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Multi-faceted energy planning: A review

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ABSTRACT

Energy planning can be defined as a roadmap for meeting the energy needs of a nation and is accomplished by considering multiple factors such as technology, economy, environment, and the society that impact the national energy issues. Long-term energy planning is a strategic approach to study how structural changes of a nation would affect the energy demand and supply. This is done through scenario analysis which would also cater for uncertainty in planning. Good energy plan would ensure sustainable development which acts as a guiding factor for any energy scheme. In this paper, we present an overview of the different facets of energy planning based on a comprehensive literature review. It present the risks, uncertainties and errors involved in energy planning. The econometric, optimization and simulation models are reviewed and five appropriate computer models, that can be used for a small developing island nation's long-term energy planning using scenario analysis, are discussed. This paper also discusses the inquiry method and elaborates on why it can be used for energy planning in small developing island countries. Validation process of energy models is also presented and finally, recommendations are made for energy planners.

Contents

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1. Introduction

The development of a nation is highly dependent on its energy sector, as was demonstrated during the oil crisis in the 1970s. World-crisis.net [1] reports that the economy of oil importing countries can be adversely affected when there is a shortage in oil supply since it causes high price inflation. The energy sector of an economy interacts with demand, supply, technological progress, a technology's market potential, the environment and the society. Good energy planning takes into consideration of all these variables and parameters. Energy is utilized in all sectors of the economy, broadly taken as industrial, commercial, agricultural and residential. Hence, energy plays a role in production in the industrial sector as well as being a final product for consumption heating, transportation, cooking, etc. [2]. The amount of energy used for a unit of production (i.e. kilowatt hour (kWh) per tonne or kWh per dollar of output) or the amount of energy utilized per unit of service to satisfy household needs (e.g. kWh per lumens of light) depends upon the technology adopted by the end-user of energy [3].

Consumers will choose the type of technology used for harnessing energy by considering the technical and economic feasibility [4]. They are influenced by the policies in place (e.g. standards and labeling policy: energy star rating on electrical appliances has influenced customers to purchase energy-efficient appliances or carbon taxation policy that have influenced industrial consumers to emit less carbon) made on the basis of the energy planning research. An energy plan should always aim to support sustainable development. Neves and Leal [5] note three important sustainable development criteria: environmental, economic and social. Environmental criterion includes the reduction of the greenhouse gas (GHG) emissions, air pollution and depletion of natural resources which are caused by limited or inefficient supply chain and inefficient energy use. Economic criterion includes the reduction of fossil fuel dependence and increase in local investment in renewable energy (RE) and energy efficiency projects that generate business and wealth. Social criterion includes the improvement of human health, creation of jobs, greater comfort and the involvement of citizens in decision-making processes.

However, these are not the only criteria that guide energy planning; technical and geopolitical ones are also significant. The people responsible for making final policy decisions for a national energy system are governmental ministers and officials, but they must be guided, through energy planners, to make judicious decisions. Energy plan is one of the pillars for developing policies for sustainable development of a country. This paper reviews literature on the different aspects involved in energy planning focusing on risks, errors and uncertainty in energy planning, energy planning models, geographical level of energy planning and validation of planning methods. There are many existing reviews of energy planning literature mainly dealing with energy planning models (econometric, optimization and simulation). The present paper looks at the recent work published in these areas with some examples where such models are used. This review attempts to coherently bring together published literature on different aspects of energy planning. The authors believe this will be useful for energy planners in countries which are now developing their energy roadmaps as is the case in most of the Small Island Developing Countries (SIDS).

Most of the SIDS due to their relative geographical isolation, diverse topography, increasing population, and small resource base face unique challenges in their progress towards sustainable development. SIDS are heavily dependent on imported fossil fuels for most of their energy needs, due to limited technical and human resources for introduction of new energy harnessing technologies. Most SIDS have abundant renewable energy sources but financial constraints, restricted accessibility and availability of data and lack of qualified personnel lead to low penetration of renewable energy in electricity generation and transport.

Energy policies have been developed in some SIDS without any energy plan, roadmap or needs assessment. An energy plan (or roadmap) must be one of the pillars for a nation's sustainable development agenda. More often than not, energy related studies and policy development are conducted by energy consultants from developed countries or international organizations. It is imperative that the SIDS develop their own regional cadre of energy planners and specialists. The present review also focuses on inquiry method and computer assisted energy planning tools which would aid SIDS based researchers/energy planners.

The next section of this paper presents energy planning definitions and terms. Since there are risks, errors and uncertainty involved in energy planning, the third section of the paper focuses on these aspects. The forth section reviews literature on system analysis and decision making in energy planning as the results of the energy plan are used by governments for policy making process. The fifth section discusses energy planning models and presents five computer models that can be used for long-term national energy planning using scenario analysis. The inquiry method of energy planning is reviewed in Section 6 while Section 7 discusses the geographical level of energy planning. Section 8 presents validation of planning methods and finally some conclusions are drawn.

2. Definition of energy planning and planning terms

2.1. Energy planning definition

Different authors have defined energy planning in a variety of ways. A survey of some of them reveals a range of important emphases. According to Thery and Zarate [6] energy planning determines the optimum combination of energy sources to satisfy a given demand. This is done by taking into consideration the multi-criteria for decision making, which are, quantitative (economic and technical criterion) and qualitative (environmental impact and social criterion). Cormio et al. [7] suggest that the basis for energy planning is to satisfy the forecasted energy demand over a given time period by taking into account political, social and environmental considerations, as well as historical data collected for previous energy plans for the location under consideration. Hiremath et al. [8] more concisely state that energy planning involves finding a set of sources and conversion devices so as to meet the energy requirements/demand of all tasks in an optimal manner. Kleinpeter [9] identifies the main aim of energy planning as the guarantee of supply, which is achieved by sound management of the natural energy sources, diversification of energy supply sources to reduce energy imports, and rational use of energy.

In view of the above discussion, it is obvious that any energy planning needs to foster sustainable development. A good energy plan is based on sound research on the national energy consumption and energy supply, energy prices, demand and supply technologies, population growth, environment and social impacts, success of an energy harnessing technology and influence of political situation of

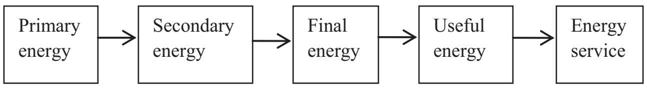

Fig. 1. Energy chain.

a country. It is critical to understand the importance of the contribution that energy planning makes to the knowledge base for better energy policy making and for consumers to make better choices. Good decisions are always based on robust research findings.

Energy planning requires a balance between energy supply and energy demand. Organization for Economic Co-operation and Development (OECD) and International Energy Agency (IEA) reports two methodologies for energy balance [10]:

(i) Partial substitution balance: where the electricity production is given an energy value which is equal to the hypothetical amount of fuel required to generate an identical amount of electricity in a thermal power station using combustible fuels. This methodology has mainly been used in the 90's.
(ii) Physical energy content balance: this is widely used methodology now for energy balance where different forms of energy are expressed in one single unit.

An energy chain is represented in Fig. 1 and should be well understood so that there is no repetition of energy commodities in the energy balance. Primary energy includes energy in its natural form, i.e. it has not been transformed or converted. Examples of primary energy are: solar, hydro, wind, geothermal, biomass, ocean, solid fuels (coal), liquid fuels (oil), and gaseous fuels (natural gas) [10]. Secondary energy includes energy that has been converted from primary energy, such as electricity or heat energy. Final energy includes energy made available to the consumer before its final conversion, i.e. before its utilization. Prime examples include grid-delivered natural gas or electricity at the point of a wall socket [11]. Useful energy includes energy that is available to the consumer after its final conversion, i.e. in final utilization. For example lighting, refrigeration, motive power, heating and cooling [5]. Energy service is not an energy carrier but it is a kind of energy that delivers an energy service; for example, heat radiated from a residential heat source or the kilometers traveled by a passenger car [11].

According to Kleinpeter [9], energy balance may be achieved at various steps of the energy chain. In *primary energy balance*, quantities of different energy forms are needed to satisfy a final demand. Here, common units are used for all energy forms with conventional equivalence coefficients (between different energy forms) based on a specific heat content. *Final energy balance* (or *supplied energy balance*) shows all flows of energy, based on the actual calorific value (heat content). This balance provides an accurate account of the actual operations taking place to make energy available to the end user. *Useful energy balance* is the same as final energy balance except in this balance additional information such as efficiency of appliances must be used.

In addition, energy balance includes commercial energy that are available in the market at a price (e.g. electricity, coal, and oil) and non-commercial energy that are not available in the market such as agro waste, solar energy for water heating, etc. [12]. This avoids duplicity of energy sources and forms; considers losses in transmission and distribution; and introduces statistical difference to balance the supply and demand [9].

2.2. Energy planning terms

Thery and Zarate [6] have summarized the three different energy planning terms: short-term (hours, days, months, one year), medium-term (from one year to 10 years) and long-term (beyond 15 years) energy planning. The purpose of short-term planning is to ensure the reliability of services since decisions are made on existing technologies while medium-term planning ensures meeting energy demand for longer term by considering possibility of introduction of new energy technologies. The purpose of long-term energy planning is to develop new infrastructure and/or promote new technologies by anticipating changes in energy demand and keeping in mind constraints concerning the turnover rate of installations [6]. One disadvantage for such long periods of planning is the possibility of neglect of some important structural changes that may play a vital role [9]. This leads to scenario analysis in long-term to model for different structural changes. Furthermore, development of new technologies, political constraints and social and environmental requirements will have significant impact on the planning. Kydes et al. [13] view the results of long-term modeling in explaining how environment and economy are affected by assumptions on costs, rate of technological progress and efficiency improvement made in long-term study without reducing the uncertainty.

3. Risks, errors and uncertainties in energy planning

Probably, one of the main risks in energy planning is the shortage of adequate sources of energy. Oil deposits are distributed unequally in the world; 70% of them are located in the Middle East. In this situation, the supply of oil is dependent on the relationship between the political leaders of the oil suppliers and buyers and it is also dependent on the stability within the oil supplying country. Chesshire [14] reports that mismatch between the location of the major fossil fuel supply and that of the major needs for energy influence of pattern of development of energy supplies. However, REN21 [15] reports that global demand for renewable energy is increasing and new markets and investments are increasingly shifting towards developing countries despite global economic crisis, policy uncertainty and declining policy support. It further reports that modern renewable energy can substitute for fossil and nuclear fuels in power generation, heating and cooling, transport fuels and rural/off-grid energy service markets. Maugeri [16] and PWC [17] also report that new resources such as shale oil (which are conventional oil trapped in unconventional rocks and stones with low porosity and permeability) have boomed in production in 2012 in US market and are becoming significant due to their relatively low cost. Maugeri [16] further reports that shale boom is dependent on the drilling intensity and availability of rigs and fracking tools. Shale oil has the potential of supplying 12% of the world's oil supply by 2035 [17].

Talinli et al. [18] state that among the several factors (such as economic, technical, social and environmental) affecting energy production process, public safety and acceptance are more important than any other risk factors. The willingness to socially or environmentally accept an energy supply technology is a risk factor in energy planning. For example, nuclear energy supply is now viewed very cautiously, particularly since the Fukushima nuclear disaster in Japan following the earthquake and tsunami in March 2011. Some alternative energy supplies, for instance, are culturally unacceptable for some communities, such as biogas from pig manure [19]. Competition for land use between biofuels and food production is also problematic [20]. Huang and Wu [21] note the risks such as the volatile fuel prices, uncertainty of technology change and capital cost reduction. However, according to REN21 [15] levelised cost of generation from onshore wind and solar PV have fallen while average global costs from coal and natural gas generation have increased. In its latest report, REN21 [22] also projects that investment in renewable energy will increase but new finance sources such as community funds or pension funds have to support investment. It also reports that renewable energy is a low risk investment; nothing more than standard industrial risk.

Errors in energy planning would produce inaccurate results from energy models, leading policy makers to arrive at bad decisions. Kleinpeter [9] discusses two types of forecasting error in energy planning, inherent and specific. Kleinpeter [9] and Schrattenholzer [23] discuss inaccurate, incomplete or unavailable data leading to inherent forecasting errors. Inaccessibility of data because “owners” are not willing to disclose can also contribute to inherent errors. Freedman et al. [24] report that data collected by government agencies are not suitable to use in models and hence models use synthesized data which do not show the true picture of the situation. Hence, they conclude that more effort should be made in collection of data for analytical purposes and quality control and documentation [24].

Another potential weakness lies in the model itself: if it is oversimplified, the results from the data would not portray the reality. Hogarth and Makridakis [25] warn that accumulation of redundant information, failure to seek possible disconfirming evidence, and overconfidence in judgment are liable to induce serious errors in forecasting and planning. Lawrence et al. [26] have reviewed literature over the last 25 years and state that human judgment can be demonstrated to provide significant forecasting accuracy but it can also be subject to many biases.

According to Makridakis [27] statistical methods for forecasting underestimate future uncertainty since statistical methods do not fully utilize the historical information that data contain. It is further reported that the forecasting accuracy can be improved by understanding and correcting the problems inherent in statistical methods. Orrel and McSharry [28] mention that when dealing with complex systems, equations in models are highly sensitive to external influences and small changes in parameters can lead to huge difference in forecasted values.

Since energy planning deals with externalities [13], most of which belong to the group of environmental impacts, the uncertainty surrounding the size of any given impact can be substantial. Uncertainties in energy planning deterministic models can be addressed through the use of scenarios [23]. Scenarios are the main tools to address complexity and uncertainty of future challenges [29,30]. For example, large-scale uncertainty in cogeneration planning in the long-term is addressed by defining various scenarios [31]. Rachmatuallah et al. [32] used scenario planning for electricity generation in Indonesia since it encourages and harnesses “foresight rather than forecasting”. To handle uncertainties of variation in production cost of RE technologies over time, the concept of learning rates to compute the costs of energy systems in the future was adopted and Monte Carlo simulation was performed [33].

In addition to scenarios, to handle uncertainties in energy planning, various methods such as interval linear programming, fuzzy mathematical programming and stochastic mathematical programming are discussed in [34]. Dong et al. [34] developed an inexact optimization model to effectively deal with uncertainties expressed as interval numbers and probability distribution, which exerted advantages in reflecting complexities of practical energy planning problems. This method successfully identifies capacity expansion schemes and energy resource utilization technologies over a long-term planning period. Another method IFMI-MEM (interval full-time mixed integer municipal-scale energy model) developed by Zhu et al. [35] can tackle complicated inexact programming problems that contain both infinite objectives and constraints due to the effects from some external factors. This method is applied to energy systems of Beijing under variety of uncertainties and reasonable solutions have been generated as both binary and continuous variables. Lin et al. [36] developed a hybrid interval-fuzzy two-stage stochastic energy systems planning model (IFTEM) to deal with various uncertainties that can be expressed as fuzzy numbers, probability distributions and discrete intervals. The developed IFTEM is then applied to a hypothetical regional energy system. Sadeghi and Hosseini [37] used Fuzzy Linear Programming (FLP) for optimizing supply energy systems in Iran and conclude that FLP can be a serious competitor for others confronting uncertainty approaches, i.e. stochastic and Minimax Regret strategies. Due to uncertainties involved in energy planning, the next section discusses how system analysis is done and decisions are made.

4. Systems analysis and decision making

The main aim of energy planning is to match the supply and demand for energy over a given period of time. Understanding the energy system that confronts the energy supply and demand is crucial and since energy planning has uncertainties involved, decision analysis (DA) technique is applied. According to Huang et al. [38] DA is concerned with making decisions with uncertain outcomes and difficult tradeoffs. The DA is classified into three groups by Zhou et al. [39] as shown in Fig. 2 and they conclude that multi criteria decision making (MCDM) technique is gaining popularity. In single objective decision making (SODM) method available alternative with uncertain outcomes are evaluated under a single objective situation while in MCDM, as the name suggests, decision is based on a multiple objectives.

The decision support system (DSS) is a computer based system which provides option for decision makers to explore different strategies under various configurations and facilitates communication among managers and also between different levels of management in an organization [38]. Hunt et al. [40] present a new integrated tool and decision support framework to approach complex problems resulting from the interaction of many multi-criteria issues. The framework is embedded in an integrated tool called OUTDO (Oxford University Tool for Decision Organization). OUTDO explores how changes in external parameters affect complicated and uncertain decision-making processes by integrating Multi-Criteria Decision Analysis (MCDA), decision rationale representation and management, and probabilistic forecasting.

Thery and Zarate [6] have identified three levels of decision making:

(i) the strategic level – for long-term planning based on the evaluation of several energetic scenarios such as projections on the evolution of the demand, of the social and political context and of the production system;
(ii) the tactical level – for medium-term planning based on the strategic decisions; and
(iii) the operational level – for short-term planning of the energy production by evaluating its optimal operating parameters.

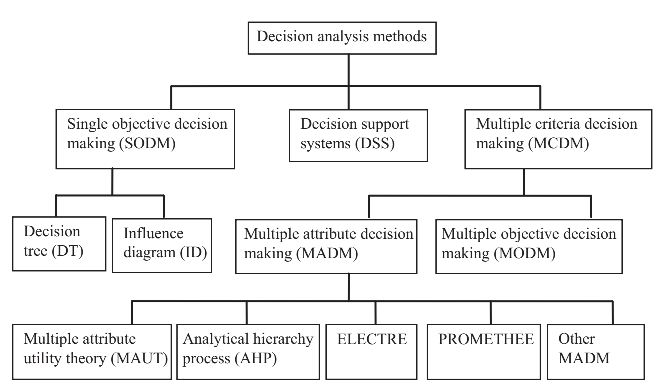

Fig. 2. Classification of decision analysis methods [39].

Terrados et al. [41] argue that although there are several multi-criteria decision aid (MCDA) methods (such as optimization, goal aspiration or outranking models); the steps to be followed in each of these are similar:

(i) problem definition,
(ii) identification of alternatives,
(iii) criteria selection,
(iv) decision matrix elaboration,
(v) weights assignment,
(vi) prioritization and
(vii) decision making.

For energy planning decisions (such as renewable energy planning, energy resource allocation, building energy management, transport energy management and electric utility planning), Pohekar and Ramachandran [42] discuss several methods of MCDM. These are weighted sum, weighted product, analytical hierarchy process (AHP), preference ranking organization method for enrichment evaluation (PROMETHEE), the elimination and choice translating reality (ELECTRE), the technique for order preference by similarity to ideal solutions (TOPSIS), compromise programming (CP) and multiple attribute utility theorem (MAUT). From their review, they conclude that MCDM methods are popular in renewable energy planning, followed by energy resource allocation.

Løken [43] has also reviewed various studies using multi-criteria decision analysis in energy planning and concludes that different methods will most probably give different recommendations; this does not mean that a method is wrong but simply that different methods work in different ways. Terrados et al. [44] discuss a case using SWOT analysis to diagnose the provincial energy system structure, before construction of the problem tree providing the objectives for the project. The authors highlight community participation, inter-disciplinarity and SWOT methodology as the three main issues for success of energy planning. However, before decisions are made appropriate energy planning models/computer assisted tools have to be selected and planning to be done within a framework. The following section reviews these models and tools.

5. Energy planning models

Jebaraj and Iniyan [45] have presented a comprehensive review of how energy planning models, forecasting models, energy supply–demand models, optimization models and emission reduction models have evolved chronologically in time. They have reviewed three types of energy planning models and Kleinpeter [9] gives indicators for each on how to determine the total energy demand: (i) *energy demand models*, which do not investigate the energy supply in detail though he points out that energy demand can be found sector-wise, as industrial, residential and transport; (ii) *energy supply models*, which simulate the energy demand given as a projected value; and (iii) *integrated energy supply and demand models*.

However, to facilitate efficient selection of a model, it is vital not only to identify the overall purpose of use of the model, but also to devise specific questions. According to Lapillonne et al. [46], energy models should try to answer the following questions satisfactorily:

1. How would the increases in energy prices affect the magnitude of energy demand (energy savings) and energy price allocation among energy sources (energy substitution)?
2. What will be the role of non–price-related energy policy measures (such as economic incentives, regulations, etc.)?
3. More globally, how the changes brought about by the energy crisis and economic recession affect energy demand?

Kleinpeter [9] discusses two ways of evaluating total energy demand for energy supply models. The first is to determine the final or delivered energy to each demand sector and then convert it into primary energy, taking into consideration of conversion losses. Summing of the various types of primary energy allows calculation of the total energy demand, covering national supply and energy imports. The second way is to separate demand of different energy sources with the conversion losses occurring.

The energy supply part of energy planning deals with ensuring availability of primary energy or fuels. As the level of geographical aggregation increases in an energy planning model, importation of the resource part of the supply heightens. In long-term energy planning, primary energy resources that can be converted into reserves have to be considered, to avoid projections of catastrophic situations of energy supply shortages [23]. To reduce the importation of resources for supply, distributed energy can be considered in energy planning.

Distributed energy resource (DER) technologies such as combined heat and power (CHP) generators, micro-turbine gas generators, solar photovoltaic, and wind generators should be considered in energy planning. One review of the state-of-the-art multi-objective planning of distributed energy resource states that a DER reduces the network energy losses, increases the network quality by minimizing negative impacts, and increases investment and operation costs [47]. Alarcon-Rodriguez et al. [47] further report that DERs which are not allowed to work in isolated mode or that are connected to radial networks or DERs which have variable output (such as wind or solar generator) do not increase network reliability. Furthermore, DERs whose production is not coincident with demand or whose capacity exceeds the capacity of their network leads to an increase in line losses and a voltage rise. Another name given to DERs can be integrated community energy systems (ICES); Mendes et al. [48] discuss these, giving an overview of six bottom-up tools for optimizing planning and analysis of ICES.

Energy planning models depending on their methodology and features are categorized as shown in Fig. 3.

5.1. Econometric models

Cleveland and Morris [49] define econometrics as the application of statistical methods to the analysis of economic data and theories. In the Econometric model the energy planner's choice and decisions should be explained and justified at each stage. Econometric models can be static, where the planner covers a given period by defining the start and end time; or dynamic, where the planner includes information relating to economic development and structural trends for the planning period. These models can be simple or complex, i.e. incorporating lots of variables (concerned with energy sources, energy sectors or energy users) and parameters. Karanfil [50] has raised the issue of numerous studies using econometric models where results are

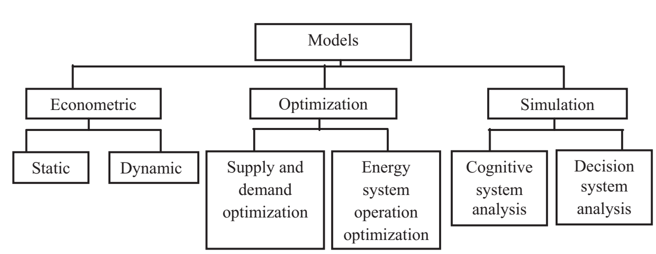

Fig. 3. Summary of energy planning models [9].

contradictory. Karanfil [50] states that it is vital to understand which variable (economy or energy consumed) influences the other since it has policy implications. For example, if energy consumption is found to be a stimulus for economy growth then energy conservation policies may impede economic growth. However, GEA [51] reports that the relationship between economic growth and energy use is two-directional; high-quality energy services are necessary for economic growth while in turn economic growth increases demand for energy services.

Kahzzoom [52] presented an econometric model for the estimation and simulation of industrial demand for natural gas in Canada. Rahman [53] developed a dynamic equilibrium model comprising of two sectors, energy and the macro economy of India. The model is highly aggregated; both in the number of sectors of the economy as well as the number of energy forms it considers. He concludes that if the model is disaggregated then there are lots more factors and correlation between sectors which should be included. Zhidong [54] developed an integrated econometric model consisting of macroeconomic sub-model, energy sub-model and environment sub-model and used it to perform a long-term (until 2030) simulation study for China. Similarly, Gan and Li [55] developed a comprehensive econometric model consisting of macroeconomic sub-model and an energy-environment sub-model for the study of Malaysia's economy, energy and environment outlook to 2030. As described in the reference scenario, Malaysia's dependence on imported fuel will increase in the near future due to increasing demand and carbon emission too will triple by 2030. However, in their renewable energy scenario, projections indicate that the use of RE is a strategic option to improve energy security and environmental performance of Malaysia in the long term.

The mathematical structure of the National Energy Modeling System (NEMS), a large-scale energy-equilibrium model currently in use at the U.S. Department of Energy, has shown that the computation of equilibrium fuel prices and quantities in NEMS can be viewed as an instance of a nonlinear complementarity problem (NCP) or variational inequality (VI) [56]. The format remains valid for a variety of generalization. Pokharel [57] used static log-linear Cobb–Douglas functions to develop econometric models for energy situation in Nepal. The models are developed for the fuel sector and consumption sector. Pokharel [57] further concludes that planners have to study the energy end-use patterns and their implications on economic sector, before formulating the plans for economic growth. Also, if planners want to set a target for economic growth they must also outline energy requirements to meet economic targets.

5.2. Optimization models

Optimization models use objective functions, i.e. mathematical formulas describing the minima and maxima depending on definition. These models are typically used to identify least-cost energy systems while simulation models simulate the behavior of consumers and producers under various signals (prices, income, policies) which may not be optimal behavior [58,59].

Optimization models are prescriptive in nature, in which the best possible solution is reached by satisfying the goal function. The key features of optimization model are [9]:

- accurate equations and reliable data bank
- objective elements are only in the mathematical equations
- equations are optimized, i.e., maximum and minimum value can be determined
- energy supply and demand must balance
- accurate data (with respect to their quantity and reliability) must be available.

A bottom-up energy system optimization model i.e. energy flow optimization model (EFOM) is used to support policy planning for the sustainable use of energy [60]. The model aims at the determination of an optimal mix of technologies for the energy system subject to a number of boundary conditions such as emission limits. Lehtila and Pirila [60] further note that all energy system models have limitations and since in bottom-up optimization model the objective is to minimize the total system cost on a national level, this can lead to non-optimal solutions for individual sectors. The cost of electricity generation is minimized over a definite time horizon using the EFOM model [61] and using this model they also investigate reducing harmful emissions by optimizing the role of conventional fuels, increasing the role of RE sources and implementing energy saving techniques. Zhang et al. [62] use a multi-period optimization model to calculate optimal pathways of China's power sector for two cases. In one case, decision makers can well predict carbon tax policy in the long-term future and make decisions based on that and in another case decision makers can only well predict carbon tax policy in a short-term future and make decisions based on that.

5.3. Simulation models

Simulation according to Kleinpeter [9] is a method or process whereby any phenomenon or system with similarities can be transposed and represented by a simpler or less complex model. Dynamic Simulation Model presented by Caselles-Moncho [63] is able to take into account the technical, political and economic variables influencing the decision maker as well as their interrelationships and evolution over time. This work provided a representation of the economic viability of power plants operating in the recently restructured Spanish Electricity Sector. Alam et al. [64] present a quantitative dynamic simulation model as a system study for rural household biomass fuel consumption in developing countries such as Bangladesh. Popescu et al. [65] developed an original simulation and prediction model for the space heating consumption of buildings connected to a partially controlled system. A bottom-up simulation model has been introduced in Daioglou et al. [66] for household energy use in five developing world regions. This model is called global residential energy model (REMG) which is able to reproduce many of the underlying dynamics that determine future residential energy demand and it can also be further improved.

Mardan and Klahr [67] showed how the discrete event simulation (DES) tool and energy systems optimization (ESO) tool are combined for a non-existing system and they also discuss how DES and ESO can improve system analysis. Sarica et al. [68] employ an integrated simulation/optimization approach to investigate and better understand the dynamics of a hypothetically optimized power sector (under transmission line and production technology based constraints) on generator profits, electricity prices, availability and supply security.

Since a simulation model uses scenario analysis, details on scenarios are listed below. Scenario planning does not rely on the forecasting of a single most likely future. Instead, it considers multiple possible futures or scenarios, and examines how well alternative possible business plans (options) would perform for each of the scenarios [69]. Soontornrangson et al. [69] conclude that scenario writing is a critical part of the planning process and writing unrealistic scenarios can result in loss of millions of dollars. Amer et al. [70] also mention that scenario planning stimulates strategic thinking and helps to overcome thinking limitations by creating multiple futures. They have also discussed on scenario selection, appropriate number of scenarios and the issues in scenario validation.

Van Der Heijden [71] highlights criteria for scenarios; there must be at least two scenarios to reflect uncertainty, scenarios must be plausible and internally consistent and must be relevant to clients concern. Scenarios must produce new and original perspectives on the issues. Randolph and Masters [4] have given a series of steps to develop scenarios systematically:

(i) Pose a key focus question about the future.
(ii) Identify the drivers or factors that will affect the answers to that question. According to Rachmatullah et al. [32], the success of planning will depend on how well one is able to identify and describe external factors (social, political and economic) in the scenarios.
(iii) Prioritize, cluster and ultimately combine the drivers into two critical uncertainties that serve as the axes of a two-by-two scenario matrix.
(iv) Develop scenario storylines describing the future associated with each of the four pairs of drivers in the four quadrants of the matrix. To the extent possible, the storylines should reflect accurate technical information.
(v) Label each quadrant scenario.

Scenarios can include objective (quantitative) and subjective (qualitative) elements into future planning. An important function of scenarios is that they are suited to study the consequences of given decisions in a predefined and reproducible way, which leads to more robust decisions [23]. For instance, Laitner et al. [72] present a scenario analysis of United States (U.S.) Technology Energy Futures to the year 2050 and investigate key energy issues and decisions that could improve or reduce the ability of the U.S. to deal with the uncertainties that may challenge its economy. One of the conclusions is that introducing policies to improve energy efficiency and accelerate the introduction of new technologies does not appreciably reduce the prospects for economic growth. Sadorsky et al. [73] define and analyze four scenarios (business as usual, focus on climate change, focus on energy security, and a clean and secure energy future) for the future of renewable energy. The methodology for the development of four energy scenarios for Colombia to support long term energy policy is given in [74].

Kleinpeter [9] counts simulation as cognitive analysis since the future is unknown that should be discovered and the improbable events are disregarded through senseless scenarios. In order to make sensible decisions several scenarios are studied so that contradictions between them can be studied.

5.4. Framework for an energy planning model

Models can have a bottom-up (engineering) approach or a top-down (economic) approach. The two approaches are quite different; bottom-up models include the description of energy-related work, which is to be accomplished at minimum costs by a given menu of technologies, while top-down models consider energy demand in the form of function, which depends on total or sectoral economic product, energy prices and so forth [23]. Top-down models would ask the question: *by how much does a given energy price movement change energy demand or energy-related carbon emissions?* Bottom-up models would ask questions like: *how can a given emission-reduction task be accomplished at minimum cost* [23]?

Energy planning must be done within a framework and the planner decides the framework. There are many frameworks from which the planner can choose:

(i) Accounting frameworks. A modeler explicitly accounts for the outcome of a decision. The main function of this is to manage data and results [59]. Instead of simulating the behavior of a system where outcomes are unknown, accounting frameworks require users to explicitly specify outcomes making it a top-down approach.
(ii) Integrated resource planning (IRP) framework – IRP is a process of meeting energy demands which must satisfy the various economic, social and environmental objectives while considering widest possible range of traditional and alternative energy resources [75]. According to The Tellus Institute of Boston [76], IRP framework (a bottom-up approach) makes planning more open by considering the needs and ideas of relevant governmental agencies, consumer groups and other stakeholders, and also provides a chance for interested parties both inside and outside the planning region to review, understand and provide input to planning decisions.

5.5. Computer-assisted tools

Computer-assisted tools have econometric, optimization, or simulation models as a subset and ideally have features that would be able to deal with uncertainties in energy planning. Connolly et al. [77] have reviewed 37 computer-assisted tools to identify suitable energy tools for analyzing the integration of renewable energy into various energy-systems under different objectives. The review was based on the region, energy sectors, costs, thermal generation, renewable generation, storage/conversion and transport. Connolly et al. [77] argue that there is no computer-assisted energy tool which can address all issues related to integrating renewable energy; rather, the 'ideal' energy tool is highly dependent on the specific questions being answered.

Using Connolly et al.'s detailed study [77], a computer assisted energy tool can be selected for long-term national energy planning for small developing island countries based on scenario analysis and optimization tool. In view of this objective, the following 7 criteria were used to select computer-assisted tools out of the 37 tools that Connolly et al. [77] discuss:

C1: geographical area – desired is national energy system
C2: charges for using the software – desired is free
C3: number of users – desired is more than 100, which would indicate that it is well known
C4: term of study – desired is long-term analysis (more than 20 years)
C5: able to create scenarios
C6: bottom-up analysis – since this is the engineering approach
C7: optimization.

Based on the above criteria, five computer-assisted energy tools have been identified that could be used for long-term planning in small developing island countries:

(i) Long-range energy alternatives planning (LEAP). LEAP is an integrated modeling tool that can be used to create models to perform variety of tasks, including energy forecasting, greenhouse mitigation analysis, integrated resource planning, production of energy master plans, and energy scenario studies [78]. It uses physical accounting and simulation methodology. Almost 150 countries worldwide are using this software, applying it at many spatial levels including local rural areas, large metropolitan cities, and at the national, regional and global levels. Bala [79] demonstrated the potential of LEAP with proper data inputs as a tool for planning for sustainable energy development in Bangladesh. The GHG mitigation potential of a number of selected Biomass Energy Technologies has been assessed in Vietnam using a LEAP model where 6 different scenarios have been considered.
The potential of biofuels in the transportation and electricity generation sectors has been studied using LEAP during the

timeframe from 2005 to 2030 [80]. Likewise, the LEAP model was used to estimate total energy demand and the vehicular emissions for the base year 2000 and extrapolated till 2030 for future predictions [81]. In addition, the LEAP model was run under three alternative scenarios to study the impact of different urban transport policy initiatives that would reduce energy demand and emissions in the transport sector of Rawalpindi and Islamabad. Park et al. [82] used a hybrid System Dynamics (SD) and LEAP model to assess future CO_2 reduction and energy savings in the Korean petroleum oil refining industry by investigating five new technologies. They report that energy intensive industries such as petroleum refining are dynamic evolutionary systems and system dynamics provide an appropriate framework to capture the aggregate level adequately. LEAP was used to conduct full-fledged scenario analysis for Lebanon's electricity sector and examined the technical, economic and environmental implications of base, renewable energy and natural gas scenarios [83]. The LEAP model has also been used for scenario analysis in GHG reduction/mitigation/abatement, CO_2 and SO_2 emissions reduction in different countries and cities throughout the world [84–93]. Authors [94–96] have used LEAP for economic analysis of implementation of energy demand side management and use of renewable technology. Sustainable long-term planning for energy/power supply and demand forecasting, scenarios of clean energy futures, scenarios of smart technology options, etc. using LEAP at different locations have also been presented in [97–107]. Other LEAP studies have analyzed transport sector fuel demand, GHG mitigation in the transport sector, fuel reduction and projection of transport energy demand [108–114].

(ii) EnergyPLAN. This is a deterministic model that optimizes the operation of a given energy system on the basis of inputs and outputs defined by the user. The inputs include demands, renewable energy sources, energy station capacities, costs and a number of optional regulation strategies emphasizing import/export and excess electricity production [115]. The output include energy balances and resulting annual productions, fuel consumption, import/export of electricity, and total costs including income from the exchange of electricity [115]. Based on the technical and economic analyses of the consequences of implementing different energy systems and investments, EnergyPLAN assists in designing national or regional energy planning strategies. It uses simulation/optimization methodology and can simulate one year at a time, which can be combined to create a scenario of multiple years. Numerous publications by various authors have involved EnergyPLAN. Connolly et al. [116] used EnergyPLAN to analyze how Ireland's energy system could be 100% renewable and from their analysis it was found that the optimum scenario would be a combination of biomass, hydrogen and renewable energy for electricity generation. The thermoelectric generators, which can recover waste from both industrial and private sectors, are applied to district heating systems and power plants via the use of the EnergyPLAN model, where the system efficiency was also determined [117]. Alberg Østergaard et al. [118] used EnergyPLAN to describe a scenario for supplying Aalborg Municipality energy needs through a combination of low temperature geothermal heat, wind power and biomass. The use of EnergyPLAN for integrating different types of technologies (supply, transport and storage) in energy systems has also been demonstrated [119–125].

(iii) In*vert*. In*vert* uses dynamic bottom-up simulation, for up to 25 years period in 1-year time-steps, with different scenarios such as energy price scenarios and different consumer behavior, and their impact on future renewable as well as conventional energy sources at national and regional levels [126,127]. Stadler et al. [128] elaborate on how In*vert* has been designed to answer the core question: "How can public money – for promoting sustainable energy systems – be spent most efficiently to reduce GHG emissions?" Tsioliaridou et al. [129] have used the In*vert* simulation tool on how different renewable energy source technologies would affect the CO_2 reduction and reduce costs, by looking at the existing and future electricity potential up to the year 2020. Kranzl et al. [130] have used In*vert* to obtain efficient portfolios promoting sustainable energy systems. In*vert* is applied to assess the possible costs and benefits of renewable energy sources of heating policy harmonization for 6 European member states [131].

(iv) ORCED. The Oak Ridge Competitive Electricity Dispatch (ORCED) model was developed by ORNL (Oak Ridge National Laboratory) to dispatch the power plants in a region to meet the electricity demands for any given year up to 2030 [132]. This tool can simulate 1 year at a time, which can be combined to create a scenario of multiple years. The ORCED's operation (modeling of demand, supply and dispatch) and explanation of key results from ORCED are discussed in [133]. Connolly et al. [77] referred to articles which discuss the application of ORCED model to assess impact of plug-in electric hybrid vehicles, identify the contribution of hydropower to GHG reduction and design mechanisms for policy makers to recover transition costs from a regulated to a restructured market.

(v) The MARKAL/TIMES tool can also be considered for a study; however, since it is not free to use, it is regarded as being of limited interest. The Integrated MARKAL-EFOM System (TIMES) is a mathematical modeling scheme for representing, optimizing and analyzing energy systems on a flexible time and regional scale [134]. This model has been designed for the long-term analysis of energy, environmental and economic (E3) issues over a time-horizon ranging from several years to decades. It is an optimization methodology.

In the choice of models, the first consideration for the energy planner is whether the values determined will have any economic significance and whether the chosen model is suitable for the location under study. Urban et al. [135] investigate whether the main characteristics of developing countries are adequately incorporated in present-day energy models. They studied 12 energy models and state that LEAP, MESSAGE, RETScreen and WEM are models which address large number of characteristics of developing country. After a model has been chosen, the energy plan can be made and the quantity of different energy forms can be influenced in the following ways:

- taxes – for example, an environmental tax
- subsidies – given, for example, for the promotion of renewable energy technologies
- emission permits – under which the emission of a pollutant is allowed only up to the equivalent amount for which the permit is held
- legal measures – labeling of energy-consuming goods and standards for electrical products, such as placing restrictions on the entry of certain low-grade electrical appliances into the country
- education and capacity development – even though it is a slow process, education and capacity building at all levels are always beneficial in long-term planning [23].

Since long-term energy plan shows scenarios beyond 15 years, energy technologies in demonstration phase can also be considered into the study. The next section reviews literature on technological progress and the Delphi method of energy planning.

6. Inquiry method of energy planning

This method is normally used for determining the potential of energy technologies which are currently in research phase to be included in the long-term energy planning. Logical reasoning is made on whether new technologies in their initial development stages can contribute significantly in the future or whether new technologies in the advanced development stages are competitive enough with other technologies [9]. Chen et al. [136] have used expert survey (inquiry method) in the technology portfolio planning process to generate a set of technology alternatives which is then assessed under different scenarios.

6.1. Technological progress

Energy conversion technologies provide a bridge between energy demand projections and energy supply. In order for a new energy technology to be considered for medium- or long-term planning, its development phases (which are distinguished by Grubler et al. [137]) must be considered since technological progress plays a decisive role in energy planning.

In judicious energy planning, an energy planner must also consider the lead time of a new technology. Energy suppliers view lead time as the time required for a new technology to be introduced into the market, whereas for energy users lead time would be the time after the introduction of a technology into the market for it to become attractive to energy users so that they substitute their current source by the new technology. This lead time would depend on the payback period and the economics of the new technology; and it can be influenced by government subsidies and tax reliefs [9]. Lead time can be found from the experience curve, which describes the technological progress as a regular function of cumulative experience.

An energy planner also has to consider which energy technologies should warrant research and development (R&D) and how much to spend on R&D. As Miketa and Schrattenholzer [138] mention that R&D expenditure generally do pay off. They use stylized optimization model which uses two factors learning curve (2FLC) for R&D of the global electricity supply system to analyze the optimal R&D support for an energy technology.

The unit cost of many products and services decrease as the experience increases; this pattern of technological progress is known as learning curve, progress curve, experience curve or learning by doing [139]. Schrattenholzer [23] elaborates that an experience curve describes a situation in which specific technology costs decrease by a fixed amount after each doubling of the cumulative installed capacity of a technology. McDonald and Schrattenholzer [139] assemble data on experience accumulation and cost reductions for numerous energy technologies (such as wind turbines, solar PV modules, solar panels, ethanol, nuclear power plants, gas turbines and 20 other technologies), estimate learning rates for the 26 data sets, analyze their variability and evaluate their usefulness for applications in long-term energy models. The learning rate of 27 electricity production technologies is also given in [140].

Alberth [141] tests empirically, using historical data, the validity of experience curves for forecasting and providing a first order approximation of the uncertainties that exist for potential growth technologies such as renewable energy technologies (RETs). It further states that regardless of the various limitations of experience curves, they continue to be widely used. To overcome the weakness of experience curves, Jamasb and Köhler [142] have suggested possible extensions of the learning curve;

(i) care must be given to choice of learning rate and sensitive analysis can be useful,
(ii) include R&D expenditure in the learning curve in addition to capital investment and
(iii) need for more research into the nature of real effects and processes that learning curves tends to capture.

The International Energy Agency (IEA), publication on 'Experience curve for energy technology policy' demonstrates how energy policy maker can exploit the experience curve phenomenon to set targets and to design measures to make new technologies commercial. It also informs that experience curves provide powerful tools for formulating low-cost strategies to reduce and stabilize CO_2 emissions in the long term [143].

Market penetration models take into account the maturation period of new technology. Schrattenholzer [23] further states that from an overall and long-term perspective it can be advantageous to invest in energy technologies that are more expensive than the cheapest competitor, because doing so will make the new "learning" technology economically advantageous and thus lead to overall cost savings in the longer run.

Experience curves can be used for introducing new technologies in long-term planning. However, in small developing island countries there may be lack of data on experience curves and in such cases new technologies can be introduced through inquiry method.

6.2. Delphi method

A Delphi survey is a series of questionnaires that allow experts or people with specific knowledge to develop ideas about potential future developments around an issue [144]. Linstone and Turoff [145] inform that Delphi method has proven a track record for collecting and synthesizing information from independent experts in order to develop consensus outlook on a topic under consideration. Alberts [146] and Sharma et al. [147] explain that characteristics of Delphi technique are anonymity, iteration of series of questions (where once consensus is reached on a question it is omitted from succeeding iteration), controlled feedback and statistical group response. Also the participants may suggest new questions for upcoming iterations. Alberts [146] conclude that participants prior experience with an issue (that is issue under discussion) became the critical factor in the success and failure of the Delphi method used to develop wind energy policy. Utgikar and Scott [148] report the drawback of Delphi method; complete anonymity of the Delphi technique can lead to a lack of accountability of opinion and achieving a consensus often means that extreme opinions are generally eliminated. However, Makkonen et al. [149] state that the number of rounds is sufficient once stability (not consensus) is reached on responses. The value of Delphi method is in finding reasons for divergence that is, exploring the reasons for finding the reasons for differences in opinion than in establishing a common opinion.

The Delphi method allows two possible approaches [9]:

(i) the forecast-oriented Delphi method, in which the future system is known. The key questions are the extent to which the considered technology can be implemented over the planning period, and when and how these techniques should be implemented
(ii) the prospective Delphi method, in which the future system is unknown since the technology to be used is yet to be invented or developed. Hence, in this inquiry method a wider range of experts (national and international) can be consulted, which can be costly. The questionnaire in this method helps to encourage diversity of responses that will statistically enhance the process and help to determine the direction to be taken [9].

Terrados et al. [41] used the Delphi method, SWOT analysis (Strengths Weaknesses Opportunities and Threats) and the combination of these two methods to support multi-criteria decision-making analysis in energy planning. They suggest three best practices – SWOT, Electre III procedure and a combination of SWOT, Delphi and Promethee techniques – in energy planning applications. Terrados et al. [41] further suggest that the SWOT analysis in particular establishes problems faced by the energy sector and suitable strategies to overcome them.

Celiktas and Kocar [144] gathered information from two-round Delphi survey (using online surveys) which was used to foresight Turkish renewable energy futures. Similarly Qu et al. [150] conducted a two-round Delphi survey of 61 bioenergy experts in China to determine whether there is a consensus among the experts concerning forest bioenergy and if this consensus agrees with policy-makers in China. In addition, two-round Delphi survey was conducted and results were presented focusing on prospects of European electricity market [149]. Cowan et al. [151] used Delphi method to capture knowledge from experts in the field related to sustainable energy and then used analytic hierarchy process (AHP). Sharma et al. [147] illustrate the process followed for Delphi technique and evaluate the responses received from experts to analyze the critical issues that afflict the power sector of Kerala. Bonacina et al. [152] have used Delphi survey on gas storage in Italy.

An integrated Delphi and fuzzy AHP based framework is used in analysis which also helps prioritizing the balancing factors according to the different role players in a Turkish utility company [153]. The Delphi-SWOT hybrid paradigm is proposed by Tavana et al. [154] to identify and evaluate strategies for locating a pipeline to transport oil and gas from Caspian basin to world markets.

7. Geographical level of energy planning

7.1. Global or international energy planning

Due to the lack of a global government, no planning in the conventional sense of legislation and execution happens at the international or global level [23]. The legislation in a national context is also important in the global perspective, as is the case with joint agreements between different governments in international conferences or meetings (e.g. the United Nations Framework Convention on Climate Change (UNFCCC)) [11]. Schrattenholzer [11] lists the following international institutions playing roles in global energy planning:

- Global Environmental Facility (GEF) – supports developing countries to carry out environmental projects, including ones in the area of climate change.
- Carbon Technology Institute (CTI) – fosters international cooperation for accelerated development and diffusion of climate friendly technologies and practices for all activities and greenhouse gases.
- Prototype Carbon Fund (PCF) – mitigates climate change through promotion of sustainable development and to demonstrate the possibilities of public–private partnerships.

7.2. National energy planning

In this type of planning the decision making is based on the national economy. According to Schrattenholzer [11] national energy policies can be formulated and carried out by existing decision-making bodies and within an existing jurisdictional framework, which often makes national planning easier than international planning. In national energy planning, the range of energy technologies is large, the performance indicator of the economy is GDP, and a complete energy and non-energy database has to be present for a credible and robust national energy plan. In Section 2 of this paper it was stated that energy plan needs to foster sustainable development. Yüksel [155] reports that sustainable development of a society implies that in the long-term energy plan the energy sources are readily and sustainably available at reasonable cost and can be utilized for all energy use and services without causing negative social impacts. Vera and Langlois [156] have discussed 30 national-level energy indicators whose methodologies are given in [157] for sustainable development (in the social, economic and environmental dimensions) which can be used for monitoring. It is important for policy makers to understand the implications of selected energy, environmental and economic programmes, policies and plans and their impact on the shaping of development and on the feasibility of making this development sustainable. These energy indicators are more than just energy statistics as they provide a deeper understanding and associations of the energy, environment and economy nexus.

7.3. Regional or local energy planning

Regional or local energy planning refers to energy planning for a city or town or an energy system of a city or town. Planning at these levels can of course, contribute to national energy planning. Examples of local energy planning include urban transportation, district heating, regional development, or plans dealing with environmental problems such as deforestation (fuel wood), urban air quality and waste management [11].

Advanced local energy planning (ALEP) is based on a sustainable approach and it is much more than traditional local energy planning (LEP). According to International Energy Agency [158] ALEP makes the use of comprehensive models of systems analysis that are capable of simulating and optimizing the whole system, rather than considering its components. ALEP provides a long-term strategic energy plan that satisfies different sustainability goals (such as reduction of GHG, responsible use of natural resources, social equity, and ecological and economic development). In addition, it involves all affected groups and decision makers to maximize the chance of realization, employs principles of modern project management and is a continuous process rather than a project with a defined end.

One review presents 14 state indicators and 4 policy indicators for local energy planning [5]. The authors stipulate that indicators need to be comprehensive, limited and open-ended so that future changes can be made to these energy sustainability indicators. Another review interrogates on the application of different models for decentralized energy planning or local energy planning [8].

After reviewing 6 energy models for integrated community energy systems (ICES) planning (HOMER, DER-CAM, EAM, MARKAL/TIMES, RETScreen, H_2RES) Mendes et al. [48] conclude that the Distributed Energy Resources Customer Adoption Model (DER-CAM) and the Economic Evaluation of Microgrid (EAM)– which have several successful applications – can be considered preferable tools for the purpose of ICES design modeling. They further concluded that system thinking is a highly valuable approach for designing energy futures. The central theme of decentralized energy planning, suggest preparing an area-based plan to meet the needs and development of alternative energy sources at least cost to the economy and the environment [58]. Deshmukh and Deshmukh [159] report that centralized (national) energy planning does not cater for the needs of rural areas due to urban areas given priority for energy supply, social and environmental benefits. Regional or local energy planning would encourage development of economically productive activities [159]. A new ‘hybrid” methodology that combines SWOT analysis, characteristics of

MCDA techniques and the Delphi method was used to design a renewable energy plan for a Spanish region [44].

8. Validation of planning methods

Foresight (the basic ingredient of all effective action) is the key of modern economic life and it enables us to act with competence. There is no model or method to forecast the future accurately and precisely. However, planning is crucial and so some qualitative evaluations can be performed. These evaluations can give an indication on the adaptability of a planning method and also help to determine in a retrospective examination of reason for the deviation between the planning figure and the real value [9]. In order for energy models to be reliable and accurate, they must adequately map the real world system, provide a reliable formula that translates inputs (energy policies) into outputs (impacts), handle uncertainties in the energy planning term, and respond to the needs of the model users [23].

Before choosing a planning method, the model should be validated. According to Gass [160] model validation tests the agreement between the behavior of the model and the real world system being modeled, and that validation is the most important aspect for the analyst to consider. The Texas advisory energy council has accepted the following criteria for validating a model [9]:

- workability – what things can be achieved by the model?
- clarity – how understandable are the results of the model?
- verifiability – is the model running as the planner has intended?
- validity (coherence) – to what extent do the results of the model agree with the real world data?

Gass [160] admits the difficulty in validating a model of a not-yet-existing system or one that makes assumptions about the possible states of the future. However, the following measures can be applied:

1. face validity or expert opinion – have decision makers who know the system being modeled to review the model for credibility
2. variable-parameter validity or sensitivity analysis – compare the model's variables and parameters with real world data and also test how output is affected once data are changed
3. hypothesis validity – Do pair wise or higher level relationships correspond to similar relationships in the real world?

Rahman [53] has validated econometric model using two indicators; first, the model's ability to fit historical data and second, the model's ability to predict the turning points. The Romanian energy system model was developed with the help of EnergyPLAN tool and it was validated by calculating the percentage difference between the simulated results with the official statistical data [161]. Similarly, Alam et al. [64] validated their dynamic simulation model by comparing the model with the reported values and found the difference between the two to be less than 15%. Qudrat-Ullah and Seong [162] have confirmed that structural validity test is the core of system dynamics based simulation modeling validation process and that this test takes temporal precedence over behavior validity tests. Popescu et al. [65] validated their simulation model using statistical and neural network modeling.

9. Conclusions

This review has attempted to discuss the various factors that are involved in energy planning and summarizes new and recent literature related to energy planning. Long-term energy planning is carried out for strategic planning to study the impacts of structural changes, environment and social requirements and new technologies on the energy system. Global, national or regional energy plan must foster sustainable development which implies that in the long-term energy sources must be sufficiently and readily available at reasonable cost to cater for energy needs of the society without having adverse effects socially and environmentally. However, main risk of energy planning is the shortage of adequate energy sources. This risk can be overcome by considering new resources and modern renewable energy. In addition, inherent errors in energy models can be avoided by collection of accurate and sufficient data and the use of scenarios deals with uncertainties in energy planning as no one knows the future with certainties. A detailed literature survey has shown that scenarios analysis is the best way for dealing with uncertainties in energy planning.

Multi-criteria decision making methods, models and inquiry methods are increasingly being used for energy planning. Econometric models are used to study the relationship between energy and economy and can be used for long-term planning. There are a variety of energy planning computer-assisted tools which includes optimization and/or simulation features and host of other features. The choice of computer tool depends on the user and his study objectives. LEAP is one of the computer-assisted tools that can be used for long-term national energy planning for small developing island countries. Experience curve of technologies can be used to consider renewable energy technologies in the long-term planning. However, due to lack/absence of data in small developing island countries, inquiry method can be used.

Regional energy planning is based on a city or town or an energy system in a town or city and it contributes towards national energy planning. For a credible national energy plan complete energy and non-energy data has to be present and it must provide indicators for energy security, economic growth, social and environmental impact. In addition, before the application of any energy planning methodology it has to be assessed, evaluated and validated. Finally, we believe that young and/or novice researchers and energy planners would benefit from this review to get an idea on what is involved in energy planning – from definitions to the validation of energy model.

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