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A new approach to micro-level energy planning—A case of northern parts of Rajasthan, India

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Abstract

The gap in demand and supply of energy can be met by optimal allocation of energy resources. In developing countries like India, demand for energy is constantly rising. Conventional energy supply options have failed to cope up with this increase. Therefore, it is required to plan the allocation at micro-level also. A micro-level energy planning thus becomes pragmatic for sustainable development. Micro-level energy planning 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 considers energy consumption patterns in northern part of Rajasthan, India to arrive at micro-level plan using multi-objective goal programming approach. Optimal energy resource allocation for various end-uses has been deduced. In conventional micro-level energy planning the region is defined as village or taluk or district. Inter-village energy mix have been attempted to define region for energy planning in the present text. The results of inter-village mix show that the energy mix of two villages at micro-level results in better utilization of available energy sources compared to an individual village. The methodology suggested gives the flexibility of defining a region to the energy planner.
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Keywords: Micro-level energy planning; Goal programming; Inter-village mix

Contents

1. Introduction

In developing countries, constant endeavor is to evaluate various alternatives for meeting increasing energy demand from techno-economic point of view. A large number of models have been developed for energy planning. However, these models are suitable for centralized energy supply system of conventional energy supply system using mainly conventional sources. It has resulted in inequities, external debt and environmental degradation [1]. In the present system, the energy supply to the region remains inadequate, erratic and unreliable due to increasing pressure from urban centres. As a result, development of economically productive activities in rural areas has been far slower than in the urban areas.

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The role of centralized (macro) energy planning is questionable when it comes to addressing the variations in socio-economic and ecological factors of a region [2]. Decentralized (micro) energy planning is in the interest of efficient utilization of resources. The regional planning mechanism takes into account various available resources and demands in a region.

Rural areas in developing countries essentially depend on traditional fuels for all their energy requirements, such as thermal and electricity requirements. Also, dual energy and environment crisis, i.e. a lack of sufficient energy sources on one hand and the exploitation of forests for fuel-wood creating ecological imbalances on the other hand are issues to be addressed [3].

Ramakumar et al. [4] have developed a single objective linear programming model for the design of integrated renewable energy system (IRES), wherein energy resource allocation for the minimization of cost was calculated on the basis of system efficiency. Joshi et al. [5] had developed a linear programming model for decentralized energy planning for the three villages in Nepal. The optimization aimed at minimizing cost function considering mix of energy resources and conversion devices. Sinha and Kandpal [6–8] 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 Srinivasan and Balachandra [9], considering different energy sources and their end-use combinations. Multi-objective non pre-emptive goal programming model was developed by Ramanathan and Ganesh [10]. The optimization was carried out with respect to cost, efficiency, local available resources, use of petroleum products, employment generation, and emissions.

In the present text, a generalized multi-objective goal programming model based on a linear function has been developed for optimizing the energy supply. The model can take into account the resource constraints with respect to supply, efficiency and utilization. The model is also capable of carrying out detailed sensitivity analyses. The main purpose of this study is to analyse the viable technical options and resource utilization option for different end-uses for fast track development of the region. The purpose of imposing constraints on certain activities in the model is to ensure that the end-use demands are met.

The model has been employed for rural household sector of Jhunjhunu district located in northern part of Rajasthan, India. The data used in the study are based on detailed household energy survey of four neighboring villages.

2. Region under investigation

Energy demand patterns in northern part of Rajasthan point towards the rural agriculture nature of its economy. Detailed survey was conducted in *Panthadiya* village, a village in *Morva* Panchayat, which is a study village, for the micro-level energy planning. The *Panthadiya* village is also considered to study inter-village energy resource allocation with the neighboring villages namely *Bisanpura 1st*, *Bisanpura 2nd*, *and Morva*. Table 1 shows information related to demography and livestock of the surveyed villages.

The secondary data available with government offices is compiled over a period of several years by the concerned officials. Furthermore, data regarding several aspects having an important bearing on rural energy planning are not readily available in the published statistics [11–13]. Hence, survey was conducted for the household energy needs using multi-stage schedules for the present investigation. The secondary data was analyzed to select households by stratified sampling, based on landholdings and community, for the energy survey. This survey was conducted during December 2004–October 2005, which is considered to be the base year for this study (2004–2005).

Table 2 shows the variation in secondary and primary data for number of households in the surveyed villages. The variation in the data is attributed to methodology adopted for estimating number of households. The secondary data for number of households as reported in the Census, 2001 [14] is calculated on the basis of landholdings as per the government records. It is observed that, in most of the families, operational landholdings records available in government offices are not updated. Therefore, primary data on actual number of households is estimated by consulting *Sarpanch* and senior citizens of respective villages. The estimated primary data on number of households is then used to conduct the survey.

Table 3 shows the population of the villages as reported in Census 1991 and Census 2001. The recorded population growth rate for a decade is 0.29, 0.21, 0.07, and 0.19 for *Panthadiya*, *Bisanpura 1st*, *Bisanpura 2nd*, and *Morva* village, respectively.

Exponential regression analyses were carried out for estimating future populations. The estimated populations for the surveyed villages in the present year are shown in Table 4.

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), (iv) large farmers (2.5 ± 5 ha) and

Table 1
Demographic information and livestock population of surveyed villages

Name of the village	Population	Total land (in ha)	Irrigated land (in ha)	Number of cows	Number of buffalos	Number of camels
Panthadiya	1483	522	481	366	340	36
Bisanpura 1st	647	190	169	239	111	11
Bisanpura 2nd	717	185	167	112	242	20
Morva	2477	857	733	341	672	60

Source: Census, 2001.

Table 2
Variation in secondary and primary data for number of households

Name of the village	Number of households as reported in Census 2001	Number of households estimated after survey
Panthadiya	182	240
Bisanpura 1st	95	101
Bisanpura 2nd	86	135
Morva	327	355

Table 3
Population of surveyed villages

Name of the village	Population as reported in Census 1991	Population as reported in Census 2001
Panthadiya	1154	1483
Bisanpura 1st	538	647
Bisanpura 2nd	670	717
Morva	2088	2477

Table 4
Estimated populations of surveyed villages

Name of the village	Population as reported in Census 2001	Estimated population in the year 2005
Panthadiya	1483	1640
Bisanpura 1st	647	697
Bisanpura 2nd	717	737
Morva	2477	2652

(v) very large farmers (>5 ha), keeping in mind the fragmented landholding scenario of the villages. The data on number of households and cattle is estimated by consulting *Sarpanch* and senior citizens of the villages and are shown in Table 5.

The equation used to compute the energy requirements for device-end use combination is as follows:

$$\begin{aligned}&\text{Energy consumption}\\&\quad= \text{number of devices used}\\&\qquad\times \text{energy consumed for 1 h of usage}\\&\qquad\times \text{average number of hours of usage of the device}\\&\qquad\times \text{number of days of usage in a year}\end{aligned} \tag{1}$$

Table 6
Standard adult equivalents used in analysis [15]

Family size	Standard adult equivalent
Men: 18–59 year	1
Women: 18–59 year	0.8
Men: >59 year	0.8
Women: >59 year	0.8
Boys: 5–18 year	0.5
Girls: 5–18 year	0.5
Kids: 1–5 year	0.35
Child: <1 year	0.25

$$\text{Computation of per capita energy consumption} = \frac{\text{EC}}{p} \tag{2}$$

where EC is the energy consumed per day and p the number of adult equivalents, for whom the energy is used [15] (see Table 6).

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 7. It can be observed that in all the villages, cooking end-use contributes for maximum followed by pumping end-use, cooling end-use, lighting end-use, appliance end-use, and heating end-use to total energy requirement of the village.

3. Modelling technique

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

$$\text{Minimize} \sum d_j^- + d_j^+ \quad (j = 1, 2, \ldots, 10) \tag{3}$$

subject to,

$$\text{Objective function}_j + w_j d_j^- - w_j d_j^+ = b_j \tag{4}$$

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 5
Demography of surveyed villages

Name of the village	Landless	Small farmers (0 ± 1 ha)	Medium farmers (1 ± 2.5 ha)	Large farmers (2.5 ± 5 ha)	Very large farmers (>5 ha)	Number of cattle
Panthadiya	9 (3.75%)	81 (33.75%)	103 (42.92%)	37 (15.41%)	10 (4.17%)	820
Bisanpura 1st	0 (0.00%)	58 (57.43%)	33 (32.67%)	8 (7.92%)	2 (1.98%)	389
Bisanpura 2nd	4 (2.96%)	48 (35.56%)	54 (40.00%)	19 (14.07%)	10 (7.41%)	384
Morva	5 (1.41%)	128 (36.06%)	121 (34.08%)	77 (21.69%)	24 (6.76%)	1149

Table 7
Estimated actual end-use energy requirements for surveyed villages

Energy end-use	*Panthadiya*		*Bisanpura 1st*		*Bisanpura 2nd*		*Morva*	
	Energy requirement per person, per day (kW h)	Annual energy requirement (MW h/year)	Energy requirement per person, per day (kW h)	Annual energy requirement (MW h/year)	Energy requirement per person, per day (kW h)	Annual energy requirement (MW h/year)	Energy requirement per person, per day (kW h)	Annual energy requirement (MW h/year)
Cooking	1.495	0.895×10^3	1.499	0.381×10^3	1.463	0.394×10^3	1.455	1.409×10^3
Lighting	0.10	0.060×10^3	0.14	0.036×10^3	0.12	0.032×10^3	0.11	0.107×10^3
Pumping	–	0.790×10^3 [a]	–	0.286×10^3 [b]	–	0.327×10^3 [c]	–	0.980×10^3 [d]
Heating	0.0002	0.120	0.0002	0.051	0.0002	0.054	0.0002	0.194
Cooling	0.212	0.127×10^3	0.344	0.088×10^3	0.274	0.074×10^3	0.207	0.200×10^3
Appliances	0.055	0.033×10^3	0.082	0.021×10^3	0.061	0.016×10^3	0.052	0.050×10^3

[a] 58 tube-well pumps of 12.5 hp used for 5 h/day.
[b] 21 tube-well pumps of 12.5 hp used for5 h/day.
[c] 24 tube-well pumps of 12.5 hp used for 5 h/day.
[d] 72 tube-well pumps of 12.5 hp used for 5 h/day.

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

(i) Objective of minimum cost, i.e.

$$\sum_{i=1}^{42}(C_i X_i) \tag{5}$$

(ii) Objective of maximum system efficiency, i.e.

$$\sum_{i=1}^{42}(\eta_i X_i) \tag{6}$$

(iii) Objective of maximum reliability, i.e.

$$\sum(R_i X_i), \tag{7}$$

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

(iv) Objective of maximum utilization of local resources, i.e.

$$\sum(X_i), \tag{8}$$

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.

$$\sum(X_i), \tag{9}$$

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

(vi) Objective of maximum employment generation, i.e.

$$\sum_{i=1}^{42}(e_i X_i) \tag{10}$$

(vii) Objective of maximizing social acceptance of energy system, i.e.

$$\sum_{i=1}^{42}(S_i X_i) \tag{11}$$

(viii) Objective of minimum emissions

$$\text{Minimization of } CO_x \text{ emission, i.e. } \sum_{i=1}^{41}(CO_i X_i) \tag{12}$$

$$\text{Minimization of } SO_x \text{ emission, i.e. } \sum_{i=1}^{41}(SO_i X_i) \tag{13}$$

$$\text{Minimization of } NO_x \text{ emission, i.e. } \sum_{i=1}^{41}(NO_i X_i) \tag{14}$$

The optimization is subject to following 10 constraints:

(i) Cooking energy requirement, i.e.

$$\sum_{i=1}^{11}(X_i) \geq \text{total cooking energy requirement} \tag{15}$$

(ii) Lighting energy requirement, i.e.

$$\sum_{i=12}^{18}(X_i) \geq \text{total lighting energy requirement} \tag{16}$$

(iii) Pumping energy requirement, i.e.

$$\sum_{i=19}^{22} x_i \geq \text{total pumping energy requirement} \tag{17}$$

(iv) Heating energy requirement, i.e.

$$\sum_{i=23}^{31} x_i \geq \text{total heating energy requirement} \tag{18}$$

(v) Cooling energy requirement, i.e.

$$\sum_{i=32}^{36} x_i \geq \text{total cooling energy requirement} \tag{19}$$

(vi) Appliances energy requirement, i.e.

$$\sum_{i=37}^{41} x_i \geq \text{total appliances energy requirement} \tag{20}$$

(vii) 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 [6]. 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:

$$\sum (X_6) \leq 20\% \text{ of the total cooking energy requirements} \tag{21}$$

(viii) Limit for use of dung cake for cooking and heating: cooking pattern of the region indicates 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

$$\sum \left(\frac{X_i}{\eta_i}\right) \leq 7.5\% \text{ of the dung availability} \tag{22}$$

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

(ix) Potential limit for biogas energy, i.e.

$$\sum \left(\frac{X_i}{\eta'_i}\right) \leq \text{available biogas energy} \tag{23}$$

where i is the energy resource-end-use combinations for biogas energy source, and η' is the end-use device efficiency

(x) Potential limit for biomass energy, i.e.

$$\sum \left(\frac{X_i}{\eta'_i}\right) \leq \text{available biomass energy} \tag{24}$$

where i is the *energy resource-end-use combinations for biomass energy source and* η' is the 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.

4. Results and discussion

The estimated biomass, dung cake and biogas energy resource availability in neighboring villages are shown in Table 8. It can be seen that number of cattle to population ratio is 0.59 and 0.52, which is higher than the ratio observed in Panthadiya village (0.50), due to which the biogas energy potential is higher in *Bisanpura 1st* and *Bisanpura 2nd* villages. It can be noted that the number of cattle to population ratio is 0.43, which is lower than the ratio observed in Panthadiya village (0.50), due to which the biogas energy potential is lower in the Morva village.

Optimal energy 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 energy scenario is obtained by optimizing all objective functions simultaneously by pre-emptive goal programming method as discussed in previous article. The goal value and weighting factor for different objective functions for neighboring villages are shown in Table 9. The negative value for weighting factor indicates that the energy sources are available to satisfy the defined objective, as can be observed in Table 9. The goal value for such functions is also observed to be zero.

4.1. Optimal scenario for implementation

In this scenario, cost and employment generation objective functions are assigned a higher priority as compared to other objective functions. This scenario is important, from the view point of socio-economic development of the villages. The results of energy resource allocation are shown in Table 10.

Table 8
Estimated biomass, dung cake, biogas energy potential in surveyed villages

Name of the village	Population	Irrigated land (in ha)	Biomass energy available (MJ/year)	Number of cattle	Dung cake consumption (MJ/year)	Biogas availability (MJ/year)
Panthadiya	1640	481	9.26×10^6	820	3.74×10^6	5.61×10^6
Bisanpura 1st	697	169	3.26×10^6	389	2.67×10^6	1.22×10^6
Bisanpura 2nd	737	167	3.21×10^6	384	2.63×10^6	1.20×10^6
Morva	2652	733	14.10×10^6	1149	7.86×10^6	3.59×10^6

Table 9
Goal value, worst value and weighting factors for the objectives

Objective function	*Panthdiya village*		*Bisanpura 1st village*		*Bisanpura 2nd village*		*Morva village*	
	Goal (b_j)	Weighting factor (w_j)	Goal (b_j)	Weighting factor (w_j)	Goal (b_j)	Weighting factor (w_j)	Goal (b_j)	Weighting factor (w_j)
Cost	1.215×10^6	-27.362×10^6	0.541×10^6	-11.640×10^6	0.548×10^6	-12.098×10^6	1.769×10^6	-39.424×10^6
Efficiency	0.575×10^6	0.307×10^6	0.243×10^6	0.135×10^6	0.253×10^6	0.137×10^6	0.841×10^6	0.468×10^6
Reliability	1.805×10^6	0982×10^6	0.769×10^6	0.459×10^6	0.798×10^6	0.452×10^6	2.613×10^6	1.554×10^6
Local resources	1.905×10^6	1.905×10^6	0.812×10^6	0.812×10^6	0.843×10^6	0.843×10^6	2.746×10^6	2.746×10^6
Petroleum products	0	-1.905×10^6	0	-0.812×10^6	0	-0.843×10^6	0	-2.746×10^6
Employment	1217.70	1217.36	500.15	500.00	492.98	492.83	1785.68	1785.18
Social acceptance	1.419×10^6	1.257×10^6	0.605×10^6	0.537×10^6	0.628×10^6	0.557×10^6	2.046×10^6	1.817×10^6
Carbon emission	0.239×10^6	-1.235×10^6	0.085×10^6	-0.637×10^6	0.098×10^6	-0.593×10^6	0.294×10^6	-2.038×10^6
Sulphur emission	0	-0.046×10^6	0	-0.022×10^6	0	-0.022×10^6	0	-0.067×10^6
Nitrogen emission	86.27	-0.013×10^6	5.77	-0.005×10^6	23.32	-0.006×10^6	71.14	-0.019×10^6

The results of optimization for neighboring villages show that biomass, biogas and solar thermal should be promoted for cooking, and solar thermal for heating end-use. LPG (29.425% in *Bisanpura 1st*, 33.86 in *Bisanpura 2nd* and 25.71% in *Morva* village) 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 in all the neighboring villages.

The cost associated with optimal scenario for *Bisanpura 1st* village is Rs. 2.18 millions and the associated emissions are 471.23, 0.738, 14.18 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal scenario for *Bisanpura 2nd* village is Rs. 2.24 millions and the associated emissions are 437.39, 0.66, 13.97 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal scenario for *Morva* village is Rs. 7.51 millions and the associated emissions are 2271.52, 3.91, 41.71 tonnes/year for CO_x, NO_x and SO_x, respectively.

Table 11 shows the unutilized energy resource in implementing optimal scenario for neighboring villages in the base year (2005–2006).

It can be observed that in *Bisanpura 1st* village the dung cake (100%) and biomass energy resource (15.34%) is not utilized in optimal scenario. In *Bisanpura 2nd* village, the dung cake (100%) and biomass energy resource (18.69%) is not utilized in optimal scenario. In *Morva* village dung cake (100%) and biomass energy resource (11.21%) is not utilized in optimal scenario. Therefore, *Bisanpura 1st*, *Bisanpura 2nd* and village is considered to study inter-village energy mix with *Panthadiya* village.

4.2. Inter-village mix

The results of optimization for the inter-village mix show the similar results and are shown in Table 12. The scenario analysis shows that biomass, biogas and solar thermal should be promoted for cooking, and solar thermal for heating end-use. LPG (21.40–26.42%) is to be allocated for cooking due to the constraint of biogas and biomass energy resource potential. The contribution of LPG for cooking end-use is observed to be proportional to the use of biogas. 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 cost associated with optimal scenario for *Panthadiya–Bisanpura 1st* village-mix is Rs. 7.75 millions and the associated emissions are 1963.41, 3.22, 43.93 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal scenario for *Panthadiya–Bisanpura 2nd* village-mix is Rs. 7.37 millions and the associated emissions are 1883.95, 3.14, 43.50 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal scenario for *Panthadiya–Morva* village-mix is Rs. 12.64 millions and the associated emissions are 3725.67, 6.41, 71.53 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal

Table 10
Energy resource allocation pattern in optimal scenario for implementation in surveyed villages

Optimal scenario	End-uses					
	Cooking	Lighting	Pumping	Heating	Cooling	Appliances
Panthadiya village	1. Biomass (17.32%) 2. LPG (22.96%) 3. Biogas (39.72%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Bisanpura 1st village	1. Biomass (6.09%) 2. LPG (29.42%) 3. Biogas (44.49%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Bisanpura 2nd village	1. Biomass (3.75%) 2. LPG (33.86%) 3. Biogas (42.39%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Morva village	1. Biomass (18.91%) 2. LPG (25.71%) 3. Biogas (35.38%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)

scenario for *Panthadiya–Bisanpura 1st–Bisanpura 2nd* village-mix is Rs. 9.62 millions and the associated emissions are 2737.08, 4.70, 57.72 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal scenario for *Panthadiya–Bisanpura 1st–Morva* village-mix is Rs. 14.81 millions and the associated emissions are 4195.34, 7.14, 85.75 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal scenario for *Panthadiya–Bisanpura 2nd–Morva* village-mix is Rs. 14.88 millions and the associated emissions are 4140.06, 7.02, 85.34 tonnes/year for CO_x, NO_x and SO_x, respectively. The cost associated with optimal scenario for *Panthadiya–Bisanpura 1st–Bisanpura 2nd–Morva* village-mix is Rs. 17.06 millions and the associated emissions are 4641.11, 7.81, 99.55 tonnes/year for CO_x, NO_x and SO_x, respectively.

Table 13 shows the unutilized energy resource in implementing optimal energy scenario for inter-village mix in the base year (2005–2006).

It can be observed that the dung cake (100%) is not allocated in any inter-village mix. Biomass energy resource 11.42%, 11.95%, 10.53%, 11.08%, 11.93% and 11.86% is not allocated in optimal scenario for *Panthadiya–Bisanpura 1st*, *Panthadiya–Bisanpura 2nd*, *Panthadiya–Morva*, *Panthadiya–Bisanpura 1st–Bisanpura 2nd*, *Panthadiya–Bisanpura 1st–Morva*, *Panthadiya–Bisanpura 2nd–Morva and Panthadiya–Bisanpura 1st–Bisanpura 2nd–Morva* village-mix, respectively. The dung cake energy resource is not allocated for cooking end-use due to its higher associated emissions (0.633 kg/kW h, 0.0013 kg/kW h and 1.709×10^{-2} kg/kW h for carbon, sulphur and nitrogen, respectively). The biomass energy is unutilized is due to more potential of energy resource.

In micro-level energy planning, energy scenario when implemented is required to fulfill the objective of meeting energy requirements subject to constraints. These constraints correspond to resource availability, technology options, cost of utilization, environmental impact, socio-economic impact, employment generation, subject to present as well as future considerations. The success of energy scenario depends on accurate estimation of energy resource, energy demand and unutilized local energy resource. The quantum of unutilized local energy resource will make the plan successful.

The region for fast track IRES development is defined with respect to available energy sources and energy demand. The results of inter-village mix for present energy requirements for different end-uses show that the dung cake energy resource is not preferred in optimal energy resource allocation. Moreover, the unutilized energy resource potential of biomass energy can be observed from table for the inter-village mix with *Panthadiya* village. The results of inter-village mix show that *Panthadiya–Bisanpura 2nd* village-mix has maximum unutilized local energy potential. Therefore, *Panthadiya–Bisanpura 2nd* village-mix is identified as a region for energy planning.

Table 11
Estimated unutilized energy resources in optimal scenario for surveyed villages

Name of the village	Estimated dung cake availability (MJ/year)	Unutilized dung cake (MJ/year)	Estimated biomass energy availability (MJ/year)	Unutilized biomass energy availability (MJ/year)
Panthadiya	5.61×10^6	5.61×10^6	9.26×10^6	0.93×10^6
Bisanpura 1st	2.67×10^6	2.67×10^6	3.26×10^6	0.50×10^6
Bisanpura 2nd	2.63×10^6	2.63×10^6	3.21×10^6	0.60×10^6
Morva	7.86×10^6	7.86×10^6	14.10×10^6	1.58×10^6

Table 12
Energy resource allocation pattern in optimal scenario for implementation in Panthadiya–Bisanpura 1st village-mix

Optimal scenario for	End-uses					
	Cooking	Lighting	Pumping	Heating	Cooling	Appliances
Panthadiya–Bisanpura 1st village-mix	1. Biomass (13.99%) 2. LPG (24.87%) 3. Biogas (41.14%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Panthadiya–Bisanpura 2nd village-mix	1. Biomass (13.24%) 2. LPG (26.42%) 3. Biogas (40.34%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Panthadiya–Morva village-mix	1. Biomass (18.39%) 2. LPG (24.50%) 3. Biogas (37.11%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Panthadiya–Bisanpura 1st–Bisanpura 2nd village-mix	1. Biomass (17.28%) 2. LPG (21.40%) 3. Biogas (41.32%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Panthadiya–Bisanpura 1st–Morva village-mix	1. Biomass (16.63%) 2. LPG (25.19%) 3. Biogas (38.18%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Panthadiya–Bisanpura 2nd–Morva village-mix	1. Biomass (16.04%) 2. LPG (26.15%) 3. Biogas (37.81%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)
Panthadiya–Bisanpura 1st–Bisanpura 2nd–Morva village-mix	1. Biomass (15.05%) 2. LPG (26.30%) 3. Biogas (38.65%) 4. Solar thermal (20%)	Biomass electricity (100%)	Biomass electricity (100%)	Solar thermal (100%)	Biomass electricity (100%)	Biomass electricity (100%)

Table 13
Estimated unutilized energy resources in optimal scenario for village-mix

Name of the village	Estimated dung cake availability (MJ/year)	Unutilized dung cake (MJ/year)	Estimated biomass energy availability (MJ/year)	Unutilized biomass energy availability (MJ/year)
Panthadiya–Bisanpura 1st	8.28×10^6	8.28×10^6	12.52×10^6	1.43×10^6
Panthadiya–Bisanpura 2nd	8.24×10^6	8.24×10^6	12.47×10^6	1.49×10^6
Panthadiya–Morva	13.47×10^6	13.47×10^6	23.36×10^6	2.46×10^6
Panthadiya–Bisanpura 1st–Bisanpura 2nd	10.91×10^6	10.91×10^6	15.73×10^6	–
Panthadiya–Bisanpura 1st–Morva	16.14×10^6	16.14×10^6	26.62×10^6	2.95×10^6
Panthadiya–Bisanpura 2nd–Morva	16.10×10^6	16.10×10^6	26.57×10^6	3.17×10^6
Panthadiya–Bisanpura 1st–Bisanpura 2nd–Morva	18.77×10^6	18.77×10^6	29.83×10^6	3.54×10^6

5. Conclusion

The generalized goal programming model developed is used to identify region for fast track development of region. The region is identified on the basis of scope of utilization energy resources. An attempt has been made to incorporate needs of group of villages in micro-level energy planning. Optimal scenarios are developed for the study as well as neighboring villages by assigning higher priority to cost and employment generation objective as compared to other objectives. The results of optimization for all the villages show that biomass electricity should be promoted for lighting, pumping, cooling and appliance end-uses. Use of biomass, LPG, biogas and solar thermal is suggested for meeting cooking end-use. It is found that the present cost of energy utilization can be reduced by implementing this scenario.

It is found that mix of two villages for micro-level energy planning results in better utilization of available energy sources compared to individual village. However, the success of inter-village mix for micro-level energy planning depends on socio-economic and local political will, to implement such inter-village mix micro-plans.

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