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Micro-level Integrated Renewable Energy System Planning

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Abstract – *The gap in supply and demand of energy can be met by optimal allocation of energy resources. Seventy percent of India's population lives in villages and their main source of livelihood is agriculture. For the socio-economic development, energy allocation at the rural level is gaining importance these days. Integrated Renewable Energy System (IRES) in rural context aims at optimal resource allocation, thereby reducing dependence on commercial energy and reducing associated environmental hazards, and opening new avenues for employment generation.*

This paper describes development of IRES in rural context of India using multi-objective goal programming model. Using this model, optimum allocation of energy resources, taking into account present energy requirement is demonstrated for a region in Northern parts of Rajasthan, India. The critical parameters for optimum allocation of energy resources are energy, demand, cost, efficiency, potential, reliability, emission, social acceptance, and employment factor. The existing values of these parameters define constraints for optimum allocation problem, which can be solved by the model. The results indicate that biomass electricity generation should be encouraged for electrical end-uses. For cooking end-use biomass, LPG, biogas and solar thermal should be promoted.

Keywords – Energy resource allocation, goal programming, integrated renewable energy system, optimization, renewable energy sources.

1. INTRODUCTION

India is primarily an agricultural country and about 70% of population resides in rural areas. India also has a huge potential in renewable energy sources [1], [2]. Renewable energy has been used for generating electrical power, heat, mechanical work, and in some cases energy for transportation. However, the proper deployment of renewable energy sources for meeting energy need is need of the day.

Integrated Renewable Energy System (IRES) in rural context aims at optimal resource allocation, thereby reducing dependence on commercial energy and reducing associated environmental hazards, and opening new avenues for employment generation. The IRES, is a combination of renewable and conventional energy technologies offer, in terms of energy supply, a higher degree of operating flexibility when compared with fossil fuel based installations. In many situations, integration is likely to be competitive with conventional technologies and meeting ambitious environmental goals [3].

For effective integration of renewable energy systems with overall energy system, the scale of energy analysis and planning should be shifted from national level to regional and local level. On this scale, a much more detailed approach to assess energy demand and supply can be adopted to take account of spatial and time distribution of renewable energy sources for effective matching of supply and demand of energy. Furthermore, the need for a regional perspective in energy planning is intended to identify the most advantageous sites and technologies in order to maximize economic benefits and minimize environmental damages [4].

Renewable energy optimization models at micro-level, aims at maximizing output, efficiency, quantity of energy resources, demand, performance of energy system and energy production and/or minimization of cost, such as annual cost, operation cost, energy system cost and capital investment. The constraints used are technology, supply, demand, efficiency, resource availability and capacity. However, certain factors such as emission associated with renewable energy utilization, workforce needed for large installation and maintenance, social acceptance of the system needs to be considered. In this paper, an approach for developing IRES at micro-level has been described.

2. REVIEW OF REPORTED ENERGY RESOURCE ALLOCATION MODEL

The single and multi objective optimization approaches to the energy resource allocation at regional level has received attention of many researches in the past. Numbers of optimization models have been developed for renewable energy allocation at both macro and micro level.

Ramakumar *et al.* [5] have developed a single objective linear programming model for the design of IRES, wherein energy resource allocation for the minimization of cost was calculated on the basis of system efficiency. Joshi *et al.* [6] had developed a linear programming model for decentralized energy planning for the three villages in Nepal. The optimization aimed at

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minimizing cost function considering mix of energy resources and conversion devices. Sinha and Kandpal [7]–[9] had developed a linear programming model for determining an optimal mix of technologies for domestic cooking, lighting, and irrigation sectors in the rural areas of India. A mathematical model involving conventional and renewable energy sources is formulated along with the detailed techno-economics of the different energy conversion methods. Minimization of cost was chosen as the main objective in all their analyses.

Single objective linear programming model for micro-level energy planning was developed for Bangalore North Taluk by [10], considering different energy sources and their end-use combinations. Multi objective non pre-emptive goal programming model was developed by [11]. The optimization was carried out with respect to cost, efficiency, local available resources, use of petroleum products, employment generation, and emissions.

Optimization models like MARKEL based on bottom-up approach for energy optimization and SGM top down macro economic model has been applied by [12] to Indian renewable energy system. Mitigation of green house gas emission had been analyzed by these modes. Suganthi and Samuel [13] have developed a macro level energy planning model which maximized the GNP-energy ratio. It determined the optimum allocation of commercial energy and renewable energy sources for reduction of emission from commercial energy utilization.

However, it has been recognized that the energy planning requires incorporation of various social and reliability objectives. Macro-level optimization for minimizing cost/efficiency ration was developed by [1] and [2]. Iniyan and Sumanthy [1] developed optimal renewable energy model for various end uses in India, wherein the optimization was carried out with respect to social acceptance, potential limit, demand, and reliability of the system. Suganthi and Williams [2] carried modeling study of renewable energy in India for 2020-21 wherein in addition to social acceptance, potential limit, demand, reliability of the system, two new constraints like emission and employment were incorporated.

The renewable energy optimization models at macro-level generally deal with maximization of output, income, quantity of energy resources, profit, demand, performance of energy system, energy production and employment generation. Also, certain models aim at minimization, of capital investment and emission from renewable energy utilization. The constraints considered are technology, supply, demand, efficiency, resource availability and capacity. Such multi objective optimization studies are few at the micro-level. Hence, in the work reported, an optimization model is developed considering all the critical parameters for the design of IRES at the micro-level.

3. METHODOLOGY

The methodology adopted involves development of a model for optimal energy resource allocation for different end uses. The resource, end use, and their combination are chosen on the basis of the availability of data and the feasibility of resource utilization in the surveyed region in Northern parts of Rajasthan. In all eleven, energy resources and six end-uses have been considered, and forty-one resource-end-use combinations have been chosen as shown in Table 1.

Table 1. Energy resource - end-use combination

Energy Resources	Cooking	Lighting	Pumping	Heating	Cooling	Appliances
Dung cake	1	---	---	23	---	---
Biomass	2	---	---	24	---	---
LPG	3	---	---	---	---	---
Kerosene	4	12	---	---	---	---
Biogas	5	13	---	25	---	---
Solar Thermal	6	---	---	26	---	---
Biogas electricity*	7	14	19	27	32	37
Biomass electricity*	8	15	20	28	33	38
PV electricity	9	16	--	29	34	39
Diesel electricity	10	17	21	30	35	40
Grid electricity	11	18	22	31	36	41

* electricity generated by biogas/biomass gasifier engine

The optimization model aims at minimization of cost, usage of petroleum products, CO_2 SO_2, NO_x emissions and maximizes system efficiency, use of local resources, employment generation, social acceptance of resources, and reliability of the system. The constraints are available potential of energy resources and end-use energy requirements in the form of cooking, lighting, pumping, heating, cooling, and appliances. In addition to these constraints operational constraints are also considered for the use of solar thermal and dung cakes for cooking end-use.

Mathematical representation of model includes defining objectives and constraints. The eight are given below:

i. Objective of minimum cost (i.e. $\sum_{i=1}^{41}(C_i X_i)$) (1)

ii. Objective of maximum system efficiency (i.e. $\sum_{i=1}^{41}(\eta_i X_i)$) (2)

iii. Objective of maximum reliability (i.e. $\sum(R_i X_i)$) (3)

where i = *7-9,14-16,19-21,28-30,33-35,38-40*.

iv. Objective of maximum utilization of local resources (i.e. $\sum(X_i)$) (4)

where i = *1, 2, 5-9, 13-16, 19-21, 24-30, 33-35, 38-40.*

v. Objective of minimum use of petroleum products (i.e. $\sum(X_i)$) (5)

where, i = *3, 4, 10, 12, 17, 22, 31, 36, 41*.

vi. Objective of maximum employment generation (i.e. $\sum_{i=1}^{41}(e_i X_i)$) (6)

vii. Objective of maximizing social acceptance of energy system (i.e. $\sum_{i=1}^{41}(S_i X_i)$) (7)

viii. Objective of minimum emissions:

Minimization of CO_2 emission (i.e. $\sum_{i=1}^{41}(CO_i X_i)$) (8)

Minimization of SO_2 emission (i.e. $\sum_{i=1}^{41}(SO_i X_i)$) (9)

Minimization of NO_x emission (i.e. $\sum_{i=1}^{41}(NO_i X_i)$) (10)

The optimization is subject to following ten constraints:

1. Cooking energy requirement (i.e. $\sum_{i=1}^{11}(X_i) \geq$ Total cooking energy requirement) (11)
2. Lighting energy requirement (i.e. $\sum_{i=12}^{18}(X_i) \geq$ Total lighting energy requirement) (12)
3. Pumping energy requirement (i.e. $\sum_{i=19}^{22} x_i \geq$ Total pumping energy requirement) (13)
4. Heating energy requirement (i.e. $\sum_{i=23}^{31} x_i \geq$ Total heating energy requirement) (14)
5. Cooling energy requirement (i.e. $\sum_{i=32}^{36} x_i \geq$ Total cooling energy requirement) (15)
6. Appliances energy requirement (i.e. $\sum_{i=37}^{41} x_i \geq$ Total appliances energy requirement) (16)
7. Limit for solar thermal usage for cooking: The solar thermal cookers cannot cook all varieties of food and therefore they are not meeting the total cooking requirement. As such, solar thermal cookers can be used for low-temperature cooking purposes only, which form approximately 20% of the total cooking requirement [7]. Therefore, for this reason, the potential limit for the use of solar thermal cookers is considered to be 20% of the total cooking energy requirement. The constraint function is:

   $\sum(X_6) \leq$ *20%* of the total cooking energy requirements (17)

8. Limit for use of dung cake for cooking and heating: Cooking pattern of the region indicate that the dung cakes are not fully consumed for the cooking and heating applications. It is observed that in most of the families 10-25% dung available is used for making dung cakes. Therefore, it is assumed that 75% of the dung cakes produced are used for cooking and heating applications. Therefore, constraint function is:

$$\sum\left(\frac{X_i}{\eta_i}\right) \leq 75\% \text{ of the dung availability,} \tag{18}$$

where i= dung cake for cooking and heating end-use.

9. Potential limit for biogas energy (i.e. $\sum\left(\frac{X_i}{\eta_i^{'}}\right) \leq$ Available biogas energy (19)

where i = energy resource-end-use combinations for biogas energy source, and η’ = end-use device efficiency)

10. Potential limit for biomass energy (i.e. $\sum\left(\frac{X_i}{\eta_i^{'}}\right) \leq$ Available biomass energy (20)

where i = energy resource-end-use combinations for biomass energy source and η’ = end-use device efficiency)

Where, C is the unit cost of energy, η the efficiency of the system, X is the quantum of energy, R the reliability of the system, e the employment generation factor, S the social acceptance factor of the end-use resource combination, CO, SO, NO the emission in resource end-use combination, subscript i denotes the end-use resource combination.

The unit cost of energy used in the optimization model is taken from current published data. The cost of solar photovoltaic electric conversion is estimated to be Rs. 15/kWh [14] and diesel electricity is estimated to be Rs. 15/kWh (based on present cost of diesel) and the cost of grid electricity for household and agriculture applications is estimated to be Rs. 3/kWh and Rs. 0.75/kWh respectively [15]; the cost of the biomass gasifier electric conversion and biogas electric conversion systems is estimated to be Rs. 2.50/kWh and Rs. 1.25/kWh respectively [14]; the cost of dung, biomass, LPG, and kerosene is estimated as Rs. 1/kg, Rs. 3/kg, Rs. 21.8/kg, and Rs. 10/lit respectively.

The energy system efficiency is calculated by multiplying the external efficiency of energy source and the end-use device efficiency. The external efficiency is the energy source efficiency just before the end-use point. The energy system efficiencies used in the model are: 12% for solar photovoltaic system [16], 23% diesel electric system, 18.40% grid power system, 21.89% biomass gasifier conversion system, 28.16% for the biogas electric conversion system, 16.15% biomass direct combustion, 40% solar direct thermal, 44% biogas system, 32.40% kerosene system and 36% for LPG system [1], [17].

The reliability factor of 0.1 at 10000 hours for solar photovoltaic system, 0.9 at 10000 hours for biomass energy and 0.9 at 10000 hours for biogas energy system is used in the model as reported by [18].

Table 2 provides details of the number of people employed in developing various energy resources, along with the total consumption of energy resources. Thus, for every million kWh of coal energy consumed, on average, 1.947 persons were employed. Considering the same values for consumption by household sector, the employment potential per million kWh of the *net* coal energy consumed has been calculated by accounting system efficiency [17].

Social acceptance factor for solar, biomass/biogas, and commercial energy sources are 7.12, 10.49, and 74.49 respectively is used in the model [1].

Stoichiometric quantity of pollutants per weight of fuel can be accurately determined. The stoichiometric composition of energy resource, available in India is shown in Table 3a and b.

The emission rates of carbon oxides for end-use can be obtained by using following formula:

$$= \frac{CarbonContent}{(CalorificValue)x(SystemEfficiency)} x3.6 \; Kg/kWh \tag{21}$$

Similarly, emissions rates of sulphur oxides and nitrogen oxides for end-uses are calculated.

Based on the objectives and constraints the multi objective goal programming model has been built and is discussed below:

$$\text{Minimize} \sum d_j^- + d_j^+ \quad (j = 1,2,\ldots,10) \tag{22}$$

Subject to,

$$ObjectiveFunction_j + w_j d_j^- - w_j d_j^+ = b_j \tag{23}$$

Where, d_j^- and d_j^+ are the underachievement and overachievement of the goal respectively.

Each of the objective function is referred as goal for the optimization. First, all the objectives are individually optimized, and the optimum value for each of the objectives are fixed as the corresponding goal b_j. Worst possible value, i.e minimum value for the maximization objectives and maximum value for the minimization objective for the objective function is calculated and referred as L_j. Then the weighing factor w_j for each of the goal is calculated as difference in the value of goals and the worst value of the goals.

Table 2. Gross employment potential of energy sources [17]

Energy source	Number of persons employed	Consumption (10^9 kWh)	Number of employees (per million kWh)
Coal (including soft coke and petroleum)	610,600	313.59	1.947
Petroleum and natural gas	35,629	263.92	0.135
Grid electricity	---	---	6.9
Non commercial resources	2,806,000	11.22	250

Table 3a. Stoichiometric composition of solid and liquid fuels (weight %) [17]

Energy Resource	Carbon (%)	Hydrogen (%)	Sulphur (%)	Nitrogen (%)	Oxygen (%)	Calorific Value (MJ/kg)
Dung cake	33.40	3.90	0.07	0.90	---	11.76
Biomass	50.00	6.00	---	0.10	40.50	15.00
LPG	82.70	17.30	0.02	---	0.10	46.00
Kerosene	86.00	13.30	0.50	0.10	---	44.00
Diesel	87.00	10.70	1.20	0.10	---	42.33

Table 3b. Stoichiometric composition of gaseous fuels (volumetric %) [17]

Energy Resource	Methane (%)	Ethane (%)	Propane (%)	Carbon monoxide (%)	Carbon dioxide (%)	Hydrogen sulphide (%)	Nitrogen (%)	Oxygen (%)	Calorific Value (MJ/m^3)
Natural gas	93.35	3.13	0.10	---	0.49	---	1.93	---	39.47
Biogas	50.10	---	---	0.90	35.8	7.2	---	6.00	20.14
Grid electricity (weightings) Coal:65% Oil:3% Gas:1%	---	---	---	---	---	---	---	---	3.6

Table 4. Standard adult equivalents used in analysis [20]

Family Size	Standard Adult Equivalent
Men 18-59 yr	1
Women 18-59 yr	0.8
Men >59 yr	0.8
Women >59 yr	0.8
Boys 5-18 yr	0.5
Girls 5-18 yr	0.5
Kids 1-5 yr	0.35
Child <1 yr	0.25

4. CASE OF IRES

Renewable energy resources play a significant role in supplying the energy needed in the rural region of the developing countries for improving the living environment and for economic development. To design IRES at micro-level, the region in which energy needs are both for thermal and electrical applications are particularly suitable for design of IRES at micro-level. Moreover region should be rich in resources both renewable and conventional. On the basis of these considerations, such region is identified in Rajasthan, India for optimizing of IRES energy sources at micro level.

Details of Survey

Energy use patterns are closely linked to agro-climatic and socio-economic conditions. Energy problems in rural areas are closely linked to soil fertility, landholding, livestock holding, etc. Energy planning of any region should be based on the existing levels of energy consumption. However, the information available in published form is either at the sate level or at the national level. Devdas [19] highlighted that the regional developmental activities have to be based on detailed information from each sector. Hence, a detailed energy survey was conducted at *Panthadiya* village of Jhunjhunu district located in Northern part of Rajasthan, India in by visiting and consulting, to understand the household and agriculture energy use patterns in various socio-economic zones. For this purpose, survey was conducted to investigate household and agriculture energy consumption due to cooking, lighting, pumping, cooling, heating and appliances energy needs. The survey consists of collecting secondary and primary data. The secondary data such as landholding, demography, and livestock population, was collected form respective government offices. The secondary information was analyzed to select households for stratified sampling (based on landholdings and community) for the energy survey.

The classification adopted for the primary survey based on landholding was: (i) landless, (ii) small farmers

(0±1 ha), (iii) medium farmers (1±2.5 ha), (v) large farmers (2.5±5ha) and (vi) very large farmers (>5ha), keeping in mind the fragmented landholding scenario of the village. The data on number of households and cattle is estimated by consulting Sarpanch and senior citizens of the village.

During the survey, it is observed that only 2 to 3 houses in the village are using pumps for pumping end-use. Therefore, the pumping end-use energy requirement for household is neglected for the present study. The energy needs were estimated for various household and agriculture end-uses such as cooking, pumping, heating, cooling, lighting and appliances. The detailed survey questionnaire was developed to collect relevant data for various end-use energy requirements per household.

The primary survey has considered only six important end-uses and for each end-use commonly used devices have been considered. This survey was conducted during December 2004 to April 2005, which is considered to be the base year for this study (2004-05). The equations used to compute the energy requirements for device-end use combination are as follows:

Energy consumption = (Number of devices used) x (energy consumed for 1 hour of usage) x (Average number of hours of usage of the device) x (Number of days of usage in a year) (24)

Computation of Per Capita Energy Consumption = *EC/p* (25)

where, EC = energy consumed per day and p = number of adult equivalents, for whom the energy is used as shown in Table 4 [20].

The average estimated energy requirement per person for end-uses, in the *Panthadiya* village is calculated by using above equations and the result of analysis is shown in Table 5.

Table 5. End-use energy requirement for *Panthadiya* village

End-use	Energy requirement per person, per day, kWh	Annual energy requirement MWh/yr
Cooking	1.495	0.895 x 10^3
Lighting	0.10	0.060 x 10^3
Pumping*	---	* 0.790 x 10^3
Heating	0.0002	0.120
Cooling	0.212	0.127 x 10^3
Appliances	0.055	0.033 x 10^3

* *58 tube-well pumps of 12.5 hp used for 5 hours per day*

Table 6. Goal value, worst value, and weighting factors for the objectives

Objective function	Goal (b_j)		Worst value (L_j)		Weighting factor (w_j)
Cost	Min	1.215x10^6	Max	28.577x10^6	-27.362x10^6
Efficiency	Max	0.575x10^6	Min	0.268x10^6	0.307x10^6
Reliability	Max	1.805x10^6	Min	0.823 x10^6	0982x10^6
Local resources	Max	1.905x10^6	Min	0	1.905x10^6
Petroleum products	Min	0	Max	1.905x10^6	-1.905x10^6
Employment	Max	1217.70	Min	0.34	1217.36
Social acceptance	Max	1.419x10^6	Min	0.162x10^6	1.257x10^6
Carbon emission	Min	0.239x10^6	Max	1.474x10^6	-1.235x10^6
Sulphur emission	Min	0	Max	0.046x10^6	-0.046x10^6
Nitrogen emission	Min	86.27	Max	0.013x10^6	-0.013x10^6

5. RESULTS AND DISCUSSIONS

This section presents the results of energy resource allocation in *Panthadiya* village for the base year (i.e. 2004-05). Different scenarios are developed with an aim to identify the feasible scenario for implementation. The selection of scenario is carried out on the basis of cost incurred in energy consumption, associated emissions, and use of local resources. The developed optimization model is solved using WINQSB package on computer. Six different scenarios were developed, with priorities for the objectives. Details of each scenario and the optimum allocations are discussed subsequently.

Present Energy Consumption Scenario

The present energy consumption pattern is shown in Table 6 and it shows that the study village is dependent on grid electricity for end-uses such as lighting, pumping, cooling and appliances. For thermal end-uses such as cooking and heating mainly biomass and dung cakes are used. Heavy dependence on grid electricity is mainly due to its present lower cost for the region and social acceptance of commercial energy systems. The cost of energy associated with present energy scenario is Rs. 5.38 millions at the present prices and the associated emissions are 3829.05, 27.05 and 3.66 tons/year for CO_2, NO_x, and SO_2, respectively. The present energy consumption scenario is taken as a reference scenario for the purpose of comparison of projected scenarios in terms of associated total energy cost, maximum use of local resources, employment generation and emissions.

Development Scenarios

Optimal scenario is described in terms of goal values for individual objective functions by maximization or minimization. The goal value for an objective function is obtained by optimizing each objective function individually by linear programming technique. Next, the multi-objective optimal scenario is obtained by optimizing all objective functions simultaneously by pre-emptive goal programming method. In this method, weighting factors for individual objective function are determined. The weighting factor for an objective function is the difference between goal value and the goal obtained by reversal of optimization i.e. for maximization to minimization or minimization to maximization. The goal value obtained by reversal of optimization from maximization or minimization is called the worst value. The goal, worst and weighting factor for objective functions are shown in Table 6.

Scenario 1 – Equal Priority Scenario: In this scenario, all the objective functions are taken into account while arriving at energy resource allocation. This scenario is developed without assigning priority to objective functions. The optimal energy resource allocation pattern is shown in Table 7. The results of optimization without assigning priority to objective function show that, , use of biomass, LPG, solar thermal and PV electricity should be promoted for cooking end-use, PV electricity for lighting, cooling and appliance end-uses, biomass electricity for pumping end-use, and solar thermal for heating end-use. Energy resource allocations in scenario1 also show that biomass can meet 30.00%, LPG can meet 37.65% and PV electricity can met 12.35% of total cooking energy requirement. Similarly, PV electricity can meet 100% of lighting, cooling and appliance end-use requirement.

The associated cost and emission with scenario 1 are tabulated for comparing it with the present energy scenario as shown in Table 8. The comparison of present and scenario 1 show that the cost associated with scenario 1 is almost two and half times the present cost of energy consumption, and the associated emissions are reduced. The selection of energy scenario is primarily guided by the cost incurred, and also by avenues for higher employment generation, use of local resources, and associated emissions. Since, the cost associated is higher with this scenario therefore scenario 1 should not be promoted for implementation. In order to implement this scenario, cost of PV electricity should be decreased.

Hence, different scenarios are developed by varying the priority of objective functions to reduce the associated cost.

Scenario 2 – Priority Scenario: In this scenario, the objective functions are divided into three categories: economic, security-acceptance and environmental. Under economic objectives cost of energy, system efficiency, reliability of energy system, and employment generation are considered; while under security-acceptance, minimization of imported petroleum products, maximization of local resources and social acceptance are considered. The environment related objectives include the minimization of CO_2, SO_2 and NO_x.

In this scenario, the priority of environment emissions is varied from one to three and the economic objectives have always given higher priority as compared to security-acceptance objectives. The priorities are shown in Table 9 and the results of energy resource allocation are shown in Table 7.

Case 1: The results of optimization show that when environment objectives are given higher priority, PV electricity should be promoted for lighting, cooling and appliance end-uses since the energy source is emission free. There are no constraints on the availability of the solar energy in the village, since it is available most of the time during a year and is observed to be available for more than 270 days in a year. The results of analysis show that grid electricity is only to be preferred for pumping end-use from the point of view of present subsidized prices.

Case 2: The results are almost similar as observed case 1 except the allocation of dung cake for cooking end-use. In this case biomass energy share in cooking energy requirement is reduced from 48.83% to 27.60%. Solar thermal and PV electricity is also allocated for cooking end-use due to decrease in the environmental priority from one to two.

Case 3: The results of optimization when economic objectives are given higher priority than security-acceptance and environment objectives show that large portion of LPG (33.41%) and biomass electricity (39.44%) is to be promoted for cooking. The results of optimization show that PV electricity (7.15%) should also be allocated for cooking end-use. Solar thermal with its low cost, will meet 20% of the cooking energy requirement, and total heating energy requirement. Biomass electricity should be promoted for pumping, cooling and appliance end-uses and PV electricity for cooling end-use due to increase in priority to social-acceptance objectives.

The associated cost and emission with scenario 2 are tabulated for comparing it with the present energy scenario as shown in Table 8. The comparison of cost associated in present energy consumption scenario and scenario 2 show that the cost increases by many folds, when environment emissions are given a priority and can be observed in case 1 and 2 as shown in Table 8. If the security-acceptance objectives are given more priority it also results in higher cost than present energy consumption scenario. Therefore, these scenarios should only be preferred only when the reduction in environment emissions is the priority. In order to implement these scenarios, cost of PV electricity should be decreased.

Different scenarios are again developed to reduce the associated cost by varying the priority of economic objectives as discussed in scenario 3.

Scenario 3 – Economic Objective Scenario: In this scenario, changes are made within the priorities of economic objectives. Priority to cost objective function is varied from one to three, and the employment generation is always given higher priority as compared to efficiency and reliability. In this scenario, the other objective-functions have given lowest priority. The chosen priorities are shown in Table 10 and the results of energy resource allocation are shown in Table 7.

Table 7. Energy resource allocation for *Panthadiya* village in different scenarios

End-uses	Energy Consumption scenarios						
	Present energy consumption scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Cooking	1. Dung cake (15%) 2. Biomass (70%) 3. LPG (15%)	1. Biomass (30.00%) 2. LPG (37.65%) 3. Solar Thermal (20%) 4. PV electricity (12.35%)	1. Dung cake (13.30%) 2. Biomass (48.83%) 3. PV electricity (37.87%)	1. Biomass (6.59%) 2. Solar Thermal (20%) 3.Biomass electricity (73.41%)	1. Biomass (22.24%) 2. LPG (57.76%) 3. Solar thermal (20%)	1. Biomass (17.32%) 2. LPG (22.96%) 3. Biogas (39.72%) 4. Solar thermal (20%)	1. Biomass (17.32%) 2. LPG (22.96%) 3. Biogas (39.72%) 4. Solar thermal (20%)
			1. Biomass (27.60%) 2. Solar thermal (20.00%) 3. PV electricity (52.40%)	1. Solar thermal (20%) 2. Biomass electricity (80%)	1. Biomass (22.24%) 2. LPG (57.76%) 3. Solar thermal (20%)		1. Biomass (17.32%) 2. LPG (22.96%) 3. Biogas (39.72%) 4. Solar thermal (20%)
			1. LPG (33.41%) 2. Solar Thermal (20%) 3. Biomass electricity (39.44%) 4. PV electricity (7.15%)	1. Solar Thermal (20%) 2. Biomass electricity (80.00%)	1. Biomass (22.24%) 2. LPG (18.10%) 3. Biogas (39.66%) 4. Solar thermal (20%)		
Lighting	Grid elect. (100%)	PV elect. (100%)	PV elect. (100%)	Biomass electricity (100%)	Biomass elect. (100%)	Biomass elect. (100%)	Biomass elect. (100%)
			PV elect. (100%)	Biomass elect. (100%)	Biomass elect. (100%)		
			PV elect. (100%)	Biomass electricity (100%)	Biomass elect. (100%)		Biomass elect. (100%)
Pumping	Grid elect. (100%)	Biomass electricity (100%)	Grid electricity (100%)	Biomass electricity (100%)	Biomass electricity (100%)	Biomass elect. (100%)	Biomass elect. (100%)
			Grid electricity (100%)	Biomass electricity (100%)	Biomass electricity (100%)		
			Biomass electricity (100%)	Biomass electricity (100%)	Biomass electricity (100%)		Biomass elect. (100%)
Heating	1. Dung cake (20%) 2. Biomass (80%)	Solar Thermal (100%)	Solar thermal (100%)	Solar thermal (100%)	Solar thermal (100%)	Solar thermal (100%)	Solar thermal (100%)
			Solar thermal (100%)	Solar thermal (100%)	Solar thermal (100%)		
			Solar thermal (100%)	Solar thermal (100%)	Solar thermal (100%)		Solar thermal (100%)
Cooling	Grid elect. (100%)	PV electricity (100%)	PV electricity (100%)	Biomass elect. (100%)	Biomass elect. (100%)	Biomass elect. (100%)	Biomass elect. (100%)
			PV electricity (100%)	Biomass elect. (100%)	Biomass elect. (100%)		
			PV electricity (100%)	Biomass elect. (100%)	Biomass elect. (100%)		Biomass elect. (100%)
Appliances	Grid elect. (100%)	PV elect. (100%)	PV elect. (100%)	Biomass elect. (100%)	Biomass electricity (100%)	Biomass elect. (100%)	Biomass elect. (100%)
			PV elect. (100%)	Biomass elect. (100%)	Biomass electricity (100%)		
			PV elect. (100%)	Biomass elect. (100%)	1. Biomass elect. (99%) 2. PV elect. (1%)		Biomass elect. (100%)

Case 1: The results of optimization when energy cost is assigned the highest priority show that biomass and biomass electricity for cooking; and solar thermal for cooking and heating should be preferred, due to their low cost and higher potential for employment. Biomass electricity is to be promoted for lighting, cooling and appliance end-uses due to its low cost (Rs. 2.50/kWh) compared with other energy resources. Biomass electricity should be promoted for pumping end-use due the lower costs as Rs. 2.50/kWh and is local energy resource.

Case 2: The results of optimization when employment generation is assigned the higher priority than cost, results in the almost same energy resources allocation for the end-uses, except the use of biomass electricity for cooking in place of biomass. Therefore, a decrease in the priority of the cost function from one to two does not change the energy resource allocation.

Case 3: The results of optimization when employment generation is assigned the highest priority and cost is given the lower priority, as in case 3 show the similar energy resources allocation as observed in case 2. The biomass electricity is to be allocated for different end-uses, due to high employment potential in bio-energy resources at the lesser cost. Therefore, a decrease in the priority of the cost function from one to three does not change the energy resource allocation.

The associated cost and emission with scenario 3 are tabulated for comparing it with the present energy scenario as shown in Table 8. The comparison of costs associated with present energy consumption scenario and scenario 3, show that the cost and environmental emissions are reduced for all the cases. In all the cases, biomass electricity is to be promoted for lighting, pumping, cooling and appliance end-uses, which is due to availability of biomass in the village. Therefore, case 2 scenario should be preferred for implementation which will have higher employment generation potential due to the use of local available resources at the optimal cost.

Table 8. Comparison of cost and emission for present energy consumption scenario and different scenarios

		Cost associated, million Rs/year	*Emissions associated*		
			CO_2, tons/year	*SO_2, tons/year*	*NOx, tons/year*
Present energy consumption scenario		5.38	3829.05	3.66	27.05
Scenario 1		13.16	1630.82	0.02	3.02
Scenario 2	*Case 1*	15.43	2679.47	2.49	20.67
	Case 2	16.91	1405.79	1.58	7.04
	Case 3	11.43	618.83	0.02	1.04
Scenario 3	*Case 1*	5.89	1096.68	---	2.21
	Case 2	5.83	864.00	---	1.75
	Case 3	5.83	864.00	---	1.75
Scenario 4	*Case 1*	6.20	1615.20	0.04	2.86
	Case 2	6.20	1615.20	0.04	2.86
	Case 3	5.17	1621.72	29.68	2.86
Scenario 5		5.06	1445.11	29.74	2.48
Scenario 6	*Case 1*	5.06	1445.11	29.74	2.48
		5.06	1445.11	29.74	2.48

Table 9. Priority of objectives

Objectives	Case 1	Case 2	Case 3
Emissions	1	2	3
Economic	2	1	1
Security-acceptance	3	3	2

Table 10. Priorities of economic objectives

Objective	Case 1	Case 2	Case 3
Cost	1	2	3
Employment generation	2	1	1
Efficiency	3	3	2
Reliability	3	3	2

Table 11. Priorities for security-acceptance objectives

Objectives	Case 1	Case 2	Case 3
Petroleum products	1	2	3
Local resources	2	1	2
Social acceptance	3	3	1

When the employment generation is assigned higher priority than reliability and efficiency of energy system, the cost associated in achieving the scenario 3 increases as compared to present energy consumption scenario. Therefore, this scenario should only be preferred when the employment generation is the priority.

Different scenarios are again developed by varying the priority of security-acceptance objectives to find acceptable scenario at the lower cost and higher employment generation options as discussed in scenario 4.

Scenario 4 – Security-Acceptance Scenario: In this scenario, the security-acceptance objectives functions are given the higher priorities and other objective-functions are given the lowest priority. The chosen priorities are shown in Table 11 and the results of energy resource allocation are shown in Table 7.

The results of optimization in case 1 and case 2 show that LPG and solar thermal is to be promoted for cooking energy requirements, since minimum use of petroleum products lead to maximum use of local resources. All the cases result in almost similar energy resources allocation pattern for the end-uses except the use of biomass and biogas for cooking end-use. Therefore, increase in the priority of the social acceptance factor from three to one does not major change the energy resource allocation.

The associated cost and emission with scenario 4 are tabulated for comparing it with the present energy scenario as shown in Table 8. The comparison of present energy consumption scenario and scenario 4 shows that the cost associated in the cases 1 and 2 are higher than in reference scenario i.e. present energy consumption scenario, and the associated emissions are reduced. Therefore, these scenarios should only be preferred when the maximum use of local resources is the objective. The results of optimization when social acceptance and use of local resources objective is given a higher priority than use of petroleum products objective show the reduction in associated cost and environment emissions. It can be seen that the SO_2 emissions increases from 3.66 to 29.68 *Tons*/year due to the allocation of biogas for cooking. Therefore, case 3 of security-acceptance scenario should only be preferred when the social acceptance and use of local resources is the priority. Different scenarios are developed by assigning higher priority to cost and employment generation to find acceptable scenario at the lower cost and higher employment generation options as discussed in scenario 5.

Scenario 5 - Cost-Employment Generation Scenario: In this scenario, cost and employment generation objective functions are given a higher priority as compared to other objective functions. This scenario is important, where the objective of energy resource allocation is socio-economic development. The results of energy resource allocation are shown in Table 7.

The results of optimization show that biomass, biogas and solar thermal should be promoted for cooking, and solar thermal for heating end-use. LPG (22.96%) is to be allocated for cooking due to the constraint of biogas and biomass energy resource potential. Biomass electricity is to be promoted for lighting, pumping, cooling, and appliance end-uses due to their high employment generation potential at the lower costs.

The associated cost and emission with scenario 5 are tabulated for comparing it with the present energy scenario as shown in Table 8. The comparison of present energy consumption scenario and scenario 5 shows that the cost associated is lower than the present cost of utilization, and the associated emissions are reduced. Therefore, this scenario should be preferred only when the maximum use of local resources and employment generation are the objectives.

Scenario 6 – Efficiency Scenario:

Case 1: In this scenario, the maximization of system efficiency is given the first priority and the other objective functions are given a priority of two. The results of energy resource allocation are shown in Table 7.

The results of optimization resulted in similar results as observed in scenario 5 and show that, biomass electricity is to be promoted for lighting, pumping, cooling and appliance end-uses. The energy allocation is due to the system efficiency of 21.89%. Biomass and biogas for cooking, and solar thermal for cooking and heating is to be allocated due to their resource availability and associated system efficiency of 16.15%, 44% and 40% respectively.

Case 2: In this case due to technological advancement, increase of 25% is assumed for all renewable energy sources. The optimization problem is carried for new values of system efficiency. The optimization results for energy resource allocation are shown in Table 6.

The results of optimization for case 2 show that even though 25% increase in system efficiency of renewable energy sources, do not change the energy resource allocations as observed case 1. Thus, the solution is found to be not sensitive to 25% increase in the system efficiency.

The associated cost and emission with scenario 6 are tabulated for comparing it with the present energy scenario as shown in Table 8. The comparison of present energy consumption scenario and scenario 6 shows that the cost and emissions associated, in all the cases is still higher than the present cost of utilization. Therefore, these scenarios should not be preferred for implementation.

6. CONCLUSIONS

A multi objective goal programming model for energy resource allocation has been developed. This model gives decision makers a tool to use in making strategic decisions on matters related to energy policy. The objective of this work is to determine the optimum allocation of energy resources to six end-uses in the household and agriculture sector in *Panthadiya* village. Eleven different energy resources were selected, based on either their present or potential availability in village. The results of analysis show that the present cost of energy consumption can be reduced by implementing scenario 6. This scenario results in cost reduction of 1.88% of present cost of energy per year and reduction of 13.98%, 25.98% and 26.67% in CO_2, SO_2 and NO_x, respectively. Due to the use of local energy resources, this scenario will satisfy the goal of employment generation at the reduction in environment emissions. Moreover, Scenario 6 is found to be not sensitive for 25% increase in energy system efficiency due to expected technological advances. Scenario 6 resulted in the following conclusions:

- To meet the cooking energy demands: biomass, LPG, biogas and solar thermal should be promoted.
- To meet the lighting energy demands: biomass electricity should be promoted.
- To meet the pumping energy demands: biomass electricity should be promoted.
- To meet the heating energy demands: solar thermal should be promoted.
- To meet the cooling energy demands: biomass electricity should be promoted.
- To meet the appliances energy demands: biomass electricity should be promoted.

Biomass electricity generation should be encouraged for all end uses. Grid electricity for all end-uses should be discouraged. Solar photovoltaic can be used for small-scale applications, where the connections from the grid are expensive and there are no other economically competing technologies. This resource will become more prominent in near future, especially when environmental quality receives a higher importance.

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