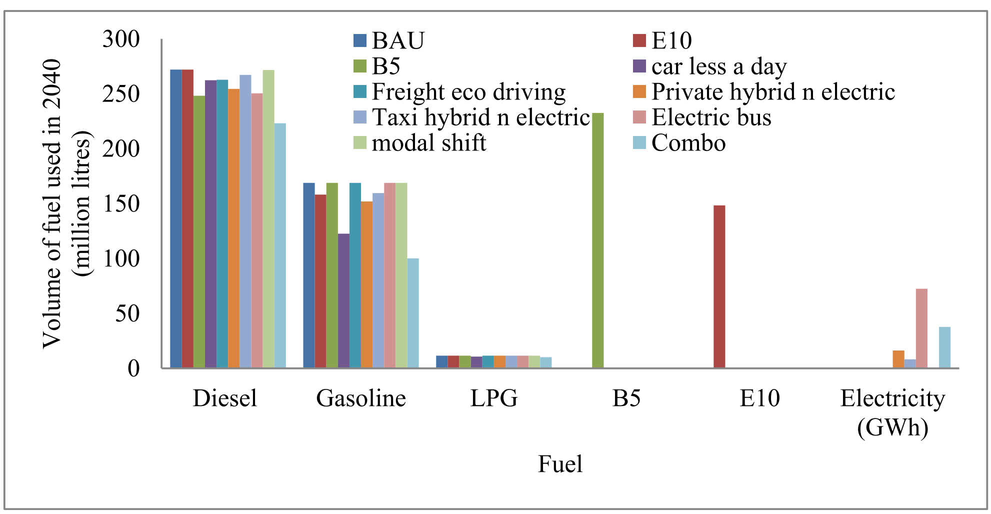

Fig. 13. Fuel consumption in 2040 by different scenarios in road transport.

and oil production, on average 5 million litres can be produced at a small scale biodiesel plant (LMCInternational, 2008b). However, considering Table 7, this annual production of biodiesel is insufficient to supply for biodiesel demand from 2030 to 2040.

In the past few years (2009–2016) annual coconut oil production is only around 5000 tonnes, Fig. 17. Taking out 30% of this actual coconut oil production, only 3500 tonnes would be available to be used for biodiesel production, provided that no coconut oil is exported. Then taking coconut oil density as 0.92 kg/l and biodiesel yield from coconut oil as 80% (Beer et al., 2007), only 3 million litres of biodiesel can be produced annually with the current oil production. However (GoF, 2013), reports that only 35% of the total annual nut production (250 million/year) is used for copra production from which coconut oil is produced. They report that 30% of annual total nut production is not harvested and the remaining 35% is used in households. Hence, the overall annual biodiesel production taking into consideration current coconut oil production and the nuts not harvested is estimated to be 9 million litres, This calculation is based on; 6 nuts equivalent to 1 kg copra and 60% of copra is converted to coconut oil (Raghavan, 2014).

This 9 million litres of biodiesel production will be able to cater for demand till 2035 but after that there needs to be more production, Table 7. Given that 70% of existing coconut trees are senile whose production is 25–30 nuts/tree/year from 50-60 nuts/tree/year when they were below 40 years old and area of coconut plantations are decreasing, there should be plans for planting new trees. Some parts of Fiji have already started establishment of seed nurseries (GoF, 2013).

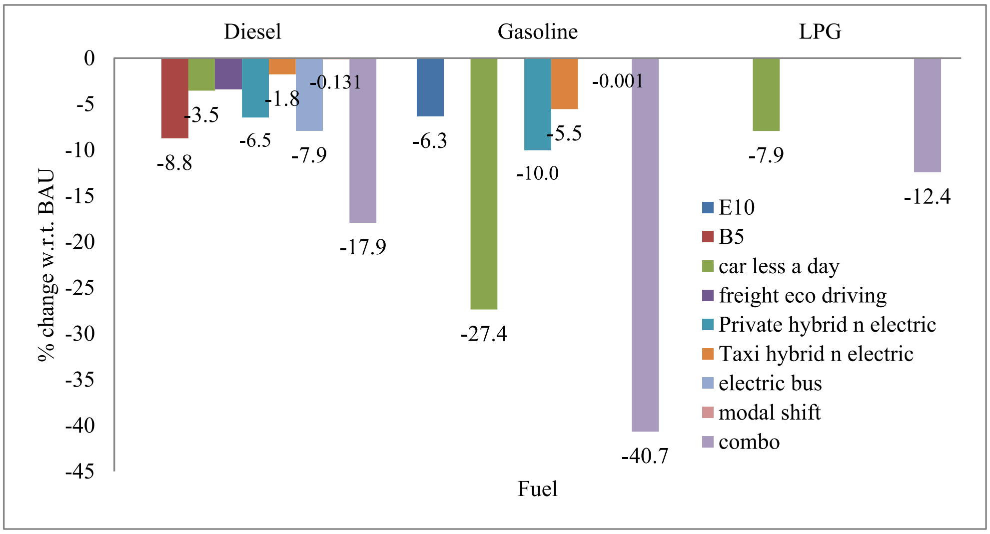

Fig. 14. Reduction in volume of fossil fuel consumption compared to BAU in 2040.

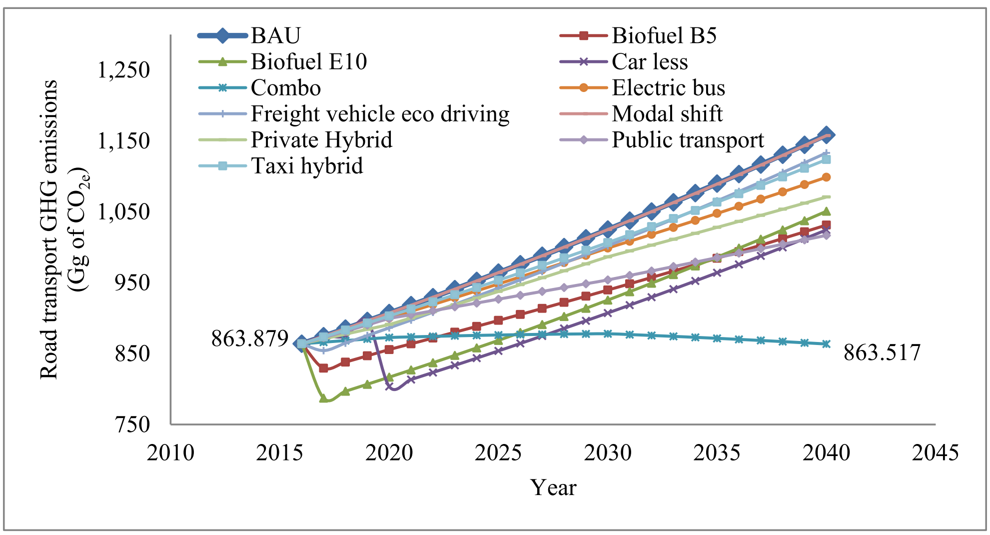

Fig. 15. GHG emissions by different measures by 2040 for road transport.

Fiji, presently has an approved biodiesel B5 standard. However, there is no investment in biodiesel industry.[4] One reason can be the high cost of biodiesel production. The capital cost of production of palm oil based biodiesel ranges from USD5.4–8.6 million for plant capacity ranging from 60-143 million litres respectively while overall production cost ranges from USD0.88–0.82/litre of biodiesel produced (Demirbas, 2009). Fiji can start with small-scale biodiesel production plant with a capacity of 5 million litres[5] and assuming biodiesel plant capital cost to be USD0.75/litre, total capital cost comes to around USD3.75million. This is huge cost for Fiji. There needs to be incentives given to investors to invest in biodiesel production. However, investors need to feel confident that biodiesel market in Fiji is for long haul and not just short run. FDoE has taken the lead in preparing B5 and E10 standard in Fiji. In addition, they are reviewing the National Biofuel Policy for Fiji to increase investments in biofuels. Pilot projects where donor agencies need to assist in setting up biodiesel plant and for vehicles (maybe government vehicles) to volunteer to operate using biodiesel B5.

While this is ongoing, Department of Energy together with Agriculture department, Forestry department, Lands department and community representatives need to work on planning for planting of coconut trees. The area of coconut plantations is reducing; 1991 had 49500 ha of coconut plantations while in 2009 there was only 17800 ha of coconut plantation left. Rise in coconut timber sales from senile plants, low returns from coconut farming, expiring land leases, and occurrences of natural disasters such as tropical cyclones are some factors for reduction. Two species are predominant in Fiji; Fiji Tall and Malayan Dwarfs comprising of 4000 ha each while 2000 ha is of hybrid varieties and remaining are mixed variety (GoF, 2013).

In addition to creating new coconut seed nurseries, there needs to tax incentives, subsidies and other supporting policies made to encourage private investments. Involvement of locals from the start of any project is one of the most important factors for success. Capacity building and development needs to be part of the project. There can be further research on variety of coconut tree that is most feasible for

[4] In 2010, Fiji had an operational biodiesel plant in Lami which supplied around 300 vehicles to run on biodiesel. However, this plant shut-down within a year of operation.

[5] This production can be increased in modular form in later years if there is positive response from consumers.

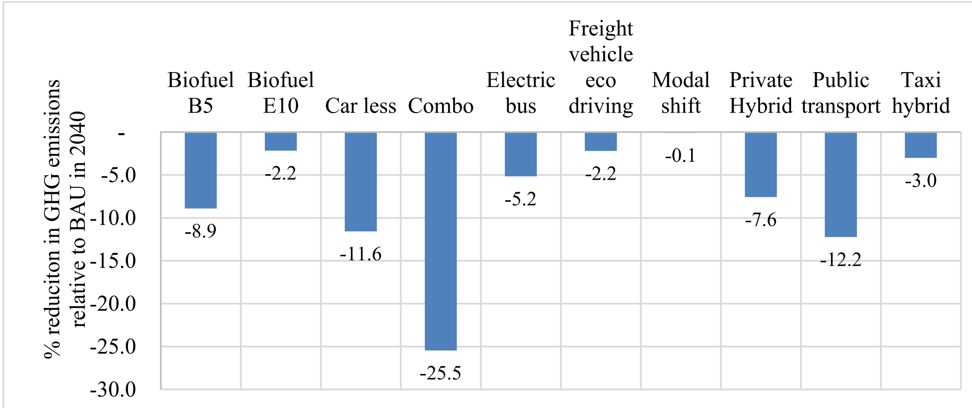

Fig. 16. GHG emissions reduction relative to BAU in 2040 for road transport by different measures.

biofuel production. Factors such as number of fruits per year, time it takes to mature, proneness to diseases, and other factors can be studied during research.

Introduction of ethanol E10 use in road transport have the potential to reduce gasoline consumption by 6.3% relative to BAU in 2040. Fiji has an approved E10 standard. According to analysis, in 2040, almost 15 million litres of ethanol E100 need to be produced which would then be blended with gasoline to produce E10 biofuel, Table 7. A study conducted by The World Bank revealed that molasses is the most attractive feedstock for ethanol production in Fiji comparing it to feedstock such as cassava and sugarcane juice in terms of security of supply, food security and favorable financial gain (LMCInternational, 2008a). Over the past years, molasses production has been varying depending on sugarcane production, Fig. 18.

In Fiji, 80% of the total molasses produced is exported while 20% is sold to local distilleries. Based on production rate of 200 ml of ethanol/kg of molasses (Inamdar, 1994; Shapouri and Salassi, 2006) and if no molasses is exported but used for ethanol production, then over the past years, on average 20 million litres of ethanol could have been produced annually, Fig. 18.

However, sugar production has been declining recently, so taking the lowest ethanol production as 9.4 million litres annually, which means 1.6 million tonnes of sugarcane production with 38000 Ha harvested, can potentially supply for E10 production almost till 2035. After which, ethanol production capacity has to increase to cater for growing demand. Fiji has taken steps to revive its sugar industry. Fiji Sugar Corporation is undergoing reform under the “Proposed Sugar Industry Reform Framework” which Fiji government further developed, initially drafted by Deloitte of New Zealand (FSC, 2015). There are seven main activities outlined in the reform framework (from cane development to incentive based remuneration of FSC management) that aims to revive the sugar industry in Fiji. In its annual report 2011, FSC chairman's message for one of the way forward is to make investments in ethanol production (FSC, 2015).

Table 7
Amount of biodiesel and ethanol production to meet B5 and E10 demand respectively at intermediate year.

Volume (million litres)	2020	2025	2030	2035	2040
Biodiesel	1.0	3.2	5.7	8.5	11.6
Ethanol	0.6	1.4	5.3	9.8	14.8

For a 10 million litre ethanol production plant in Fiji, cost is estimated to be USD4million based on production cost of USD0.4/litre (Shapouri and Salassi, 2006). Additional annual operational cost of USD0.335/litre of ethanol produced will also be present (Inamdar, 1994). With this high capital cost, serious investment has to sought for ethanol production to start in Fiji.

Lots of lessons can be learned from Brazil who is the highest ethanol producer in world. In Brazil, private investment funds ethanol mill construction as opposed to government subsidies that were given previously (Coelho et al., 2006). Hence, GoF needs to heavily subsidize investments during the initial plant construction and installation. Government gasoline vehicles and other voluntary vehicles can be in the pilot program to test E10 in their cars. The progress and output of this pilot should be greatly publicized so that other gasoline car drivers are encouraged to use E10. As part of this strategy, GoF can also reduce

Table 6
Existing tax policies in Fiji regarding land transport. Information Source: (GoF, 2017a).

	Existing tax policy	Implication
1.	Zero duty on new and second hand hybrid vehicles	More hybrid vehicles are imported into country. Reduce fuel usage
2.	5–7% subsidy given to business setting up electric charging stations around country	Attract investment
3.	Reduction in duty in passenger vehicles not exceeding 2500 cc, Rough Terrain Vehicles and second-hand good trailer.	More vehicles will be imported
	Reduce duty on 10–22 passenger vehicles, Auto Rickshaws and Quad bikes	Promotes public transport and reduces congestion
4.	Increase in duty for second hand vehicles	Demote importation of second hand vehicles
5.	Imported vehicles will be Euro 4 compliant	Cleaner fuels used in vehicles
6.	Second hand vehicles have to be less than 5 years old from date of manufacture for diesel and unleaded vehicles while hybrid, LPG and electric vehicles second hand vehicles 8 years or less from date of manufacture	Restricts importation of very old cars so fuel efficiency in imported cars are improved.
7.	Introduction of Green Tax: Increase the fiscal duty on: (i) Motor Spirits (44 cents per litre to 46 cents per litre); (2) Automotive and industrial diesel oil (18 cents per litre to 20 cents per litre). Green Tax will not apply on white benzene, kerosene and premix. Rebate of 2 cents per litre for Inter-island vessels, Bus and Fishing industries will be in place.	Promote fuel saving measures to be undertaken by vehicle owners.
8.	Luxury cars exceeding 3000 cc will have $20000 levy upon sales	Demote excessive sales of luxury vehicles.

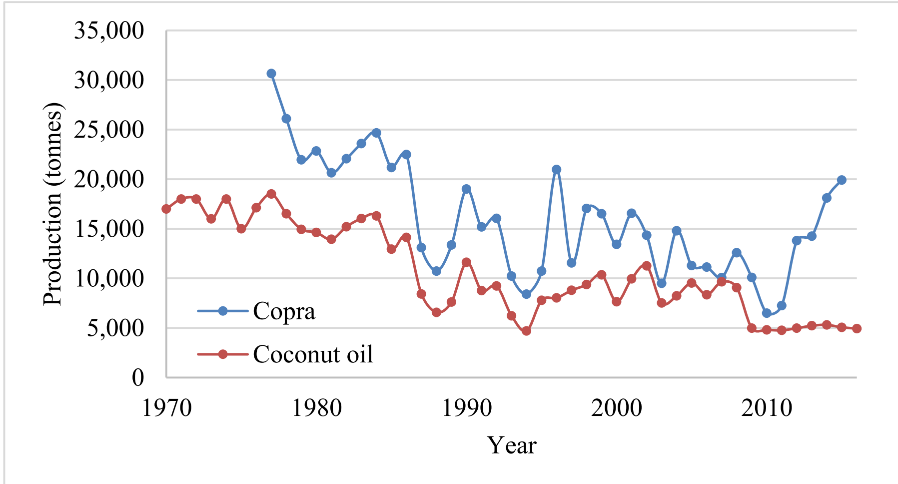

Fig. 17. Coconut oil and copra production over the past years in Fiji.
Data Source: (FBoS, 2018).

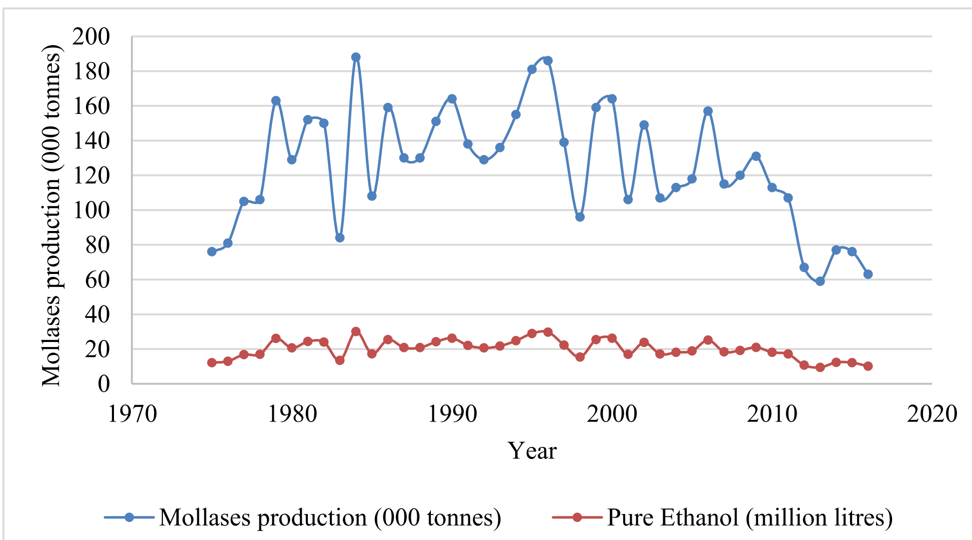

Fig. 18. Actual molasses production in Fiji.
Data Source: (FBoS, 2018).

duty to promote import of flux-fuel cars that can run on either 100% hydrous ethanol or different blends of ethanol and gasoline as is the case in Brazil (Lopes et al., 2016). Stable government oversight, clear rules on local ethanol stock, right ethanol production scale and private sector involvement are some of lessons learned from ethanol industry in Brazil (Moraes, 2011) which can be considered by Fiji.

For Fiji, ethanol from molasses does not pose any food security problem as only 20% of the molasses produced is used locally by distilleries while the remaining is exported. Fiji is on the path to reviving its sugar industry and future ethanol production is greatly dependent on this industry. Investors will only invest in this technology if they see good return on their investments and long-term scope of ethanol use in Fiji. Detailed economic feasibility study needs to be done on ethanol production in Fiji considering the interaction between ethanol prices, gasoline prices, sugar market and molasses export price. In addition, there needs to be provision that current service stations are able to cater for biofuel (B5 and E10) sale.

Eco-driving for freight transport in land transport will reduce volume of diesel consumption by 3.4% compared to BAU in 2040. Eco-driving techniques involve simple things to improve fuel economy of vehicles such as regular vehicle maintenance (checking tyre pressure) and improving driving techniques. Some of these techniques involve (i) avoiding over speeding or applying hard brakes, (ii) reducing excessive idling (it is recommended to turn engine off if idling would be more than 5 min), (iii) reducing air conditioning usage in vehicles and (iv) observing and acting on user-interface which may be installed in vehicles to improve fuel economy.

Implementation of eco-driving is relatively quick and is relatively cheap option. Eco-driving for truck drivers in Fiji will be new and LTA with other authorities need to act together to promote this. Lots of media coverage and publicity for this strategy needs to be done to create understanding acceptance of eco-driving.

Training on eco-driving techniques for drivers can be included during license renewal or organizing short workshop/training sessions. There can also be incentives given to trucking companies to take-on eco-driving. GoF during their annual budget announcement can provide subsidies for trucks to install eco-driving technologies. These technologies include, meters telling drivers what speed they are going, how much fuel they have used or setting up speed limits in their trucks so trucks do not exceed this limit (Killian, 2012). informs that there should be ongoing trainings of drivers as well as instructors on eco driving techniques with positive reinforcement, and incentives given to drivers for engaging and maintaining compliance on eco driving so that eco driving does not wean within weeks or months of its initiation.

Carless days promotes public transport and has the potential to reduce emissions by almost 12% compared to BAU emission in 2040 while volume of diesel, gasoline and LPG consumption reduces by 3.5%, 27.4% and 7.9% respectively compared to BAU consumption in 2040. This strategy will also be new in Fiji which would make people opt for public transport or carpooling or non-motorized for short distance travel. However, activating and making this strategy a success needs enormous preparation and acceptance. It first needs voluntary participation from private vehicle owners and studying their response to this strategy before making it mandatory. Execution of this strategy needs to be well planned and thought and needs to incorporate public behavior as it involves all private road transport passengers. Manilla, New Zealand and other countries experience for carless days need to be studied carefully to learn best practices and actions to avoid to promote public carless days (Dooney, 2017; Emong, 2017).

As part of preparation process, there needs to be work done on improving public transportation in Fiji. In the case of Fiji, these are buses, minivan and taxis. Local authorities need is to make buses more appealing so people opt for this mode of transport rather travelling in private vehicles. Few things have to considered; making the travelling time in public transport comparable to travelling time in private vehicles, comfort of passengers need to match or be close to that of private vehicles, cost of travelling in public transport have to be cheaper and public transport have to be convenient to potential passengers. Another strategy could be imposing high parking levy in cities and towns. In order to achieve these, government should make transportation planning their priority.

New bus services need to registered to provide for increased in number of public transport, and new light rail introduced to ease transition into public transportation. New roads have to be built for increase in bus services and new rails have to be constructed. There also needs to be plan for making or widening sidewalk for pedestrian walking and making separate and safer bicycle pathways. Local authorities need to plan and provide for secure parking of bicycles as well as there can be rental bicycles available to public at a reasonable cost.

Introduction of electric buses, hybrid and electric vehicles for private and taxi services have the potential to reduce volume of diesel consumption by almost 16% while volume of gasoline consumption can reduce by 15.5% compared to BAU. In this case, for electric buses by 2040, there will be 18.1 GWh of electricity demand based on 2.15kWh/mile fuel economy for electric buses while electric cars consumption will be 24.4 GWh based on 5.03 kWh/km as fuel economy for private vehicles and taxis. One of the bus company's in Fiji has shown interest in operation of BEB which would cost around FJD0.5 million (Baoa, 2014).

The reduction in fossil fuel demand will only be possible if electric charging stations are selling electricity generated from renewable energy sources and electric or hybrid vehicles are operated efficiently. For electric vehicles and buses there needs to be charging infrastructure built around the country as this will encourage car owners and bus companies to purchase electric transport. GoF currently has tax incentives for investors to set up electric charging stations around the country, Table 6 (GoF, 2017b). There is another option of charging plug-in electric vehicles at homes, which needs necessary infrastructure to be installed at homes at a cost of around USD1000/home (Marchán and Viscidi, 2015). They also report that electric vehicles are also expensive compared to diesel or gasoline vehicles. Hence, for promotion of electric vehicles similar incentives to promote hybrid vehicles can be adapted. Introducing zero duty on hybrid vehicles has led to enormous importation of second-hand hybrid vehicles mainly from Japan while there are some brand new hybrid vehicles on the road also.

In addition, public awareness programs such as show case of pilot projects of electric vehicles and full documentary of its success technologically, financially and environmentally is necessary. This will create public confidence in this technology. There also needs to be plan for human capacity building and development for repair, maintenance and service of electric vehicles and buses (Marchán and Viscidi, 2015). recommends introduction of stronger fuel economy standards, so that potential owners are encouraged to buy electric or hybrid vehicles and encouragement of private-public partnership to promote electric charging infrastructure to be installed at offices or buildings.

6. Conclusions

Reducing its extreme dependence on fossil fuels is a major challenge for Fiji and more secure, reliable, clean and affordable sources of energy are urgently required. It is well documented that increase in import bill adversely affects Fiji's economy and foreign reserves. The present low carbon transport study quantifies the possible reduction in fuel demand by adopting newer technologies, introduction of efficiency measures and bringing in robust sustainable transport policies. This study helps develop an implementation plan for Fiji's NDC and Fiji's Green Growth Framework. It is acknowledged that detailed economic analysis is not in the scope of this study. Low carbon transportation in Fiji achieves energy security for Fiji and diversifies transport fuel supply.

Mobility management strategy such as carless days has shown significant reduction in fossil fuel consumption but it requires significant improvement in public transportation. Biodiesel production and use in land transport can reduce volume of diesel consumption by 9% while ethanol production and use can reduce volume of gasoline consumption by 6%. Electric and hybrid vehicles together with electric buses, single measure, have the highest fossil fuel reduction.

Reducing fuel consumption has a direct impact on the foreign exchange saved for fossil fuel import. One measure or strategy alone is not having much impact on the reduction of fuel demand but aggregation of several measures can have significant impact on the fuel reduction in vehicles. Hence, the transport sector as whole needs to work efficiently and in synchronous with common goal of reducing fossil fuel dependency in transport sector.

Finally, a comprehensive sustainable transport policy framework should be developed to encourage low carbon transportation in Fiji. Public awareness will be a key component of this framework for sensitization and acceptance of new technologies. In addition, strengthening of technical education and research will help build human capacity needed for decarbonizing the transport sector in Fiji.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jup.2018.08.001.

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