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ScienceDirect
Renewable and Sustainable Energy Reviews
11 (2007) 729–752
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Decentralized energy planning; modeling and application—a review

R.B. Hiremath[a], S. Shikha[b], N.H. Ravindranath[b,*]

[a] *AE and CST, IISc, Bangalore 560012, India*
[b] *CST, IISc, Bangalore 560012, India*

Received 22 July 2005; accepted 26 July 2005

Abstract

Energy planning is carried out at a centralized level using computer-based modeling. The centralized energy planning models and approaches have already been reviewed in literature. Decentralized energy planning (DEP) is a concept of recent origin with limited applications. Literature shows that different models are being developed and used worldwide. This paper gives an overview of different decentralized energy models used worldwide, their approaches and their applications along with a few emerging energy models. The central theme of the energy planning at decentralized level would be to prepare an area-based DEP to meet energy needs and development of alternate energy sources at least-cost to the economy and environment. Ecologically sound development of the region is possible when energy needs are integrated with the environmental concerns at the local and global levels. Taking into account these features, this paper explains the need of DEP and shows how different types of energy planning and optimization models, supply demand models, regional models, resource models and neural models have been carried, adopted and applied at decentralized level.

Keywords: Decentralized energy planning; Energy models; Optimization models; Rural energy; Renewable energy technologies

*Corresponding author. Tel.: 91 80 22933016; fax: 91 80 23600683.
E-mail addresses: rahul@aero.iisc.ernet.in (R.B. Hiremath), shikha@astra.iisc.ernet.in (S. Shikha), ravi@ces.iisc.ernet.in (N.H. Ravindranath).

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doi:10.1016/j.rser.2005.07.005

Contents

1. Introduction

The energy-planning endeavor involves finding a set of sources and conversion devices so as to meet the energy requirements/demands of all the tasks in an optimal manner. This could occur at centralized or decentralized level. The current pattern of commercial energy oriented development, particularly focused on fossil fuels and centralized electricity, has resulted in inequities, external debt and environmental degradation. For example, large proportions of rural population and urban poor continue to depend on low-quality energy sources and inefficient devices, leading to low quality of life. The current status is largely a result of adoption of centralized energy planning (CEP), which ignores energy needs of rural areas and poor and has also led to environmental degradation due to fossil fuel consumption and forest degradation. CEP exercises cannot pay attention to the variations in socio-economic and ecological factors of a region, which influence success of any intervention. Decentralized energy planning (DEP) is in the interest of efficient utilization of resources. The regional planning mechanism takes into account various available resources and demands in a region. This implies that the assessment of the demand supply and its intervention in the energy system, which may appear desirable due to such exercises, must be at a similar geographic scale. In this regard, the district is accepted as the appropriate planning level. Planned interventions to reduce energy scarcity can take various forms such as (a) energy conservation through promotion and use of energy-efficient stoves for cooking and water heating, compact fluorescent bulbs in place of ordinary incandescent bulbs, (b) supply expansions through energy plantations and (c) alternatives—renewable sources of energy such as micro/mini/small hydro power plants, wind, solar and biomass-based systems.

Energy planning models have been reviewed earlier by Jebaraj and Iniyan [1] focusing on macro or national level models. Another review article on computer-aided modeling and planning has been presented by Sagie [2]. A review of more than 90 published papers by Pohekar and Ramachandran [3] focused on neural networks and analysed the applicability of various methods and models. The focus of this paper is to review the different DEP models and approaches.

2. Energy models

Energy models are, like other models, simplified representations of real systems. Models are convenient tools in situations where performing tests or experiments in the real world are impractical, too expensive or out-rightly impossible. Computer models offer several advantages over mental models and thought experiments:

(a) They are explicit; their assumptions are (should be) stated in the written documentation and open for review
(b) They compute the logical consequences of the modeller's assumptions
(c) They are comprehensive and able to interrelate many factors simultaneously.

Energy system models are thus useful, as they depict immensely complicated systems that are beyond the ability of the human brain to comprehend and understand. These models can be used to perform comprehensive calculations and system analyses. They can help identify market subtleties and unveil system dynamics that would otherwise have gone unnoticed. Furthermore, the assumptions that form the base of the models are explicitly and unambiguously stated (unlike thought experiments and mental models), so that they are open for critique and review. Further this allows for risk, hedging strategy and sensitivity analysis for policy makers and investors. The next section presents the ways in which energy models can be classified.

3. Classification of energy models

There are general characteristics, which are shared by all models. For instance, any model will always be a simplification of reality and includes only those aspects that the model developer regarded important at that point of time. Grubb et al. [4] mention that any model dealing with future situations unavoidably makes use of estimates and assumptions which may or may not turn out to be valid under certain circumstances, but will at the time of application inevitably be uncertain. The problem with classifying energy models is that there are many ways of characterizing the different models, while there are only few models—if any—that fit into one distinct category. An example of a classification is given by Hourcade et al. [5] who distinguished three important ways to differentiate energy models, namely (a) purpose of the models, (b) their structure, and (c) their external or input assumptions. On the other hand, Grubb et al. [4] use six dimensions to classify energy models, including (a) top-down vs. bottom-up, (b) time horizon, (c) sectoral coverage, (d) optimization vs. simulation techniques, (e) level of aggregation, and finally (f) geographic coverage, trade, and leakage. Other ways of classification include: the applied mathematical techniques, the degree of data intensiveness, the degree of model complexity and the model flexibility.

Thus, the models could be reviewed using the following approaches:

1. General and specific purposes of energy models
2. The model structure: internal assumptions and external assumptions
3. The analytical approach: top-down vs. bottom-up
4. The underlying methodology
5. The mathematical approach

6. Geographical coverage: global, regional, national, local or project
7. Sectoral coverage
8. The time horizon: short, medium, and long term
9. Data requirements.

The following section gives an overview of the various types of energy models, which are applied for DEP.

3.1. Optimization models

Optimization models are prescriptive rather than descriptive and tell the user how to make the best of a given situation in relation to a predefined goal. The optimization model has a goal or an objective represented by a function usually referred to as an objective function that is to be maximized according to the given alternatives and the imposed constraints. As opposed to accounting models, optimization models have several degrees of freedom and therefore there is not only one feasible solution to these problems, but also many; infinitely many in fact. The objective is to identify the best, from all these solutions. The output of an optimization model should be the best way of accomplishing a goal, rather than a prediction. So instead of being "what if" tools, they are "how to" tools. Optimization models are most useful in situations when the problem is to choose the best from a set of well-defined alternatives. This applies in particular when the problem relates to technology choice. Following section gives a review of the optimization models applied at the decentralized level.

Das [6] had developed a multi-objective linear programming (MOLP)-based dynamic optimization model to analyze the renewable energy policy for Tamil Nadu, a state in India. Suganthi and Jagadeesan [7] had developed the mathematical programming energy–economy–environment (MPEEE) model. The model maximizes the gross net product (GNP)/energy ratio based on environmental constraints, to meet the energy requirement for the year 2010–2011 for India. An overview of energy planning research was presented by Luhanga et al. [8] on implementation of the long-term energy alternative planning (LEAP) model for rural area in Tanzania through the use of optimization models in combination with a forecasting model.

Raja et al. [9] had presented an energy planning optimization model using linear programming (LP) technique for sustainable agriculture development in the Chellampatti block of Madurai district, Tamil Nadu, a state in India. The model had been developed based on the availability of various energy sources in the block and the requirements of various human and agricultural activities.

Kanniappan and Ramachandran [10] had developed an optimization model using LP, in order to get maximum output of surplus biomass by suitably allocating the land area for the cultivation of different crops subject to meeting the food requirements for the population with regard to cereals, pulses, oilseeds, sugar and vegetables in Nilakkottai block of Dindigul district, Tamil Nadu, a state in India. Also, the model had taken into consideration the utilization of the available resources such as human labor, animal power and tractor power in the region mentioned.

The effect of wind energy system performance on optimal renewable energy model (OREM) was studied by Iniyan and Jagadeesan [11]. The model aims at minimizing cost/efficiency ratio and finds the optimum allocation of different renewable energy sources for various end-uses. The constraints used in the model are social-acceptance level, potential limit, demand and reliability. The authors also focused on the performance and reliability of wind energy systems and their effect on OREM.

Iniyan et al. [12] had formulated an OREM for the effective utilization of renewable energy sources in India for the period 2020–2021, with the objective function of minimizing cost/efficiency ratio and constraints The allocation of renewable energy sources for various end-uses such as lighting, cooking, pumping, heating, cooling and transportation has been accomplished using the OREM for the year 2020–2021.

A modified econometric model that links energy consumption with the economy, technology and the environment has been validated through comparison with an econometric and time series regression model by Suganthi and Samuel [13]. The actual requirements of coal, oil and electricity obtained from the modified model have been used as input in the MPEEE model. A Delphi study has been conducted by Iniyan et al. to find the level of social acceptance in the utilization of renewable energy sources for the year 2020–2021. A sensitivity analysis has also been done to validate the OREM.

Cormio et al. [14] had proposed a bottom-up energy system optimization model in order to support planning policies for promoting the use of renewable energy sources. LP optimization methodology based on the energy flow optimization model (EFOM) was adopted, detailing the primary energy sources exploitation (including biomass, solid waste, process byproducts), power and heat generation, emissions and end-use sectors. The proposed methodology was applied to a case study of the Apulia region in Southern Italy. The test results proved that the regional policy, aimed at satisfying the increasing heat and power demand by various end-use sectors through environmental friendly technologies, which can be supported mainly by combined cycle installations and with less effort of wind to power, waste-to-energy and biomass exploitation and industrial cogeneration systems.

Devdas [15] presents an overview of data for the socio-economic system of the target area, which are available from literature as well as from district, block, and village level records and presents a LP model for optimum resource allocation in a rural system. The objective function of the LP model aimed at maximizing the revenue of the rural system where in optimum resource allocation was made subject to a number of energy and non-energy related relevant constraints. The model presented in the paper is for micro-level planning of a rural energy system along with a detailed comparison of data for primary and secondary sources. A model estimating the output of the rural system is also presented. Model quantifies the major products and byproducts of different sectors of the rural economic system and also allocates the energy resources to different sectors of the rural economic system.

Nakata et al. [16] used optimization modeling to study efficient ways to integrate renewable energy systems to provide electricity and heat in rural Japan. The model provides minimum cost system configuration and operation taking into account hour-by-hour energy availability and demand. In the model, renewable electricity was provided by a combination of wind, photovoltaic, and biomass. Heat required was supplied from petroleum, liquefied petroleum gas (LPG), and geothermal heat pumps (GHPs).

Optimal planning of rural medium voltage distribution networks is done by Nahman and Spiri [17]. Model suggested that for selection of main initial parameters and timing of the reconstructions of rural distribution networks in long-term planning was to meet the increasing load demands with minimum total present worth cost. The model incorporated capital and exploitation costs as well as the costs due to undelivered energy and load curtailments. The optimal investment policy was determined using a constrained dynamic programming technique which indicates the best choice among possible options while taking into account all relevant technical criteria and common-sense rules.

Malik and Satsangi [18] had reviewed the energy planning problems in India at different levels. They had used a computer-based mixed integer linear programming (MILP) data extrapolation technique for energy systems planning. They have showed how the model was suitably scaled for obtaining the optimal mix of energy resources and technologies for the Wardha District (Maharastra State, India) using a computer-based MILP technique.

Nagel [19] used MILP to determine an economic energy supply structure based on biomass. The preferred field of application was the rural area because of the reasonable relation between the potential of biomass and the transportation distances that have a great influence on the economic viability. A MILP model based on the dynamical evaluation of economic efficiency could help to find the most economical and ecological supply structure. The model was developed for three different types of operating companies. The influences of different parameters on the target function could be analyzed by defining scenarios and by running sensitivity analyses. The results showed that the energy prices have the greatest influence on the economy.

A technique for computing the actual output energy of different combinations of wind–diesel engine system was developed by Zeftawy and Abou El-Ela [20]. A non-linear programming technique was used to optimize the combination of wind–diesel generation units to meet the load demand. The suggested technique was applied numerically to choose the most economical model from the different wind energy machines installed at a site in Egypt on the Mediterranean coast. An optimal generation procedure for the economical wind diesel engine system of a constructed village at the considered site was introduced. As a conclusion of the study, the share of wind energy and diesel engine energy to meet a specified load at minimum cost within the system operation constraints were deduced.

Singh et al. [21] developed an energy-planning model using multiple objective programming (MOP) technique for small, medium and large farms in Punjab, a state in India. The model had five objectives namely, minimization of energy input, maximization of gross returns, minimization of capital borrowing, minimization of labor hiring and minimization of risk for availability of energy inputs. Out of 10 farm plans, the farm plan with weights $\delta_2 = 20$ and $\delta_j = 0.001$ for $j = 1,3,4,5$ in terms of the maximum amount of gross returns was found to be the best for small, medium and large farms.

Decentralized models have been applied for block level as well as village level planning in India. An MILP model for technology selection and an LP based goal programming model at village level were developed by Deo et al. [22] at Indian Institute of Management Ahmedabad, IIMA. The models were applied to block and village level, blocks included for planning were Shahapur in Karnataka district, Dhanu block in Thana district in Maharashtra. A rural energy development programme titled Urja Gram undertook energy planning exercise at Rampur village in India. The optimal solution consisted of decision on systems selected, an allocation of energy from an energy system to an end-use in a given period and costs due to optimal solution. Energy planning exercise and the application of model demonstrated that the case study was used effectively to understand the exact implications of various interventions so as to select policies to be pursued in activating village energization process.

Audsley and Annetts [23] in his paper details the LP model used to optimize the profitability and determine the optimal planning of processes in a bio refinery factory, the complexities of defining how processes affect products and by-products and how this is used within the LP. An example of LP matrix and solution was used to illustrate the formulation and understanding of optimal planning process. The work was the culmination of 3 years funded projects to assess the potential of such centralized and integrated systems of crop processing as alternatives to more conventional separate harvesting and milling processes.

Literature review shows isolated attempts to develop and use an energy plan separately at the district, block, panchayat and village level. Often it is based on the estimated supply and demand. The decentralized planning should satisfy as stated above cost of supply maximization of efficiency and fulfill social implications like job creation, participation of poor, or meeting the needs of poor, reducing green house gases (GHG) emissions. But an integrated approach is missing. The question that raises interest here is the criteria for selection of optimal scale or mix? What is the mix and how it can be integrated together for a given scale of DEP and finally what is the optimal scale for DEP?

3.2. *Decentralized energy models*

The energy-planning endeavor involves finding a set of sources and conversion devices so as to meet the energy requirements/demands of all the tasks in an optimal manner. This optimality depends on the objective; such as to minimize the total annual costs of energy or minimization of non-local resources or maximization of system overall efficiency. Factors such as availability of resources in the region, task energy requirements impose constraints on the regional energy planning exercise. Thus, the DEP turns out to be a constrained optimization problem.

Normally DEP models refer to regional energy planning. Regional integrated energy plan (RIEP) is a computer-assisted accounting and simulation tool being developed to assist policy makers and planners at district and state level in evaluating energy policies and develop ecologically sound, sustainable energy plans. Energy availability and demand situation may be projected for various scenarios (base case scenario, high-energy intensity, and transformation, state-growth scenarios) in order to get a glimpse of future patterns and assess the likely impacts of energy policies.

The geographical coverage reflects the level at which the analysis takes place, which is an important factor in determining the structure of models. The global models describe the world economy or situation; the regional level models also often refer to international regions such as Europe, the Latin American Countries, South-East Asia, etc. Although literature uses the term "regional", in some cases it refers to regions within a country. National models treat world market conditions as exogenous, but encompass all major sectors within a country simultaneously, addressing feedbacks and interrelationships between the sectors. Examples of national models are econometric models for the short-term and general equilibrium models for the long-term. The regional decentralized level is sub national, referring to regions within a country such as a cluster of villages, blocks, and districts. The comprehensiveness of models focusing on the global, regional, or national level generally requires highly aggregated data and models focusing on one of these levels. They often include all major sectors and macro-economic linkages between those sectors, implying a considerable simplification of the energy sector. Local and DEP models, on the other hand, usually require a bottom-up approach using disaggregated data. Some examples of planning models applied to village, block, district and state have been described in the following section.

3.2.1. Decentralized energy planning at village level

Energy planning at the village level is the bottom limit of the application of decentralized planning principle. The individual villages form the distinct rural identities each of which is generally separated by vast unpopulated area with sparse or no habitation. They are thus the smallest aggregate social units within the rural administrate fold, where the energy consumption occurs. Thus, the village level plans must be prepared within the limits set by a panchayat or a block level plan, for the sum total of various village plans must correspond to a panchayat or block level plans. This would mean that at least some of the village level energy consumption costs would reflect the panchayat or block level (and via block level, district and state level) constraints. The following section gives some of the rare village level energy planning prepared by academicians, government agencies and NGOs.

Hamad et al. [24] proposed a village level model for application of bio-gas technology (BGT) in the new desert community areas of Egypt. The model involved a novel architectural design and house planning to optimize the role of BGT as a part of the whole community and the exploitation of its energy, fertilizer and sanitation benefits. The role of integrated decentralized energy production and distribution systems was considered by Subhash and Satsangi [25]. System analysis was used to construct scenarios for long-term energy development in selected rural clusters. An energy plan was developed for Fatehpur village (India) for the year 2001 using a generally applicable methodology.

Alam et al. [26] had presented Huq's model of integrated rural energy systems in revised form, which was prepared for a village in Bangladesh. The model formed the basis for the development of a computer model, based on the system dynamics methodology of forrester for policy planning. The model had been constructed to integrate crop production, biogas production, rural forest and agro-based industries with the aim of optimizing edible, saleable and inflammable outputs to improve the quality of life. They also presented Huq's revised model for a village in Bangladesh and discuss the simulated results for policy changes and implications of the model.

A simple LP model was used by Joshi et al. [27] to minimize the cost function for an energy-supply system consisting of a mix of energy sources and conversion devices. The model was applied to a typical village in India for both the domestic and irrigation sectors. The energy-demand assessment was made with an energy audit. The results of the study showed that wood and agricultural residues are preferred energy sources for cooking in the domestic sector when stoves with 18% or 16% efficiencies are used. Biogas becomes economically feasible only for plants holding 8 m^3 of biogas. Electricity is the best option for lighting. For irrigation, diesel-powered pumps are preferred to electric pumps. Biogas is economical for lighting only when the biogas-conversion efficiency in the mantle is taken to be twice the 2% that is presently available.

The Energy Research Institute (TERI) and the University of Waterloo (UW) undertook a joint research project (1994–1997) aimed at developing participatory planning and intervention design methodologies and tools to facilitate public participation and feature a meaningful role for women in rural energy planning. This study presents the policy implications and recommendations.

A new method for local energy planning (village) was proposed by Beeck [28] which considers several constraints: context-related issues, data expressed in monetary at least quantitative, its application to local region technology related issues, focus on small scale energy (renewable) systems data availability. The next part of the study reveals that the work is restricted to the selection of new energy systems from production of proper energy forms in order to meet increased energy demand. The demand was actually the desire for certain energy services. The method described in this uses a decision support tool that does not decide for the energy planner which actions to take. The study concludes that the planners themselves must make the ultimate decision.

Biswas et al. [29] proposed an integrated ecological, economic and social model to assist sustainable rural development in villages in Bangladesh. In the model, renewable energy technologies create income-generating activities for landless and marginal farmers and indoor air pollution for women in the household from cooking with poor-quality fuels. Because of their high capital costs, the model proposes an extension of the well-known micro-credit approach developed by non-government organizations (NGOs) such as the Grameen Bank and The Bangladesh Rural Advancement Committee (BRAC). The study states that with the assistance of an external agency composed of NGOs, business, government and university representatives, group of villagers can form village organizations, comprising cooperatives or other forms of business. They borrow money from a bank or NGO and purchase renewable energy technologies such as biogas, solar or wind, depending upon the location. By selling energy to wealthier members of the village, the village organizations would repay their loans, thus gaining direct ownership and control over the technology and its applications.

The Rehovot approach to rural planning and implementation, first developed in Israel, has subsequently been refined for application to the myriad problems of rural areas of developing countries. The method is based on integrated rural management strategies; ensuring that agricultural changes are paralleled by the development of secondary and tertiary sector activities and of appropriate social and administrative institutions. The role of ‘bottom-up’ planning systems is particularly highlighted. This holistic approach to planning is illustrated by actual case examples by Weitz [30].

The details and results of an energy model of a non-electrified rural village are given by Howells et al. [31]. The model represents a hypothetical, but a typical, South African rural village. The model was developed with MARKAL (an acronym for MARKal ALlocation)/TIMES, a modeling and optimization tool. The primary objective of the modeling process, in the approach taken, was to ascertain the least-cost method of meeting the energy needs of the village, under various constraints and user-defined bounds. The study also presents the details of the modeling project by first focusing on integrated energy-environment-economic models in general and the limitations of these models and then going on to describing the limitations associated with rural energy modeling. Finally, it focuses on the model structure itself and the results obtained.

Decentralized models have also been applied for micro-level energy planning. A MILP model for technology selection at village level and a LP-based goal programming model were developed at Indian Institute of Management, Ahmedabad by Kanudia [32]. This study was based on use of MARKAL for different cost and tax scenarios targeted towards penetration of renewable energy technologies in the power generation sector of India. Focus of this study has been more towards economic and financial aspects rather than the technology side.

Ravindranath and Hall [33] in the book ‘Biomass, Energy and Environment’ explain the important aspects of utilizing bioenergy potential in India. The authors emphasize that bioenergy has the potential to provide a decentralized village level and self-reliant energy system to meet needs in a sustainable and environmentally sound way. They also explain the approach of implementation of rural bioenergy centers (RBC) scheme and large-scale bioenergy systems. The approach suggested here aims to meet all rural energy needs in India.

Sinha et al. [34] summarize their effort to compile, computerize and analyze data from 638 village energy consumption surveys covering over 39,000 households, carried out by different organizations between 1985 and 1989. The details of the level of information provided in the survey reports, area of survey, land use pattern, asset ownership, etc., of the collated studies are presented. Results based on the analysis of the energy consumption data compiled are then discussed. Authors state that the data from the study can be used for energy planning models to meet the energy demand of the future.

The study presented by Das et al. [35] deals with selecting appropriate alternate energy technologies with priorities to end-use activities in the agriculture and household sectors in an Indian village. The paper also states that harnessing renewable energy resources has substantially speeded up the process of rural energy planning in India. The study is based on a field survey and the use of dynamic programming.

Murphy [36] states that there is renewed optimism about the potential for leapfrogging in the rural energy sector of East Africa. The study identifies economic, social, political, and cultural factors limiting the ability of rural people to rapidly switch into using and/or supplying these technologies. He finally concludes that in designing technology dissemination or energy supply projects, planners must thoroughly account for the capabilities existing in rural areas.

Zhen [37] has drawn the network diagram of an energy-supply and demand system, as well as a linear optimized model of energy integrated in the economy. The target was the least cost of energy supply and the best energy-supply structure. A supply demand model was built to predict and study long-term changes of the system. The two models are combined and applied to a village with a population of 800 people in the North China Plain. Results of computer simulation showed that in the base year (1990) if energy-transformation devices are properly installed, the cost of supply system will reach the lowest level while meeting the energy demand and saving of energy. With development of the economy and a rise of living standard, energy supply will become an important factor for rural economic development.

Village level decentralized planning approach has been, attempted on a small scale for isolated projects, for meeting one or two energy service needs of the villagers like cooking or lighting. Thus it is necessary to explore a plan to meet all the needs of the rural people staying in a village. The next question is to explore the feasibility of energy planning at village scale. In countries such as India, the lowest administration unit is a ‘‘panchayat or local council’’ consisting of 5–15 villages. Studies are required to assess the feasibility of energy planning at panchayat level.

3.2.2. Decentralized energy planning at block level

A block is a cluster of large number of villages and it is in the administrative unit in many countries. Small villages appear to be energy and economic sinks. A heuristics approach shows that a block level system possesses the necessary infrastructure and has the potential to provide energy self-sufficiency. In other words, block is an administrative unit comprising a few hundred contiguous villages and has a small town as the headquarters. The geographical boundaries of a block can provide the necessary land for producing food, fuel, fodder and fertilizer for sustainable development. Block level energy planning has been attempted in many cases but not implemented; it deals with planning for meeting all the basic needs of a block covering 80–90 villages. Some of the block level (Taluka) models have been discussed in the following section.

Rajvanshi [38] has shown that biomass at block level has the potential for providing food, fuel, fodder and fertilizer to its inhabitants. It can also provide employment in the process. The study has been conducted for a block (an administrative block of 90–100 contiguous villages) in western Maharashtra, India, where it has been shown that all its energy needs in 2000 AD can be met by proper use of agricultural residues and energy plantations via agro-energy systems. The supply options included in the study are: (a) ethanol production from sweet sorghum and molasses produced by existing sugar factories; (b) pyrolysis oil production from agricultural residues; (c) electricity production from energy plantations and agricultural residues. The study also suggests that the local energy sources can replace petrol, LPG, diesel, kerosene and grid electricity. Economic analysis for supply options shows that they can become economically viable only if electricity pricing for rural areas is done rationally. It is also shown that biomass energy-based supply options have the capacity of providing employment to about 30,000 people in the block. The study finally concludes that energy self-sufficient block may provide an alternative development model to mega city-based centralized energy systems.

A MOP-based approach was adopted for block level planning by Jana and Chattopadhyay [39]. Narayangarh block of Midnapore district in India was selected for the study. In this study, the energy allocation model was initiated with three separate objectives for optimization; minimizing the total cost, minimizing the use of non-local sources of energy and maximizing the overall efficiency of the system. The study aimed at formulating policies for block level energy planning involving all the major sectors of energy use in an integrated form at regional level (block). Multi-objective fuzzy linear programming (MOFLP) model, was used in a compromising decision support framework. As a conclusion of the study it is shown that MOFLP is a more rational alternative to single objective LP model in rural energy planning.

Sinha et al. [40] analyzed the conceptual and methodological issues in rural energy planning with the purpose of facilitating the process of developing an effective energy intervention design. The purpose of the intervention design was to augment and facilitate economically productive activities in addition to fulfilling the subsistence requirements and improving quality of life. It was concluded that intensive intervention, implemented at village cluster level by local institutions, supervised from the block, coordinated from the district, monitored at the state level and supported nationally appear to be the most promising combination for making effective intervention in the rural energy sector in the Indian context.

Deo et al. [22] explains the energy planning exercise adopted by Maharashtra Energy Development Agency (MEDA) for Dhanu block in Thane district in Maharashtra state in India. The focus of planning was fixed on augmenting the energy supply from varied sources, local as well as central, subject to understanding the limits of the available purchasing power with local population. The objective of the block energy planning was aimed at planning for future needs of the block at minimum energy supply costs. Based on field studies, energy plan was prepared for a period of 5 years (1990–1995). LP model was used to forecast the future. The rural energy section of Department of Rural Development and Panchayatiraj, undertook detailed energy planning exercise for Shahapur block of Gulbarga district in Karnataka in India. MILP was used to forecast the energy demand for 5 years with1990 as the baseline year.

Block level energy planning has been attempted in one case but only not it has been implemented; it dealt with planning for meeting all the basic needs of a block covering 80–90 villages. There are very limited efforts at the block level planning and these efforts are not based on any optimization approach.

3.2.3. Decentralized energy planning at district level

A district involves several thousand of villages with multiple blocks having differing energy resources and needs. Not much literature exists on the feasibility of DEP at district level; some of the district level energy planning case studies are reviewed in the following section:

A paper by Malik and Satsangi [18] reviews the energy planning problems in India at different levels (all India/ Rural India/State/District/Block/Village). The study is conducted in rural areas of the Wardha District for application study. It adopts proposed statistical extrapolation technique of moving first from the village level energy scenario to the corresponding block level energy scenario and then further to the district/region level energy profile. It shows the model suitability scaled for obtaining the optimal mix of energy resources and technologies for the Wardha district using a computer-based MILP. The average absolute percentage error is calculated between the actual district/region level energy scenario and the statistically projected (extrapolated) district/region level energy scenario to gauge the goodness of fit of the proposed statistical extrapolation technique.

Devdas has conducted a study on energy planning dividing his work in three parts; first deals with the data collection, second with the use of LP model to reach the objective and third with forecasting future scenarios.

Devdas [15] in his paper "Planning for rural energy system: Part I" presents a two-pronged approach for identifying the important parameter, which controls the economy in the rural system, particularly in relation to energy inputs and outputs leading to a comprehensive analysis of the energy scene in the rural systems. The literature was collected, segregated into various categories like household, agriculture, application of technologies, their impacts in the rural system, energy planning, etc. and then reviewed. Further a systematic methodology for primary survey of rural energy consumption was employed, taking into account the most significant parameters that influence the pattern and intensity of energy use. Details of sampling of design and method of administering the survey along with a brief account of some of the more salient results obtained from the survey have been presented. The study identifies several parameters, which influence energy consumption in a rural economic system. The paper also discusses the relevance of surveys for realistic planning at micro-level by drawing attention to the large discrepancies that account between statistics obtained from primary and secondary sources.

Devdas [41] in his paper "Planning for rural energy system; Part II" deals with the central importance of energy inputs in development, and presents the complex interactions within subsystems that contribute a rural energy system. This paper also brings about the importance of the primary data for realistic renewable energy planning at the micro-level in a given rural system. Factors that render secondary data are inadequate for such applications and are discussed. The differences between energy related data from secondary and primary sources in respect of representative villages in Kanyakumari

District of TamilNadu, India, are detailed. A rural system model for computing the output from various components of a rural system is also presented. This estimation is made by making use of a set of technical coefficients, which relate the inputs to the outputs from individual segments of the rural production system. The paper also presents a LP model for optimum resource allocation in a rural system. The objective function of the LP model was to maximize the revenue of the rural system where optimum resource allocation was made, subject to a number of energy and non-energy related relevant constraints. The paper also presents two models for micro-level planning of a rural energy system along with a detailed comparison of data for primary and secondary sources. A model estimating the output of the rural system has also been presented. The model also quantifies the major yields as well as the byproducts of different sectors of the rural economic system and also allocates the energy resources to different sectors of the rural economic system. Thus, an overview of data for the socio-economic system of the target area are presented, which are available from literature as well as from District, Block, and Village level records.

The paper "Planning for rural energy system: Part III" by Devdas [42] presents a technique for forecasting future scenarios The forecast was based on a set of projected inputs for the target year along with a projected set of technical coefficients. The paper identifies several areas where application of technology results in significant changes at the micro-level and discusses the application of regression or the growth rate method and the best farm method for projecting the input and the technical coefficients for the rural system for the target year. It also identifies the constraints on economic development in the study area and the gradual shift in agricultural pattern and practices as revealed by the survey conducted by the author as well as through a careful examination of the community development block and district level statistical data. The technique which was applied for projecting plausible scenarios for the rural segment of the Kanyakumari District and the significance of the results has been discussed. In the opinion of the author, the technical coefficients developed and presented in this paper can serve as useful indicators for other areas having similar socio-economic conditions and belonging to similar agro climatic zones.

Herrmann and Osinski [43] presents the decentralized concepts and the results of such planning, by giving example of Baden-Wuerttemberg in South Germany and examining the regional level (exemplified by an intensively farmed area) and local level (a community) using geographical information system (GIS) and modeling approaches. Planning in this sense needs not only a top-down but also a bottom-up approach .The participation of the people particularly at the local level has to be guaranteed and integrated within the planning process for the process to be successful.

A district involves several thousand villages with blocks or panchayats having differing energy resources and needs. Not much literature exists on the feasibility of DEP at the district level and integration of subunits within a district.

3.3. Energy supply/demand driven models

Models falling under this category are either energy optimization models or energy sector equilibrium models. The energy sector optimization models have a detailed specification of technologies in the energy supply and demand sectors along with a number of fuel forms. All these compete for a share in meeting the exogenous demands. The sectoral coverage of these models and that of the energy sector equilibrium models is quite similar. Only difference is that, in the former category models, objective is to minimize the present value of the overall system cost of meeting the given demand to determine the equilibrium shares of various technology options. While in the latter the objective is in determining the equilibrium prices based on the behavior of individual elements. Some of supply demand models applied at decentralized level are discussed in the following section.

Rijal et al. [44] had formulated a linear multiple regression energy demand forecasting model to project the energy requirements in rural Nepal. Bala [45] had presented projections of rural energy supply and demand and assessed the contributions to global warming. The output of the dynamic system model had been used in the LEAP model and overall energy balances were compiled using a bottom-up approach. A mathematical model has been developed by Balachandra and Chandru [46] for the electricity demand based on the concept of representative load curves (RLCs). An attempt had been made by Purohit et al. [47] to estimate the potential of using renewable energy technologies such as biogas plants, solar cookers and improved cook stoves for domestic cooking in India.

Hulscher and Hommes [48] in his paper has contrasted with an overall strategy for sustainable rural energy demand and supply. An outline for a demand-oriented policy was formulated, indicating the role of the government in energy pricing and market development. Special attention is given to electricity as the fastest-growing energy subsector. It was concluded that major changes are required to accommodate and institutionalize the planning of decentralized energy supply.

Parikh [49] had developed a supply demand model, which is a general LP model developed to capture energy and agricultural interactions existing in the rural areas of developing countries. On supply side, energy used for agriculture includes fertilizers, irrigation, mechanization, different technological choices, crop commodities, livestock, farmers of different income groups along with their assets, i.e. land holdings, livestock, etc. The by-products of agriculture, i.e. biomass (crop residues, animal dung, wood, etc.), can be used to generate energy. On the demand side their use for feed, fuel, and fertilizer must be considered. Twelve different energy sources and several conversion technologies, such as biogas, charcoal kilns, alcohol distilleries, etc., were considered. The model was applicable to low-income, biomass-scarce developing countries and was suitable for policy purposes because it considers several income groups separately and considers how different changes affect each of them.

Very less literature is available on the supply demand models. The literature mainly focuses in general on rural areas and not individual villages, cluster of villages, block or districts. The energy mix is not considered at all, and the supply and demand matching is hardly seen.

3.4. Energy and environmental planning models

The environmental consideration in energy planning would include local environmental factors such as land degradation, loss of forests, indoor air pollution and global environmental factors such as GHG emissions and loss of biodiversity. Energy and environmental analysis is a method to evaluate the utility of any energy system by finding the requirement of energy and resulting emissions through all the materials and processes used to build and use any system over its entire life and also to demolish it at the end of life. Thus it can be described as a macroscopic exercise used for conducting futuristic studies through dynamic assessment of the defined reference energy system comprising of many alternatives and constraints. It is done to find the optimum solution for certain objective function often system cost minimization through meeting system requirements such as the energy demand. A few studies on energy and environmental planning models applied at decentralized level are presented in the following section.

Environmental intervention scenarios for GHG emissions reduction in case of Indian power sector have been studied by Ghosh et al. [50]. An overall energy system framework was used for assessing the future role of renewable energy in the power sector under baseline and different mitigation scenarios over a time frame of 35 years, from 2000 to 2035. The methodology used an integrated bottom-up modeling framework. The paper also assessed the clean development mechanism (CDM) investment potential for power sector renewables. It outlined specific policy interventions for overcoming the barriers and enhancing deployment of renewables for the future.

Biswas et al. [29] proposed an integrated ecological, economic and social model to assist sustainable rural development in villages of Bangladesh. In the model, it is shown that renewable energy technologies reduce environmental problems, like deforestation and indoor air pollution from cooking with poor-quality fuels.

The study by Tanatvanit et al. [51] provides a brief review of energy use patterns in three economic sectors; namely, residential, industrial and transport. This paper forecasts the growth in energy demand and corresponding emissions for the year 2020 for these three sectors by using a model based on the end-use approach. The energy savings from the energy conservation strategies, such as energy efficiency improvement and energy demand management, are assessed and also the implications on electricity generation expansion planning are examined. The integrated resource-planning (IRP) model was used to find the least-cost electricity generation expansion plans. The effects of energy conservation options are analyzed using a scenario-based approach. The results of analysis reveal that the improvement of public transportation can reduce future energy requirements and CO_2 emissions in 2020 by 635 thousand ton of oil equivalent (toe) and 2024 thousand ton of CO_2 equivalent. The paper concludes that if all options are simultaneously implemented, the potential of energy savings and CO_2 mitigation in 2020 are estimated to be 1240 thousand ton and 3622 thousand ton of CO_2 equivalent, respectively.

The interconnections between energy, agriculture and environment in rural India are analyzed using a systems perspective by Painuly et al. [52]. Rural areas of developing countries use biomass for fuel, fodder, fertilizer and other purposes, and with this purpose the paper estimates the fuel–fodder–fertilizer relationships for optimal biomass allocation. The allocation is explored using a LP model, which was validated by simulating it using data for the year 1990–1991.The model was then applied for the year 2000, and several scenarios are generated to obtain answers to various policy questions. The results show that it is necessary to increase fertilizer consumption, to increase efficiencies of cooking stoves, to improve livestock feed, and/or to decrease population growth for maximizing the revenue generated in the rural system of India.

Reddy and Balachandra [53] consider various factors that influence the energy demand in India and have developed the energy and environmental outlook for the year 2010 AD. This has been done by developing an integrated mathematical model incorporating various factors such as GDP, population growth, urbanization, energy intensity, structural shifts, energy efficiency measures, fuel switching, appropriate energy pricing mechanism and environmental policies. Two scenarios, baseline as well as sustainable energy planning (SEP) are discussed. Using this framework a SEP scenario was developed. The results indicated that the energy consumption levels in 2010 are projected to decrease by about 13% (relative to baseline scenario) if the measures suggested by SEP were implemented. The corresponding decline in CO_2 emissions was about 13%. A comparison was made with the baseline scenario that showed that the implementation of various policy measures reduced the energy consumption levels and significantly improved the environment both at local as well as global levels.

Kanudia's [32] study of energy-environment policy technology selection modeling and analysis for rural India contributes to the energy-environment-modeling methodology in terms of incorporating the developing country dynamics and several non-linear parameters in a bottom-up linear formulation. The problem has been formulated as a linear program to minimize the discounted system cost over the planning horizon. The model has a planning horizon up to the year 2035. The scenarios analyzed include carbon mitigation, subsidy to RETs and an energy-efficient transport infrastructure scenario. Dantzig's two-stage stochastic programming approach has been used to examine the immediate implications of long-term uncertainties in macro-economic growth and carbon mitigation. Step-wise linearized end-use demand functions have been used to incorporate the price elasticity of demands in analyzing the carbon mitigation strategies.

Technical, economic, and environmental implications were analyzed for an evaluation model for developing local renewable energy sources by Yue and Wang [54]. This study evaluated wind, solar, and biomass energy sources in a rural area of Chigu in southwestern Taiwan. The approach adopted evaluates local potentials of renewable energy sources with the aid of a GIS according to actual local conditions, and allows the assessment to consider local potentials and restrictions such as climate conditions, land uses, and ecological environments, thus enabling a more-accurate assessment than is possible with evaluations on an approximate basis.

Chinese cities are experiencing major environmental effects from fossil fuel-based energy consumption for mainly in residential and, increasingly, urban transportation uses. Sadownik and Jaccard [55] proposes community energy management (CEM) a sustainable energy strategy, which looks at shaping the built environment, and designing urban services in consideration of energy production, distribution and use, which could affect both the long-term demand for energy and the type of energy supplied. This study explores CEM in a Chinese context by analyzing trends in land-use planning, urban transportation and residential energy, and then suggests CEM strategies that would be appropriate in directing urban development towards a more sustainable energy path. A spreadsheet model is used to evaluate aggregate energy-related emissions in the year 2015 that result from two alternative scenarios of urban growth throughout China. The model focused on how energy demands; residential energy technology penetration and transportation mode choices are affected by factors of density and mix of use in neighborhood development.

Reddy et al. [56] proposed development focused, end-use oriented, service directed (DEFENDUS) approach to energy planning. The DEFENDUS method has been used and described to demonstrate its applicability and was not confined to a particular region or source of energy. The study included; electricity for five states of India, petroleum products for the country as a whole, biomass for the state of Karnataka and a composite energy scenario for Karnataka state involving integration of all the currently used sources of energy. In every case, the total energy usage is disaggregated between the existing categories of users according to their end-uses. Then depending on the goals selected and the strategies that could be adopted to achieve them, growth rates for each category of users are used to estimate the number of users in future years. Improvements in the efficiency of end-use devices and/or substitution of energy sources are considered, to determine the possible reduction in the category-wise unit energy usage, and the corresponding energy requirement was estimated. The electricity plan for state of Karnataka comprises future demand estimation as well as the comparative costs of various supply/saving options. In oil scenarios for India, the focus was mainly on demand management through modal and carrier shifts, with emphasis on middle distillates. The biomass strategy for Karnataka included both demand and supply side measures.

The energy-environment technology packages are rarely used at local, block and district level energy planning. Thus it is necessary to develop criteria and identify environmental factors that need to be incorporated during DEP. The literature review of this section shows that there is a need to develop an approach and methodology to incorporate all the relevant environmental factors in DEP.

3.5. Resource energy planning models

IRP is an energy planning approach to identify the mix of centralized, decentralized renewables and efficiency improvements that will meet the demand for increasing energy services at least cost or least environmental impact. Solar, wind and biomass are accepted as dependable and widely available renewable energy sources. The approach involves using the local available energy resources cleverly or in other words using the optimum mix of the resources to meet the needs of rural people. Such factors are mainly incorporated in resource energy planning. The various types of renewable energy resource models have been reviewed in the following section.

Energy-planning attempts for rural areas make use of a mix of locally available renewable resources with some commercial resources to cater to the energy needs of the population. Fernandez et al. [57] have attempted to assess the level of energy resource consumption inequality in a typical hilly rural Indian village (Kanvashram village, Pauri Garhwal district, Uttaranchal, India). The Gini coefficient of inequality, a measure of inequality in the field of econometrics has been applied for this assessment. The population is segregated into different categories based on their income levels and certain socio-economic criteria, which are also likely to exercise an influence on consumption levels of energy. The results of the analysis are then discussed in the light of the findings.

To demonstrate the dependence of energy consumption on available resources, Bowonder et al. [58] have conducted a study of eight rural communities in India. The study indicates that levels of energy consumption vary widely among the communities and that consumption depends on socioeconomic and agro climatic factors. Irrigation was the most significant factor influencing energy consumption and demand. Fuel wood was used not only by the low-income households but also by the higher-income households. There is a progressive trend towards monetization of fuel wood, animal wastes and agricultural residues. Energy planning for rural communities should be location and household-specific, and disaggregated information should be generated for this purpose using baseline surveys.

Dendukuri and Mittal [59] showed that for effective energy planning, it is necessary to understand the energy-use patterns of different categories of farmers in village ecosystems and the influence of income and family size on it. This paper reports such a study conducted in a village in Andhra Pradesh, India where dry land agriculture is pursued. The household energy-use patterns observed in the village clearly showed that most energy is utilized for basic survival tasks such as cooking, cleaning, fetching fuel, water and other necessities of life. A number of measures have been suggested for enhancing the efficiency of energy use in rural household systems, which include the design and installation of a fuel-efficient improved chulha, with dampers, baffle and a grate in the combustion chamber, installation of family size biogas plants, planting of hardwood trees on field bunds, energy plantation on marginal and waste lands, utilization of solar.

Ramachandra and Shruthi [60] have focused on the wind energy resources in Karnataka state in India. The study highlights the advantage of wind energy for application in rural and remote areas. It employs GIS to map the wind energy resources of Karnataka state and analyze their variability considering spatial and seasonal aspects. Maps of locations suitable for tapping wind energy have been prepared and a spatial database with wind velocities has been developed and used for evaluation of the theoretical potential through continuous monitoring and mapping of the wind resources. Agro climatic zone wise analysis showed that the northern dry zone and the central dry zone were ideally suited for harvesting wind energy for regional economic development.

Kishore et al. [61] highlight the role of biomass resources in developing countries for addressing global climate change concerns using India as a case study. This paper highlights the need to integrate the concerns of both developing countries and developed countries. The role of various biomass technologies for improving rural infrastructure and village power are discussed in detail.

Municipal waste is a potential renewable energy resource according to Nilsson and Martensson [62]. The paper is based on a study of 12 municipal energy-plans that attempted to control and develop local energy-systems in southern Sweden. The results of the study showed that the resource energy planning follow the national energy-policies with respect to reduction of oil use, improved energy efficiency, and increased use of renewable energy.

Till 2010 resource energy planning was done using LEAP model for different biomass energy technologies in Vietnam which include biomass integrated gasification combined cycle (BIGCC) based on wood and bagasse, direct combustion plants based on wood, co-firing power plants and Stirling engine based on wood and cooking stoves. These different scenarios were considered by Kumar et al. [63] and the study showed that if the option suggested is implemented, it would result in mitigation of 10.83 million tonnes (Mt) of CO_2 in 2010.

Rabah [64] states that renewable resource especially solar energy is abundant in Kenya, which if harnessed efficiently could contribute to improving the quality of life of rural and urban poor in Kenya, and this can be done by proper energy planning only. The study suggests adoption of energy planning approach could provide useful benefits to Kenya.

Yue and Wang [54] evaluates wind, solar, and biomass energy sources in a rural area of Chigu in southwestern Taiwan by analyzing technical, economic, environmental, and political implications in order to establish an evaluation model for developing local renewable energy sources. The approach evaluated local potentials of renewable energy sources with the aid of a GIS according to actual local conditions, and allows the assessment to consider local potentials and restrictions such as climate conditions, land uses, and ecological environments, thus enabling a more accurate assessment than is possible with evaluations on an approximate basis. The results helped to build a developmental vision for sustainable energy systems based on locally available natural resources, and facilitate a transition of national energy and environmental policies towards sustainability.

Rylatt et al. [65] rates solar energy as the major resource and describes the development of a solar energy planning system, consisting of methodology and decision support software for planners and energy advisers. Intended primarily to predict and realize the potential of solar energy on an urban scale, the system will support decisions in relation to the key solar technologies: solar water heating, photovoltaic and passive solar gain. Based on a methodology for predicting the solar energy potential of domestic housing stock, it is implemented as a relational database application linked to a customized GIS. The methodology takes into account the baseline energy consumption and projected energy saving benefits. To support this, the system incorporates a domestic energy model and addresses the major problem of data collection in two ways. The paper concludes with a discussion of possible planning scenarios to illustrate how the system may be deployed at various levels of granularity to assist targeting of individual properties or city neighborhoods, or for whole-city projections.

The studies on resource energy planning models and their application at a decentralized level are limited. The models, which have been applied, are based on one of the available resources. The literature has focused on using just one or two available resources. Attempts at developing optimum energy mix of different resources which meet all the necessary needs of the rural people are limited.

3.6. Energy models based on neural networks

Artificial intelligence (AI) is a powerful tool for energy planning but still it is an emerging approach with little applications. Intelligent solutions, based on AI technologies to solve complicated practical problems in various sectors are becoming important. AI-based systems are being developed and deployed worldwide in myriad applications, mainly because of their symbolic reasoning, flexibility and explanation capabilities. Integrated energy planning based on decision support systems (DSS) approach is flexible, adaptable, and ecologically sound and gives an optimal mix of new renewable/conventional energy sources. Some of the models are discussed below.

A fuzzy based multi-objective analysis has been made by Agrawal and Singh [66], for the energy allocation for household cooking in Uttar Pradesh, India. The results focus on the economic, environmental and technical concerns as the main objectives included in the model.

Decision-making in energy sector at decentralized level was attempted using LP models by Samouilidis and Ladia [67]. The authors have made an attempt to match the real decision structure of a given energy system, by decomposing a LP energy model into smaller models, with the corresponding system decision centers, applying the 'transfer price' algorithm of Dantzing and Wolfe. The 'master' problem corresponds to the central planning unit, whereas the sub problems correspond to peripheral operating units, i.e. enterprises, usually state owned, which produce and distribute the energy carriers. The optimal plans of the peripheral units are submitted to the central unit, which through the mechanism of pricing of common resources, inputs and energy services outputs, co-ordinates the overall planning of the energy system. An illustrative example is given referring to the Hellenic national energy system.

A review of more than 90 published papers by [3] analyzed the applicability of various methods and models. A classification on application areas and the year of application is presented to highlight the trends. Review of the published literature on SEP presented here indicates greater applicability of multi-criteria decision making (MCDM) methods in changed socio-economic scenario. The methods have been very widely used to take care of multiple, conflicting criteria to arrive at better solutions. Increasing popularity and applicability of these methods beyond 1990 indicates a paradigm shift in energy planning approaches. The methods are observed to be most popular in renewable energy planning followed by energy resource allocation. It is observed that analytical hierarchy process is the most popular technique followed by outranking techniques PROMETHEE (*p*reference *r*anking *o*rganization *meth*od for *e*nrichment *e*valuations) and ELECTRE. Validation of results with multiple methods, development of interactive DSS and application of fuzzy methods to tackle uncertainties in the data are observed in the published literature.

Beccali et al. [68] show an application of the multi-criteria decision-making methodology used to assess an action plan for the diffusion of renewable energy technologies at regional scale. In this paper, a case study was carried out for the island of Sardinia in Italy. Multi-criteria decision-making was applied in order to assess groups of actions focused on the implementation part. For this, three decision scenarios were considered. In the first scenario, high priority was assigned to the environmental effects of the examined actions. In the second scenario, economic and social aspects were emphasized; in the third scenario attention was focused on the saving strategies and the rationalization of the energy production system.

MOFLP problems were presented by Borges and Antunes [69]. This approach was illustrated to tackle uncertainty and imprecision associated with the coefficients of an input–output energy-economy planning model, aimed at providing decision support to decision makers in the study of the interactions between the energy system and the economy at a local and national level. Techniques used have been illustrated in a multiple objective input–output model, supplied with actual data for Portugal, aimed at studying the interactions between the energy sector and the economy on a national level.

Pokharel and Chandrashekar [70] have applied a suitable multi-objective programming method for rural energy analysis. Multi-objective methods provide decision makers with an opportunity to negotiate and explore different energy options. As an illustration of the proposed method, authors have analyzed the energy situation of a rural area and examined the trade off between energy supply, investment for energy programs, and employment generation.

4. Conclusions

The current pattern of commercial energy oriented development, particularly focused on fossil fuels and centralized electricity, has resulted in inequities, external debt and environmental degradation. For example, large proportions of rural population and urban poor continue to depend on low-quality energy sources and inefficient devices, leading to low quality of life. The current status is largely a result of adoption of centralized energy planning, which ignores energy needs of rural areas and poor and has led to environmental degradation due to fossil fuel consumption, forest degradation and large hydro-electric projects. Thus there is a need for:

- alternate approach of planning i.e., a decentralized planning approach, and
- a shift to renewable energy to sustain economic development.

Some examples of planning models applied to villages, blocks and districts have been discussed in the paper. It can be concluded that village level decentralized planning approach has been attempted on a small scale for isolated projects for meeting one or two energy needs of the villages. Block level energy planning has been attempted but not actually implemented. There are very limited efforts at block level planning and they are not based on any optimization approach. Not much literature exists on the feasibility of DEP at district level.

Application of models for matching the projected energy demand with a mix of energy sources at decentralized level is limited. The literature mainly focuses in general on rural areas and not individual villages, clusters of villages, blocks or districts.

The energy-environment technology packages are rarely used at local, block and district level energy planning. Thus it is necessary to develop criteria and identify environmental factors that need to be incorporated during DEP. The literature review in this paper highlights the need to develop an approach and methodology to incorporate all the relevant environmental factors in DEP.

The studies on resource energy planning models and their application at a decentralized level are limited. The models, which have been applied, are based on one of the available resources. The literature has focused on using just one or two available energy resources. Attempts at developing optimum energy mix of different energy resources which meet all the necessary needs of the rural people are limited.

It can be said that in developing countries like India, local energy planning for regions experiencing development can best be supported with a modular package of models. This package should include models for assessing energy demand, supply, and socio-economic and environmental impacts at the local level. The general purpose of these models must be exploring an optimal mix to match the demand and supply. The approach has to be bottom-up rather than top-down to allow a detailed description of energy services and the resulting demand for energy forms and supply technologies. A flexible toolbox is believed to be the most suited methodology for adjustments to local circumstances. The time horizon should include the short and medium term. Thus, selection of proper model and its application at decentralized level is necessary. In addition to national level energy planning, DEP models and approaches need to be developed and made use of.

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