ENERGY PLANNING MODEL FOR SUSTAINABLE DEVELOPMENT

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Abstract: The objective of this study is to develop a mathematical model for the effective utilization of renewable energy sources in a developing country like India. DEP is one of the options to meet the rural and small scale energy needs in a reliable, affordable and environmentally sustainable way. The main aspect of the energy planning at decentralised 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. The geographical coverage and scale reflects the level at which the analysis takes place, which is an important factor in determining the structure of models. DEP planning involves multiple objectives and different kinds of constraints Present work present the methodology for the DEP. The kinds of objective functions and constraints which have to be included in the DEP have been presented in the present work. Present developed model has been applied to a typical Indian block unit, which comprises of several villages. Based on the analysis made in the present work, it is found that biomass-based energy systems have the potential to meet all the energy needs of Kunigal block.

Keywords: Decentralized Energy Planning; Energy planning; Goal Programming; Scenarios; Sustainable Energy Development Scenario

1. Introduction

Energy is universally recognized as one of the most significant inputs for economic growth and human development. The growth of a nation, encompassing all sectors of the economy and all sections of society, is contingent on meeting its energy requirements adequately. Efficient use of energy and utilization of renewable energy sources are the orders of the day when it comes to mitigating greenhouse-gas emissions and, thus, the risks of possible global climate change with unpredictable consequences for our current way of life [1, 2].

The current pattern of commercial energy-oriented development, particularly focused on fossil fuels and centralized electricity generation, 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 the rural areas and poor, and has also led to environmental degradation due to fossil fuel consumption and forest degradation. As suggested by Reddy and Subramanian [3] and Ravindranath and Hall [4], Decentralised energy planning (DEP) is one of the options to meet the rural and small scale energy needs in a reliable, affordable and environmentally sustainable way. DEP is a concept of recent origin with limited applications. Literature shows that different models are being developed and used worldwide. The central theme of the energy planning at decentralised 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 [5]. Taking into account these features, present work explains the methodology adopted for DEP by estimating the end-use energy requirement and energy resource in the region. Present work also tries to estimate the end-use energy requirement and energy resource in a typical block unit of India.

2. Models for Decentralized Energy Planning

After presenting the resources available technologies, constraints and data availability for the region, this section deals with formulating a DEP model with multiple objectives and constraints to develop an optimal energy plan at different scales is presented in this section. Energy-planning involves finding a set of sources and conversion devices so as to meet the energy requirements of all the activities 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, costs and energy requirements specific activities impose constraints on the regional energy planning exercise. Thus, the DEP turns out to be a constrained optimization problem. 'Optimization' refers to the generation of the best result given certain constraints and circumstances as introduced by the programmer [6, 7]. All optimization models have an objective function, a function one is trying to optimize and constraint functions, those functions that place a limit on the objective function. Optimization modeling therefore allows one to set certain constraints, and within those constraints determine an optimal function.

2.1 Goal programming model (GP)

All the linear programming models developed so far had a single over-riding objective, such as maximizing the revenue of the study area or maximizing the biomass energy production or minimizing the total cost of energy sources or maximizing the generation of surplus biomass, etc. However, in reality, achieving such a single objective through mathematically feasible, the outputs have little utility. Very often optimizing an energy system could involve multiple objectives namely minimizing the cost, maximizing use of local energy sources, maximizing employment, reducing emission of pollutants, etc. Thus an approach or model to optimize multiple objectives for a given set of constraints is necessary. Goal programming (GP) is powerful and flexible modeling tool to deal with the above types of multiple criteria decision-making problems in energy planning and management for sustainable development of rural areas. Goal programming provides a way of striving towards several such objectives simultaneously. The basic approach of goal programming is to establish a specific numeric goal for each of the objectives, formulate an objective function for each objective and then seek a solution that minimizes the weighted sum of deviation of nine objective functions from their respective goals. There are three possible types of goals:

1. A lower one-sided goal which sets a lower limit that we do not want to fall under (but exceeding the limit is fine).
2. An upper one-sided goal which sets an upper limit that we do not want to exceed (but falling under the limit is fine).
3. A two-sided goal which sets a specific target that we do not want to miss on either side.

GP is the most suitable technique for solving multi-objective resource allocation problems. Thus GP has been chosen for the analysis here. DEP problems have been applied most frequently in practice relative to other multi-objective decision-making techniques.

2.2 Data needs for DEP

DEP model requires the following set of data.

- Socio-economic features
- Land use: forests land, wasteland, fallow land, cropping pattern, etc.
- Energy; activities, end use devices, efficiency of devices
- Biomass production for energy; area under forests and plantations, biomass productivity, production and availability of crop residue for energy
- Energy efficiency, energy conversions, energy use
- Energy: RET (Renewable Energy Technologies) and FF (fossil fuel) technologies

- Cost of energy systems operation and maintenance cost and financial value of energy and products.

3. Description of the model

The quality and quantity of energy dictates how the societies will evolve [8]. Thus they are like "dissipative" structures [9]. For a self-organizing structure, a critical mass is required before it can sustain and grow. To achieve the goal of integrated and sustainable energy planning, energy models such as goal programming approach are used. Selection of the appropriate model is based on the requirement of data and suitability of the model at the Decentralized level to account for multiple energy needs. In a Goal Programming problem there are multiple objectives (with trade-offs) and the deviations from constraints are penalized. The optimization model used in the study consists of 7 objective functions subjected to 19 constraints. This model cannot be solved by using ordinary linear optimization and hence goal programming has been employed to solve the optimization problem. These 7 goals may be either *over* (1) or *under* (2) achieved. Deviation variables are introduced to represent the over or under achievement of the goals:
d_1^+ represents the amount of over-achievement of goal (1)
d_1^- represents the amount of under-achievement of goal (1)
d_2^+ represents the amount of over-achievement of goal (2)
d_2^- represents the amount of under-achievement of goal (2).
Note that for any goal K:
If the goal is exactly achieved: $d_1^+ = 0$; $d_1^- = 0$
If the goal is over-achieved: $d_1^+ > 0$; $d_1^- = 0$
If the goal is under-achieved: $d_1^+ = 0$; $d_1^- > 0$
In all cases all deviation variables ≥ 0
The objective of the goal programmer is to minimize deviations from the goals given by:

$$\text{Minimize: } \sum d_i^- + d_i^+ \qquad \text{where } (j = 1, 2\ldots 7) \tag{1}$$

Adding pairs of deviation variables to the goals transforms them into a set of constraints:
Subjected to,

$$L_j + w_j d_j^- - w_j d_j^+ = b_j \tag{2}$$

Where, d_j^- and d_j^+ represent the under-achievement and over-achievement of the goal respectively and w_j represents the weighing factors and b_j represents the goal values.

4. Scenarios considered for modeling

Energy scenarios provide a framework for exploring future energy perspectives, including various combinations of technology options and their implications. Many scenarios used in the literature illustrate how energy system development will affect economic development and environment. The historic trends and current priorities for the study area described earlier provide a starting point for the development of various scenarios, with and without the implementation of various technologies and policy measures. Seven scenarios are considered for analysis, namely, Business As Usual scenario (no specific policies to promote alternative energy technologies or to reduce emissions), Economic Objective Scenario (government subsidy plays an important role in this scenario) Renewable Energy Scenario (maximum use of locally available renewable energy resources), Biomass Intensive Scenario (biogas and biomass power along with energy plantations for meeting electricity needs) and Sustainable Development Scenario (high quality fuels, efficiency improvements, low environmental impacts, equitable allocation of energy resources, etc). Based on the outputs of scenarios, energy demand, cost and number people employed and CO_2, NO_x and SO_2 emissions are estimated. Though scenario approach is one of the forecasting techniques, it is especially attractive for development planning due to uncertainties arising due to various factors such as availability of resources, changing demand scenarios, technological options and cost implications. Present case scenario is for the year 2005 and BAU, RES, EOS and SDS are for the year 2020.

5. Results and Discussion

This section presents the results of energy resource allocation at Kunigal Block level for the base year (2005). Different scenarios are developed for the year 2020 with an aim to identify the optimal scenario for implementation. The selection of scenario is carried out on the basis of cost incurred in energy supply, associated emissions and use of local resources. The optimization model is solved using WINQSB package. Kunigal Block has 36 Panchayats (GPs) and 314 villages. The total area of the block is 99,110 ha and its total population is over 0.2 million. The block has 47,200 households out of which 8853 households are unelectrified. Table 1 presents a summary of the DEP for results of different scenarios, which are explained in detail in the following sections.

Table 1: Optimized energy resource allocation for Kunigal block under different scenarios

	PECS (2005)	**BAU (2020)**		**Economic objectives scenario (2020)**	**RES (2020)**		**SDS (2020)**
Activities		No priority	Equal priority	Cost (1)[b], Employment (2)[b], Efficiency and Reliability (3)[b]	ERS; Emission (1)[b], Economic (2)[b] and Security (3)[b]	BIS Cost, Employment, Local and Emissions (1)[b]	Economic, Security and Emission (1)[b]
Cooking	Biomass (65%) LPG (22%) Kerosene (13%)	Biomass (50%) LPG (50%)	Biomass (22%) LPG (21%) Biogas (57%)	Biogas (100%)	Biogas (100%)	Biogas (100%)	Biogas (100%)
Home Lighting	Kerosene (50%) Grid (50%)	Grid (100%)	PV Electricity (100%)	Biomass Electricity (100%)	PV electricity (100%)	Biomass Electricity (100%)	Biomass Electricity (100%)
Water Pumping	Diesel electricity (10%) Grid (90%)	Grid (100%)	Biomass electricity+ diesel electricity (100%)	Grid (100%)	PV electricity (100%)	Biomass electricity (100%)	Biomass Electricity (100%)
Water Heating	Biomass (100%)	Biomass (100%)	Solar thermal (100%)	Biomass using improved cook stoves (100%)	Solar thermal (100%)	Biomass using improved cook stoves (100%)	Biogas (100%)
Rural Industries	Diesel (10%) Grid (50%) Biomass (40%)	Grid (40%) Biomass (60%)	Biomass electricity+ diesel electricity (100%)	Biomass electricity (100%)	Biomass electricity (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Home Appliances	Grid (100%)	Grid (100%)	Biomass electricity (100%)	Biomass electricity (100%)	PV electricity (100%)	Biomass electricity (100%)	Biomass electricity (100%)

[a] Using improved cook stoves.

[b](1) first priority, (2) second priority and (3) third priority

Energy resource allocation in Kunigal block shows that 68% of the households used solid biomass, 22% LPG and 13% kerosene as cooking fuel under the PECS scenario. BAU (EP) scenario with equal priority for all the objective functions shows that biogas produced from the available livestock dung in the block can meet 57% of cooking energy needs and the remaining through 22% biomass and 21% from LPG. Biogas is produced from livestock dung and leaf litter collected from energy plantations raised on degraded lands. Liquefaction of biogas is not possible, so transportation of the gas is not an option. Thus, the optimized option for cooking is community biogas systems in the villages of Kunigal block under EOS, RES and SDS scenarios where 100% energy needs can be met. Under PECS and BAU (NP), traditional stoves with low efficiency are the options for water heating using solid biomass. Solar water heater is the option for heating water under BAU (EP) and RES (ERS) as over 300 days of bright sun shine is available in the region. Improved stove with efficiency higher than 25% is the option to heat water under EOS and BIS scenarios. Surplus biogas available from energy plantation appears to be the option for SDS scenario. Thus, the optimized options for water heating are surplus biogas and improved cookstoves under SDS and BIS scenarios. Water pumping energy needs under PECS are met by grid electricity (upto 90%) which is subsidized (at Rs 1 kWh) and 10% by diesel electricity which is used when grid is unavailable (shown in the Figure 1). So, PECS is largely based on grid. Kunigal is projected to have 10112 irrigation pump sets by 2020 compared to 6212 in 2005. Biomass power is the optimized solution for meeting electricity demand for agricultural pumping activity under BIS and SDS scenarios.

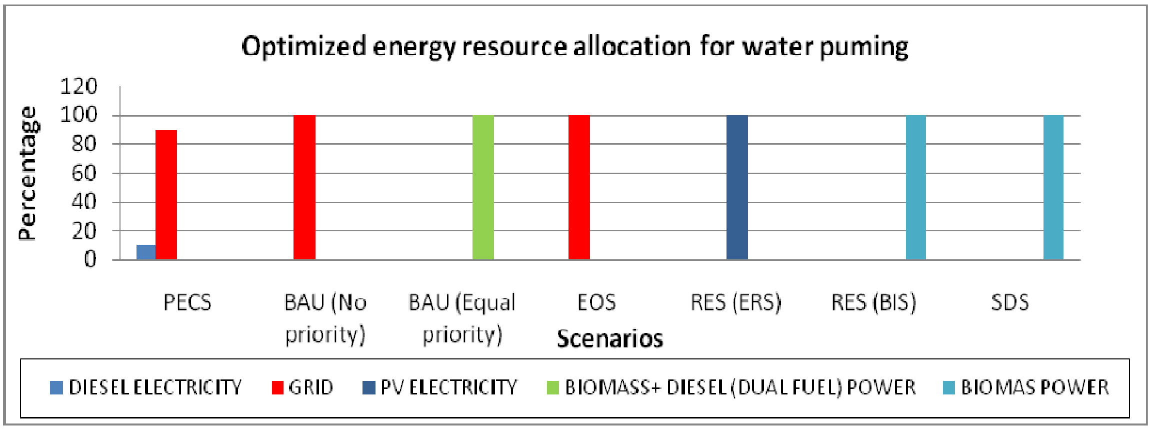

Figure 1: Optimized energy resource allocation and technology mix for meeting water pumping energy needs

Rural industries like Jaggery manufacturing and pottery depend on solid biomass while others like milk processing unit, rice mill and flour mill need electricity. Detailed Diesel (10%), biomass (40%) and grid electricity (50%) are used as source of energy for industries (shown in the Figure 2). BAU (No priority): Results show that grid electricity and biomass meet 40% and 60% of energy needs of rural industry in Kunigal block, respectively under BAU (NP). Biomass dual-fuel under BAU (EP), biomass power under EOS, RES and SDS scenarios are the optimized options for meeting the electricity needs of rural industry.

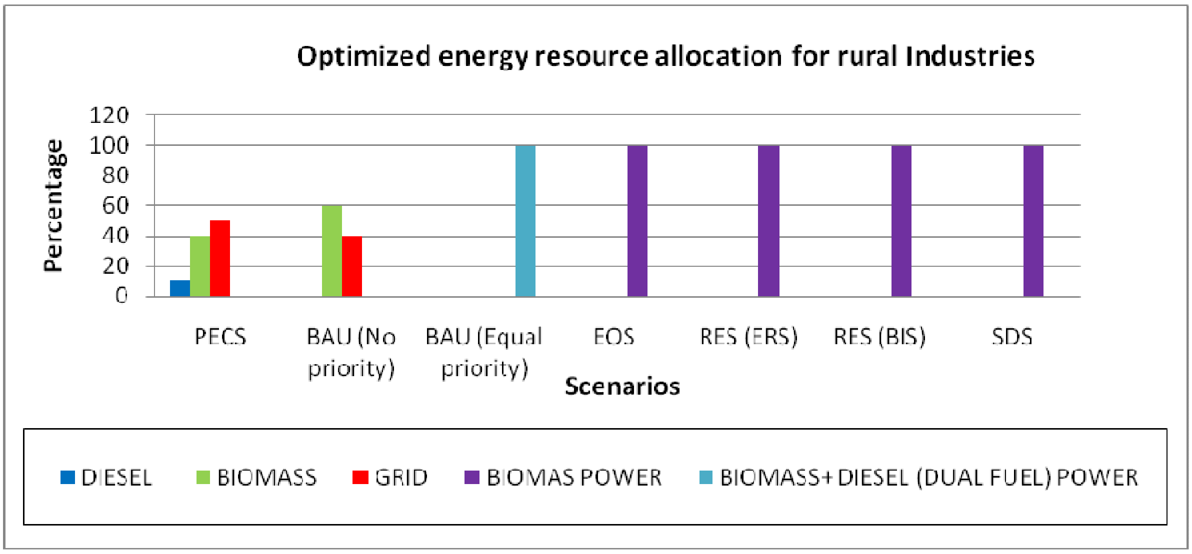

Figure 2: Optimized energy resource allocation and technology mix for rural industries in Kunigal block under different scenarios

6. Conclusions

Present work formulates the different objectives functions which have to be considered for the DEP. Present work states the constraints while formulating such problem. Although different approaches are there in the literature, Goal programming has been shown appropriate for DEP. Methodology for making objectives functions and constraints for DEP has been discussed in the manuscript. This study covers an assessment of the current energy demand and supply situation, the development of several forecasting scenarios (business-as-usual energy scenario, biomass energy intensive scenario, renewable energy scenario and sustainable development energy scenario), supply-demand balancing, the identification of intervention options, and an assessment of impacts of future trends and interventions in economic and environmental terms. Application of the present model has been shown in a typical block (Kunigal block) from India. A block constitutes a cluster of villages with distinct geographic boundary consisting of settlement, agricultural land, water bodies and any other land category, in most parts of India. Each individual village forms the distinct rural identity, each of which is generally separated by agricultural or forest land. Present model suggests that biomass-based energy systems have the potential to meet all the rural energy needs. At the block level large extent of wasteland is available (34% of geographic area). If these wastelands are used for raising energy plantation, all the electricity needs of the block could be met. High employment generation and carbon mitigation can also be achieved by adopting RES and SDS scenarios. Further, all cooking needs can be met from biogas option.

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