



## Energy Balance of an Indian Semi-Arid Rural Ecosystem using Field, Ancillary and Geospatial Data

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### ABSTRACT

This study presents an estimation of net energy balance resulting from primary production vis-a-vis energy consumption through various components in a semi-arid rural ecosystem of Ralegan Siddhi village, Maharashtra, India. An end use energy accounting 'Rural Energy Balance Model' is developed for input-output analysis of various anthropogenic energy flows within the village system boundary. An integrated approach using field, ancillary, GIS and high resolution satellite data is used for generation of various model inputs. The primary and secondary field data collection of available energy resources and consumption at household and village level were carried out using structured schedules and questionnaires. The model inputs were converted to energy equivalents using country-specific energy conversion factors. The Net Energy Balance of this semi-arid village ecosystem is estimated at 13.06 TJ, indicating a self-sustaining rural ecosystem. The results of this study are useful inputs for policy and planning the optimal utilization of available and future energy requirements for rural development.

**Keywords:** Semi-arid, anthropogenic, energy flows, remote sensing, GIS, energy balance.

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### INTRODUCTION

India is predominantly an agricultural and rural country with almost 70% of its population living in the villages. The recent census (Census, 2011) has estimated Indian rural population growth rate at 12.18%. Across the country, villages vary in population density, geographical location, availability of resources, agricultural practices, livelihood patterns etc. Most of the country's rural population lives in semi-arid tropics, an agro-ecological region characterized by scanty rainfall, largely rainfed agriculture and infertile soils (Harriss-White and Garikipati, 2008). These rural livelihoods need particular attention as they are more vulnerable to climate change due to their exposure to various dry land stresses. The rural ecosystems in semi-arid regions also need focused research on various available and future energy resources for the

sustenance of local livelihoods.

In India, a rural ecosystem consists of agricultural practices, livestock keeping including poultry, tree plantations, uncultivated land, residential rural livelihoods, industry or trade within the civil administration village boundary. Odum (1975) recognized agro-ecosystems as 'fossil fuel subsidized solar powered ecosystems'. In India, agro-ecosystems are dependent upon the input of human and animal energy drawn from the previous crops and by material recycled as animal dung and fodder waste which is used mostly as manure. Livestock keeping has been an integral part of rural livelihoods in India as animal energy is a renewable and sustainable source of energy. Most of the requirements of the village dwellers and their domesticated animals are met from the village territory.

Only limited studies are available in literature that has reported energy balance of rural ecosystem in semi-arid region of the country. Pandya and Pedhadiya (1993) presented an energy analysis of a semi-arid village ecosystem in Gujarat through various subsystems of crop, non-crop, animals and human. However, this study could not capture all possible

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anthropogenic pathways of energy flows within the village system boundary. It is important to understand and quantify the pathways of anthropogenic energy flows in a semi-arid rural ecosystem of the country. The current study was undertaken with an objective to present an assessment of net energy balance resulting from primary production *vis-a-vis* energy consumption, imports and exports through various components within the village boundary.

## MATERIAL AND METHODS

### Study area and Data Used

Village is the basic spatial unit for this study. The study area included Ralegan Siddhi village, Maharashtra, India. Ralegan Siddhi village is located in the acute drought-prone and rain-shadow zone of Parner Tehsil of Ahmednagar district, in Central Maharashtra (Fig. 1). It is at a distance of 87 km from Pune and 40 km from the Ahmednagar state highway.

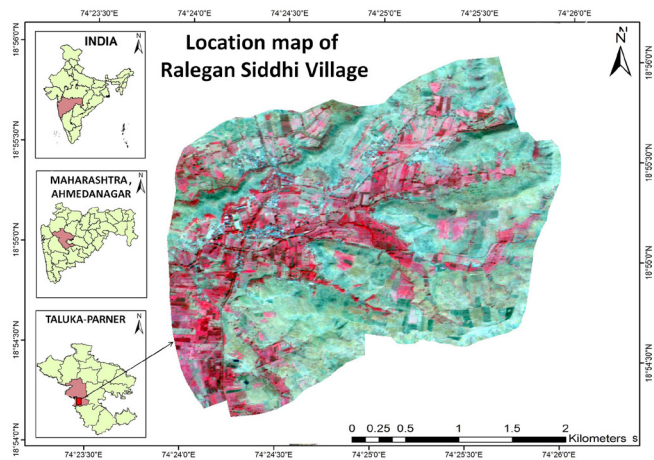


Fig.1: Location map of the study area

The village has a total geographical area of 982.31 ha. The topography of the village is very undulating and slopes vary from 3-15%. Village is surrounded by small hillocks on northeast and southern sides (Fig. 2). The temperature varies from 12°- 44 °C and rainfall is scanty 50 mm-650 mm. Soils are shallow. In lower areas, patches of black soils mixed with pebbles are seen but towards the higher areas the soils are inferior and unsuitable for cultivation.



Fig.2: Field photograph of study area

The data used for the purpose of this study includes ancillary data, remote sensing and GIS data and extensive field data. The primary data of population, occupation, social and economic status of residents, agriculture, livestock species and their produce, trees outside forests, food basket, fossil fuel, biofuel, electricity consumption including seasonal variabilities, industry /trade inputs and outputs at household level and secondary data at village level were collected through field survey. A stratified random sampling approach based on primary occupation of rural households was adopted for field data collection of 100 households using structured schedules. The secondary village level data collection was based on detailed questionnaires. The sampling methodology adopted for household data collection is illustrated in the fig. 3. Farmers were further classified into marginal, small, semi-medium, medium and large on the basis of their landholding size (ICAR based classification). The social and economic status of households was included during household sampling. The village level data was collected from Panchayat office, Gramsewak office, Talati Revenue office, block.development office, social forestry office, veterinary office and electricity office at taluka or block level. The Participatory Rural Appraisal (PRA) at the study sites was carried out using various tools of social mapping, resource mapping, transect walk, focused discussion, preference ranking, seasonal diagrams and matrix ranking. The country-specific energy conversion factors were collected through a detailed literature survey. High resolution multi-temporal IRS-P6 Resourcesat-2 LISS IV Full multi-spectral satellite data (5.8 m) were used to derive landuse and landcover classification map of the study area and estimation of above-ground trees outside forests phytomass using an integrated Remote Sensing and GIS based spatial approach with the supplement of field measurements. The multi-temporal Resourcesat-2 LISS IV satellite data used for the study include 20 October 2011, 25 December 2012 and 31 March 2013.

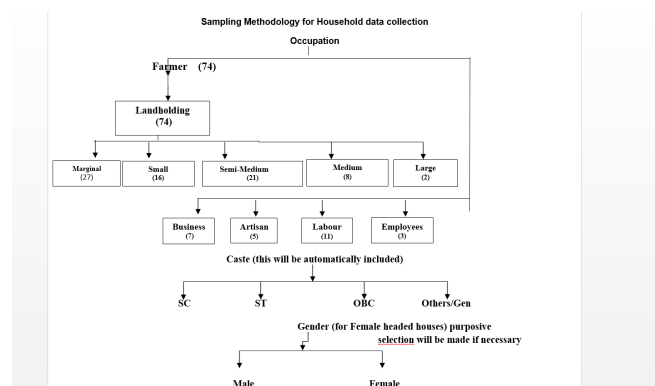


Fig.3: Sampling methodology for household data collection in Ralegan Siddhi village (number in parenthesis indicate sampled households)

The field measurements of trees outside forests (TOFs) within the village boundary were collected using a random stratified sampling design for linear, block and scattered strata as described by forest survey of India for TOF inventory (Rawat et al., 2005). In the field, the non-destructive approach of phytomass estimation was adopted. The dimensions of the sampling plot were taken 50m×20m for linear trees along the roads and canal, 32×32 m for the block strata and 50×50 m for scattered strata. The detailed field measurements at sample plots included enumeration of trees, identification of tree species, tree height using altimeter, Girth at Breast Height using measuring tape and location of sample plots using a handheld GPS.

## METHODOLOGY USED

The overall methodology of the study is illustrated in the Fig. 4.

The detailed household and village level statistical databases were prepared using the collected field data. Site-wise sample plot field data on trees outside forests were organized in a spreadsheet and processed in a database environment. The wood volume of individual trees was estimated using species-specific volume equations given by Forest Research Institute, Dehradun (FRI, 1996). General volume equations were applied for few tree species for which specific equations were not available. The estimated wood volume was multiplied by species specific gravity of wood to calculate tree phytomass. The phytomass of the individual tree was added to find out total TOF phytomass for each sample plot.

The remote sensing database was prepared using cloud-free multi-temporal Resourcesat-2 LISS IV data. The administrative boundary coverage obtained from Survey of India database was used to subset the LISS-IV images. The preprocessing of procured georeferenced data involved atmospheric correction using SACRS2 tool for LISS-IV data (Pandya et al., 2013). LISS-IV image were resampled from 5.8 m pixel to 6 m pixel to get the better approximation of the results while computing area under each land use and land cover category. The image classification on multi-temporal dataset was attempted in ERDAS IMAGINE 9.2 image processing software. The spectral classes obtained were grouped into seven categories viz. built-up land, single crop, double crop, fallow land, scrub land, fallow land, plantation and water body. The three strata of

block, linear and scattered trees outside forests were included under plantations category. The classified image was then visually analyzed for editing and refinement for inclusion and omission of misclassified patches. The classified raster image was further converted into vector format for enabling GIS analysis of the layer. The area under each land use and land cover category was estimated and land use and land cover maps were derived in ArcGIS 9.2. The plantation category of the final classified map was then used for above ground phytomass estimation based on an integrated methodology using remote sensing, GIS and field measurements of TOFs (Singh and Chand, 2012). The estimated phytomass was converted to carbon content using a coefficient of 0.5 (Brown et al., 1999).

An End use energy accounting 'Rural Energy Balance Model' has been developed under this study to provide a complete assessment of Net Energy Balance (NEB) of a Rural Ecosystem. The model is based on the principle of pathways of energy flows across the various producers and consumers, imports and exports of energy within a village system boundary. The model takes inputs for five basic subsystems of crop, livestock, residential, industry/trade and trees outside forests. The model inputs include sample mean, minimum and maximum for each unit in the analysis based on the household database projected over the village population using the statistical analysis software SPSS ver. 19. The crop biomass inputs were computed using economic yield, moisture fraction and conversion factors for each crop (Dadhwal et al., 1994 & 1996). The model takes the inputs and generates the final energy output values based on the various calculations and mathematical formulations, making the use of conversion factors fed into it. The model allows the user selectable analysis based on the three pivots (social status, occupation and economic background) and combinations therefore. The control parameters and energy references are also the basis of scenario analysis for various cases, and also include the provision for uncertainty analysis. The pivot weights may be used to project the values for each of the inputs and outputs for all the sectors. The details of the model and compilation of energy conversion factors used in the study are given by Nag et al., 2014 and Garg et al., 2014.

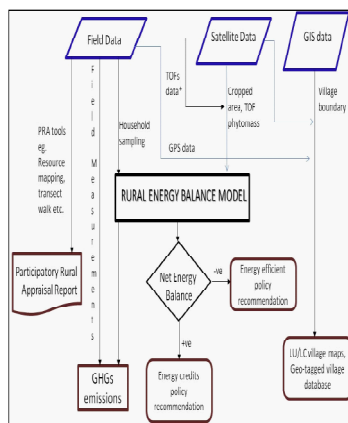


Fig. 4: Flow diagram of the methodology used in the study

## RESULTS AND DISCUSSION

Geographically, Ralegan Siddhi village lies in the semi-arid, rain shadow region of Maharashtra with poor natural resources. However, in past few decades, with tremendous efforts of local people through watershed development programmes and water management, this village has been transformed into a prosperous village. Agricultural output and economic conditions have improved by conservation of soil and harnessing water for irrigation. The recent Census 2011 has enumerated a total population of 2,317 living in 453 households.

Agriculture is the major occupation of village residents. The major crops of the village include jowar, moong, bajra, wheat, commercial crops and horticulture crops like sweet lime, pomegranate and mango. However, few farmers are also associated with dairy and poultry practices. Other occupations of the village include jobs, daily wage labours, business and artisans. The statistical data analysis of livestock data indicate different livestock categories with a maximum number of cows, followed by buffaloes, bullocks, sheep and goats. The land use and land cover map derived from multi-temporal Resourcesat-2 LISS-IV data is shown in the Fig. 5.

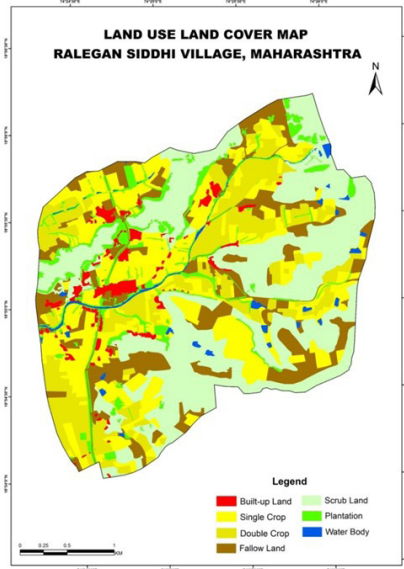


Fig.5: Land Use land cover map derived using multi-date High resolution satellite data

The data analysis indicates that crop land constitutes about 40% of the total geographic area followed by 34% of area under scrublands. Linear, block and scattered plantations together cover 7% of the area. The distribution of land under different land use and land cover classes is shown in the Fig. 6.

The energy flows in the village are mainly affected by agro climatic conditions, human and livestock population, cropping practices and tree plantations. The study result indicates that village is energy positive, mainly driven by solar energy, converted into crop and tree biomass. The crop subsystem is energy positive with 3.044 TJ (Terra Joules) as the energy output from crops produce is higher than its inputs. The

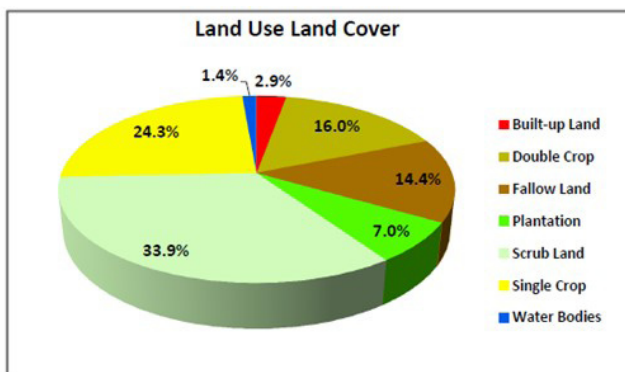


Fig .6: Remote sensing based land use and land cover classification of Ralegan Siddhi village

livestock subsystem including poultry is almost balanced with higher energy outputs in terms of milk, eggs and animal dung. The animal dung is largely consumed within the village for domestic and agricultural purposes. The eggs are sold to market outside village boundary so considered under exports from village. However, the livestock is fed with concentrated feed brought from market. So it adds to the energy import within the framework of energy balance quantification. The rural households are energy negative, mainly due to availability of commercial energy in the form of fossil-fuel derived electricity and use of biofuels, so higher inputs as compared to its outputs. The energy inputs from natural sources like sunlight and water have not been quantified in the current analysis. Therefore, trees subsystem in the rural energy balance model analysis indicates only energy production through tree phytomass. The result indicates that the net energy balance of a rural ecosystem is largely driven by primary production through crops and natural vegetation. The net energy balance of the village is estimated at 13.063 TJ. The per capita energy balance is estimated at 5.64 Giga Joules (GJ). The positive energy balance indicates 'an energy sustainable rural ecosystem' of Ralegan Siddhi village.

Participatory Rural Appraisal was also conducted to elicit the felt need of the villagers, prioritize their perceptions and bring out the reality of the issues involved in energy flow of the rural ecosystem. The major observations of PRA included various watershed dams constructed through community participation activities under the guidance and leadership of Shri Anna Hazare, a social activist. In spite of severe drought in the past three years, villagers had managed to appropriately utilize their water resources for farming and other daily activities. There are good communication, educational, health and electricity facilities in and surrounding locations. Basic amenities like water supply, tar road and hospital/PHC, veterinary clinic, etc. are also available in the village. The social and resource mapping of the village was also carried out with the involvement of local residents. There is diversity in socio-economic structure of the village with strong social fabric, harmony and peaceful development of all sections of the society. PRA focused discussions also highlighted that renewable energy sources can be encouraged to meet the domestic and commercial needs of the villagers. There were few efforts in the past for using renewable energy sources like *gobar* gas and harnessing solar energy through use of solar panels but they could not be sustained due to lack of maintenance. As the study site is characterized with both plain and hill region, there are also possibilities for wind mills. The availability and awareness about various renewable energy sources and their maintainence need due attention to improve the energy efficiency of the village.

## CONCLUSION

The study presents an estimation of net energy balance in a semi-arid rural ecosystem of Ralegan Siddhi village, Maharashtra, India. An end use energy accounting 'Rural Energy Balance Model' is developed to provide a complete assessment of net energy balance of a rural ecosystem. An integrated approach using field, ancillary, GIS and high resolution multi-temporal IRS-P6 Resourcesat-2 LISS IV data was used for generation of various model inputs. The primary and secondary field data collection of various energies used at household and village level was carried out using structured schedules and questionnaires. The village has been transformed from a resource deficient to a prosperous village through various watershed development and community participation activities. The different energy resources including fossil fuel and electricity are available in the village. The net energy balance of the village is estimated at 13.063 Terra Joules. The per capita energy balance is estimated at 5.64 Giga Joules. The positive energy balance indicates 'an energy sustainable rural ecosystem' of Ralegan Siddhi village. However, the availability and awareness about various renewable energy sources and their maintenance need due attention to improve the energy efficiency and meet the future energy requirements of the rural ecosystem together with sustainable development.

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