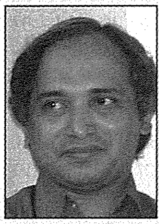

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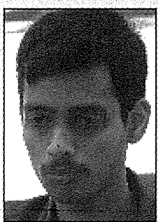

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SCOPE FOR DECENTRALISED ENERGY SYSTEMS IN INDIA

Abstract

Grid system based on centralised electricity generation has posed serious challenges to the environment as well as to the economy. These systems have failed to electrify every household in the country due to technical and economical non-feasibility apart from higher transmission and distribution losses. In this context, distributed generation (DG) have been playing a prominent role in the regional development as well as electrification of remote villages. DG optimally harvests locally available renewable energy sources and integrates with the grid. Regional Integrated Energy Plan (RIEP) based on decentralised energy systems optimises share of available resources while ensuring reliable energy supply. Spatial assessment of renewable energy sources aids in effective planning to meet the energy demand at local levels. An optimal energy plan based on renewable energy sources mitigate GHG emissions, while providing reliable energy to all citizens in India.

Introduction

Distributed generation (DG) based on locally available renewable sources of energy would play pivotal role in meeting the energy demand throughout the country. Distributed generation refers to the electric energy generation near load centres using locally available resources. Installed capacity of decentralised plants ranges from few kilowatts to megawatts. DG include various renewable energy based generating technologies such as rooftop solar PV installation, micro/pico hydro power generation, small scale wind plants, biomass gasifier, combined heat and power (CHP) plants etc.[1]. These DG systems have very minimal environmental impact and are easier to install and operate. Since the generated energy will be supplied to the local community load, transmission and distribution losses will be greatly reduced. The other benefits of DG include improvement in power quality, avoiding or reduced transmission line extension costs due to generation at load centres, reduced power loss and reduction in energy price at local level while contributing to rural electrification[2]. The centralised power systems have posed many technical challenges such as higher T & D losses, frequent voltage variation, frequency variation and reliability concerns with massive environmental pollution. There are more than 24,000 villages not electrified even today and many of them are in very remote places where the grid extension is economically non-feasible[3]. The grid extension to remote location costs about INR 1/kWh/km which is economically not viable with the present higher T & D losses[4]. T & D losses have increased from 17.5% (in 1970-71) to 24.1% (in 2011-12), over 4 decades in spite of development in technology and use of efficient transmission conductors. Figure 1 shows the T & D losses in the country over the years[5]. Increased T & D losses stress the transmission line, necessitates higher generation of electricity.

Grid expansions for rural electrification in remote areas are expensive and inefficient necessitating distribution generation system[6-8]. Even already electrified villages are facing the problem of unreliable power supply coupled with frequent severe voltage fluctuations. However DG's based on locally available renewable energy sources with the lower T & D losses have proved to be economically viable and technically feasible.

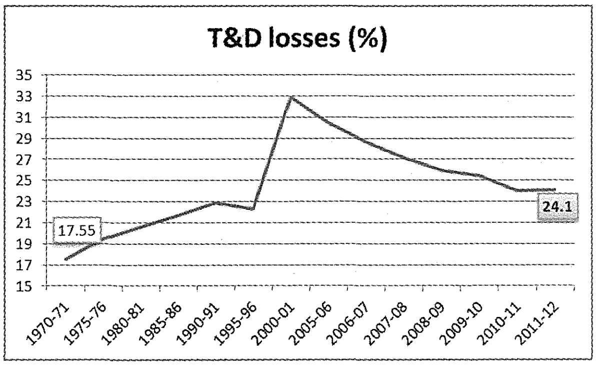


Figure 1 : T & D losses in the country from 1970-11 to 2011-12

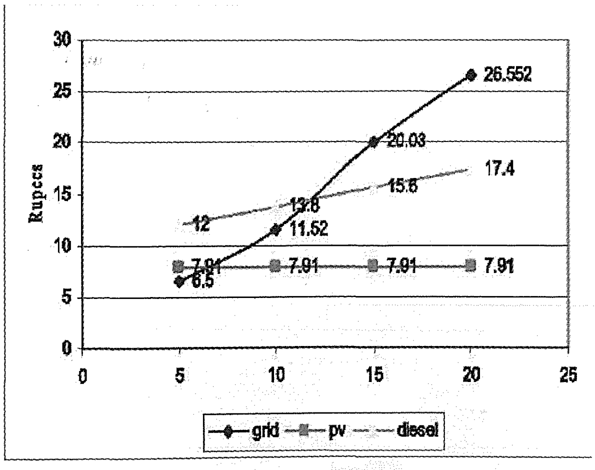


Figure 2 : Comparison of PV, diesel generator and grid electricity for rural electrification[9]

Figure 2 illustrates (Kamalapur et al. 2010) the cost appreciation as the distance of the load centre and grid increases. Beyond 6 km, grid expansions are economically non-viable. This necessitates onsite generation (DG) and distribution to households in remote areas to minimise the investment on infrastructure apart from transmission and distribution (T&D) loss of electricity. Line loss reduction with DG integration has been computed for various levels of penetration. Estimates indicate annual loss to the tune of 264 billion units (26400 GWh) or which costs minimum of INR 55 billion per year due to transmission and distribution inefficiency (Table 1). Current assessment reveals that T&D loss in India is about 24% resulting in the loss of 220 kWh/capita (per capita consumption is 917.18 kWh) of energy. Cost per capita of energy loss ranges from INR. 462 (@ INR. 2.10/kWh) to INR. 3220 (@ INR. 7/kWh) depending upon the tariff (in the respective state).

Table 1 : Expenditure due to T & D losses in India

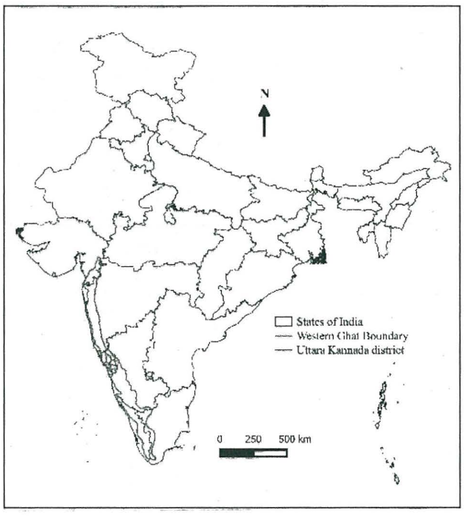
Per capita electricity consumption	917 kWh
T & D losses	24%
Per capita energy loss	220 kWh
Cost of per capita energy loss	INR 462 to INR 3220
Annual energy loss	264GWh
Total annual expenditure	INR 55,440 crores (@ INR. 2.10/kWh)

This necessitates deployment of DG using locally available resources to improve the efficiency of electricity transmission and distribution. India is targeting 22000 MW of Solar installed capacity by 2022 in which distributed generation hold the promise. India is one of the frontiers of wind generation with installed capacity of over 21 GW after China, US, Germany and Spain. Taluk level energy assessment gives insights to explore the feasibility of distributed generation opportunities and connect un-electrified villages in the region. This also helps in integrating renewable energy resources to the existing grid which will improve the power quality[10].

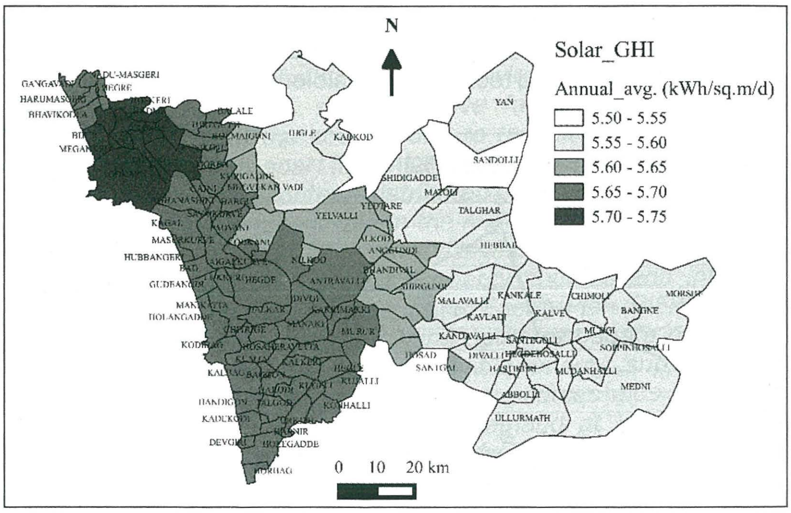
Study Area: Kumta, a coastal taluk in Uttara Kannada district, Karnataka State is located between the Arabian Sea coast on the west and Sahyadri ranges (Western Ghats) on the eastern side (14.42°N and 74.4°E). Taluk spreads over 590.45 km2 of area with population of 1,54,515 (Census 2011). Taluk is blessed with lush green forests which cover more than 65% of the geographical area and about 16% of the area is under agriculture/horticulture or plantation. Figure 3 shows the study area with annual average solar insolation and wind speed.

Spatio-temporal data are used for energy potential assessment using open source GIS platform, which also gives the seasonal and geographical variability of the available energy resources. Long term data sets acquired from NASA SSE (Solar GHI) and Climate Research Unit (CRU) (Wind Speed) are reliable and depicts the seasonal variability which is closely correlated with ground measurement[11 - 13]. Taluk experiences abundant solar insolation of more than 5.5 kWh/m^2/d throughout the year in all the villages. Coastal villages experience higher insolation compared to eastern villages which connects the taluk to Western Ghats ranges. However, decentralised generation can meet the significant electricity demand in all the villages. Figure 4 shows the seasonal variability of the solar energy potential across the villages. During summer (February to May) Kumta experience solar insolation of more than 5.6 kWh/m^2/d which reduces to less than 5 kWh/m^2/d during Monsoon (June to August). The radiation reception also varies in these months which will affect the electricity generation. During winter (October to January), taluk receives insolation ranges from 5 to 5.5 kWh/m^2/d.

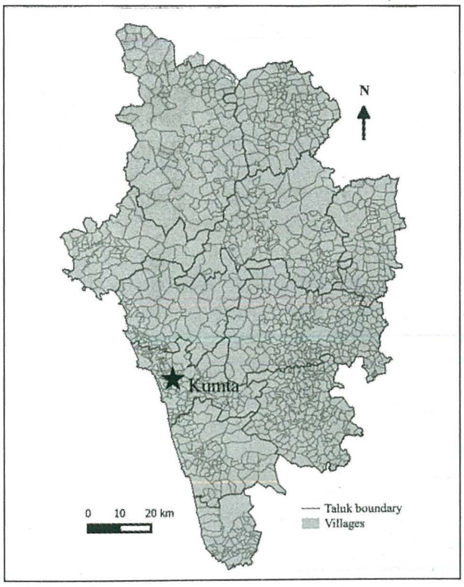
Figure 5 gives the wind speed variability in the taluk across the months. The coastal villages experience higher wind speed of more than 2.65 m/s annually compared to the eastern villages (2.61 m/s). Though the variation in annual average wind speed is minimum, seasonal variation is higher due to the swift winds during monsoon. During summer and winter, taluk experiences lower wind speed which ranges from 2 to 3 m/s. During monsoon taluk experience speedy winds varies from 3 to 4 m/s. Solar and wind resources supplement each other which supports hybrid energy systems in the region.



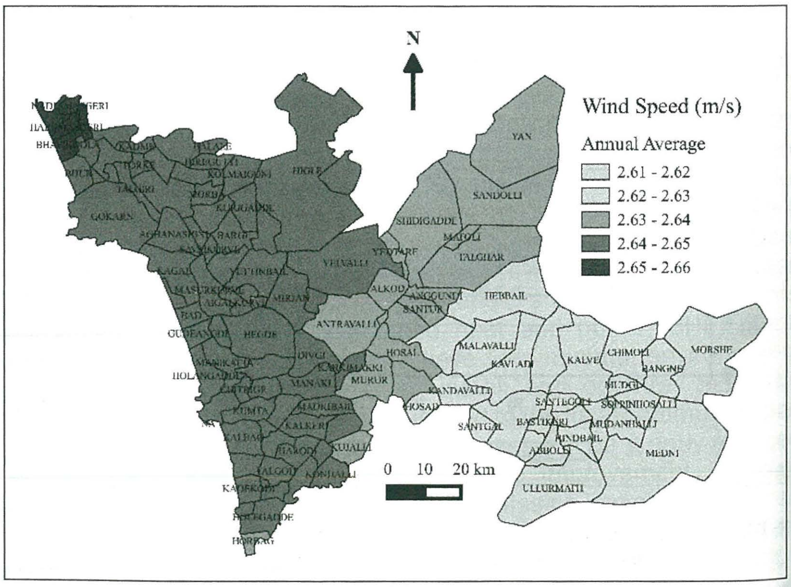
Uttara Kannada district, India



Village wise annual average solar insolation (kWh/m^2/d)



Kumta taluk, Uttara Kannada



Village wise annual average wind speed in Kumta (m/s)

Figure 3 : Study area - Kumta taluk, Uttara Kannada, Karnataka, India

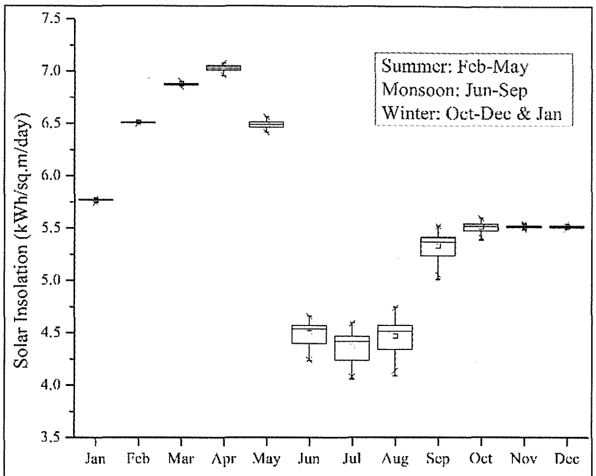


Figure 4 : Solar insolation variability

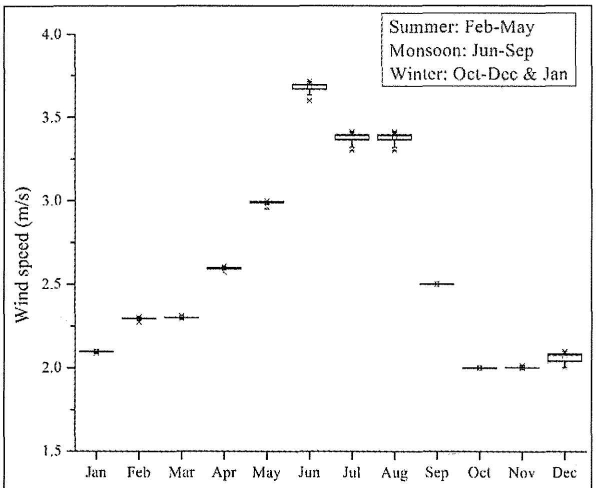


Figure 5 : Wind speed variability

Table 2 lists land use and land cover (LULC) details of Kumta taluk, blessed with bioenergy resources as most of the people practice agriculture / horticulture, which is the primary income of livelihood. About 16% of the total geographical area is under agriculture/horticulture or contains coconut and areca plantations which generates large amount of high energy residues such as coconut shell, rice stalk etc which can be used in bio-gasifiers. The taluk has 21.4% of evergreen forest, 12.5% semi-evergreen/moist deciduous forest, 7.3% of dry deciduous forest and 3.4% of acacia plantations which ensures the availability of plant residues with higher energy content throughout the year. These plant residues are being used for domestic purposes and sufficient quantity is available to use as a fuel for bio-gasifiers towards electricity generation.

Table 2 : Land use land cover (LULC) details of Kumta taluk

Category	Area (Ha)
Built up	1727.6
Cropland/Agriculture	5149.2
Open space	5984.0
Coconut/Areca	4428.9
Semi-evergreen/Moist-deciduous	7370.5
Evergreen	12638.4
Scrub/Grass	15190.2
Acacia	2018.8
Dry-deciduous	4351.5
Total	58859.63

Regional Integrated Energy Plan (RIEP)

Integrated energy plan essentially explores the locally available energy resources and feasible energy conversion technologies to meet the regional demand. The energy planning exercise carried out for Kumta taluk involves minimisation of annual cost function to a set of equality and inequality constraints using linear programming (LP) algorithm. The main objective of the energy planning is preparation of location specific decentralised energy harvesting systems for meeting the regional energy needs. This ensures least cost to the environment and the economy. Centralised energy generation and transmission cannot pay much attention to the variations in socio-economic and ecological factors of a region which influence success of any intervention. Decentralised energy planning focuses on efficient utilisation of resources, while ensuring more equitable sharing of benefits from development[14]. The integrated energy planning mechanism take into account of all resources available and end use demand of a region. This implies that the assessment of the demand and supply, and the intervention in the energy system which may appear desirable due to such exercises, must be at a similar geographic scale. Resource assessment done using remote sensing data with geographic information system (GIS) and field data compilation. Regional integrated energy model based on DG minimises the operating cost while ensuring reliable sufficient energy supply and ensures the total energy supply. The process is a constrained optimisation problem where, maximum available energy from each resource and minimum energy requirement for every end use are considered as constraints. Figure 6 illustrates the procedure adopted in the study.

The present study deals with the village wise potential assessment of renewable energy resources in Kumta taluk of Uttara Kannada district, Karnataka state. The district lies in the central Western Ghats (WG) which is one among 35 biodiversity hotspots in the world. District is a repository of diverse endemic flora and fauna and also receives higher solar insolation for about 300

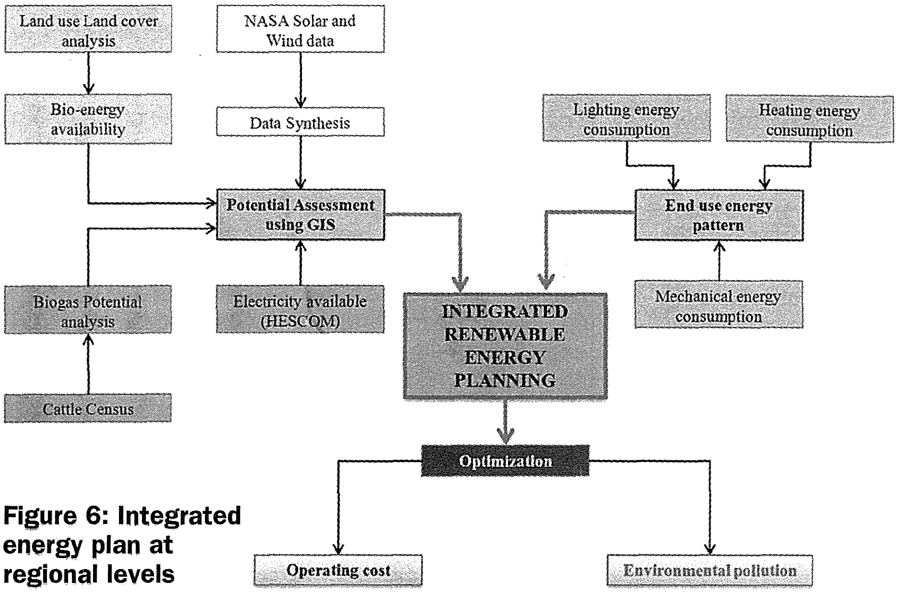


Figure 6: Integrated energy plan at regional levels

days in a year. The coastal villages of Kumta, experiences greater wind speeds which are high wind energy potential areas. Taluk also receives higher insolation which encourages the solar power plant installation. Spatio temporal (across villages and seasons) variability of resources have been analysed to optimise the energy harvesting with best locations as well as efficient end-use energy devices. Harvesting solar and wind energy ensures the availability throughout the year as wind compliments the lower solar insolation period during monsoon. Further, number of end uses and available resources are identified. Resource-task matching is modelled where the linear programming (LP) is used for optimisation. Cost minimisation is also explored while meeting the total energy demand with available local resources.

System is designed to use only locally available renewable energy sources which however have lower pollution. End use energy requirement per capita is assessed and total energy requirement per end use is computed and validated with field data. Table 3 gives the energy requirement for different end uses in the taluk.

Table 3 : Energy requirement for different end uses

End use type	Energy required (GWh/annum)
Low temperature heating	485.0
Medium temperature heating	411.7
Low power mechanical	6.2
Medium power mechanical	43.4
Lighting, fan etc.	37.2
Total	983.5

Low temperature heating (<100°C) end uses such as water heating for bathing, agro-processing (drying of local agro products such as areca nut, coconut, cashew, pepper etc.) etc. has the highest share (485 GWh/annum) in the total energy required followed by medium temperature heating (411.7 GWh/annum) and medium power mechanical end uses (43.4 GWh/annum). The agro processing activity which includes drying of areca nut, coconut, cashew nut, cardamom and other spices requires lot of low temperature heat energy (80-100°C) throughout the year. Direct electricity consumption is only for lighting, fans and television in homes, commercial spaces and road lights which consumes about 37.2 GWh/annum. Table 3 shows the efficiency of the energy conversion processes to meet the end use energy requirements.

The efficiencies of various energy conversion technologies are estimated from literatures and few are computed. However, these values do not overestimate the output energy obtained by energy conversion. Table 5 gives the load factor assumed in the present energy planning process. Maximum energy availability from each resource in the taluk has been computed by converting available quantity into its corresponding energy equivalent. Abundant solar energy is available (both solar thermal and electric energy) in the taluk where the harvestable energy is about 2860 GWh/annum. Similarly, about 670 GWh/annum of energy can be extracted from biomass and agro-horti residues in the region. Annual energy availability from all the resources in the village is given in Table 6.

Table 6 : Available maximum energy potential

Resource	Energy potential (GWh/annum)
Solar	2860.6
Wind	39.44 kWh/m^2 of swept area
Biomass	670
Biogas	12.9
Electricity	30.5
Total	3574.17

The wind energy harvesting depends on the swept area of the wind blades. The taluk has more than 31 km of coast line on the west which can generate ample energy from wind resource. Depending upon end use energy requirement, micro (few watts) to small scale (few kilo watts) wind generator can be installed in the coastal villages for irrigation and

Table 4 : Energy conversion efficiency

ηij	Low temp heating	Med. temp heating	Low power mech.	Med. Power mech.	Lighting, fan etc.
Solar	0.4	0.3	-	-	0.1
Wind	-	-	0.4	0.4	0.3
Biomass	0.15	0.15	-	-	0.3
Biogas	0.65	0.6	-	-	0.35
Electricity	-	-	0.8	0.75	0.8

Table 5 : Load factor

ηij	Low temp heating	Med. temp heating	Low power mech.	Med. power mech.	Lighting, fan, etc.
Solar	0.29	0.35	-	-	0.35
Wind	-	-	0.3	0.2	0.35
Biomass	0.29	0.35	-	-	0.35
Biogas	0.29	0.35	-	-	0.35
Electricity	-	-	0.65	0.65	0.65

electricity generation. Wind plants can also be integrated with solar or bioenergy plants which can address the intermittency issues. Energy available from biogas and electricity is limited to 0.1 GWh/annum and 0.43 GWh/annum respectively. The optimised operating costs for meeting the end use from available resources is shown in Table 7.

Total operating cost of the model is found to be INR 22.11 crores per annum with unit cost of INR 0.22 per kWh of energy utilised. Cost of generating mechanical energy from wind resources is found highest (INR 7.3 crores) followed by solar thermal energy generation (INR 4.9 crores) and generating electricity from biogas (INR 2.46 crores). However, electric energy application for medium power mechanical end use has the lowest operating cost (INR 8945.3) where the electricity is directly obtained from grid. Total energy supplied for various end uses is about 983.5 GWh/annum from all resources. Table 8 gives the energy supply patterns from resources to different end uses.

Table 7 : Optimised cost matrix of the energy model

Cost (INR/annum)	Low temp. heating	Med. temp. heating	Low power mech.	Med. power mech.	Lighting, fan, etc.
Solar	49494102.3	0	0	0	0
Wind	0	0	19711392.7	73755336.96	0
Biomass	153862.2	448498.1	0	0	52893514.4
Biogas	0	0	0	0	24679188.6
Electricity	0	0	0	8945.3	0
Total Cost (INR)			22.11 crores		
Unit cost (INR/kWh)			0.22		

Table 8 : End use energy supplied from various resources

Energy (GWh/annum)	Low temp. heating	Med. temp. heating	Low power mech.	Med. power mech.	Lighting, fan, etc.	Energy utilised
Solar	250.9	0	0	0	0	250.9
Wind	0	0	6.2	12.8	0	19.09
Biomass	234.05	411.7	0	0	24.2	670
Biogas	0	0	0	0	12.94	12.94
Electricity	0	0	0	30.53	0	30.53
End use energy supplied	485	411.7	6.2	43.4	37.2	983.5

Energy harvested from solar resource is about 250.9 GWh/annum which is used to meet the low temperature heating requirement. Wind energy resource is used for low (6.2 GWh/annum) and medium power mechanical (12.8 GWh/annum) end uses contributing about 19.09 GWh/annum. Ample biomass resource is available in the taluk which is utilised for low (234.05 GWh/annum) and medium temperature heating (411.7 GWh/annum) and also to generate electricity (24.2 GWh/annum). Similarly, biogas is used for electricity generation (12.94 GWh/annum) and grid electricity supply is utilised to meet the medium power mechanical end use energy requirement (30.53 GWh/annum). Model is successfully simulated the resources and end use combination to generate feasible solution with minimum operating cost. However, it can also be inferred that, taluk can meet all the energy needs from locally available resources while maintaining efficiency and minimum cost. Since the energy system utilises renewable energy sources, significant greenhouse gas (GHG) emission can be avoided which is an essential step to reduce global warming. This model will generate employment in the village level which contributes to the development of the region and energy security.

Discussion and Conclusion

Focus on the renewable energy potential with integrated energy plan highlight the availability of sufficient resources to meet the demand at taluk level. Kumta taluk receives abundant solar insolation throughout the year which varies from 5.5 to 5.75 kWh/m^2/day. Annual average insolation of the district is about 5.5 kWh/m^2/day where, it experience more than 5.6 kWh/m^2/day for about 250 days. District experiences wind from west coast which varies from 1.9 to 4 m/s where coastal villages have higher wind energy potential. Low speed wind turbines are most suitable for the region which can be used for irrigation and electricity generation. Wind energy generation systems can also be integrated with solar and biomass gasifier based generator for reliable electricity production. Village level energy potential maps gives insights for distributed generation from rooftop level to installation in barren lands. Seasonal variation in the resource availability will help to understand the dynamics and pattern of energy generation which is a critical information for grid integration and load expansion.

Quantification of bioenergy is carried out based on availability, which shows that about 670 GWh energy available annually. Similarly, taluk has good number of cattle and buffalo population which can generate about 12.9 GWh of energy annually. Energy from plant and animal residues can be utilised for low and medium temperature heating and also for electricity production.

Integrated energy plan with the objective of cost minimisation is developed and validated. Optimisation results shows that, annual operating cost of the system is INR 22.11 crores and unit energy cost is about INR 0.22/kWh. The simulated model could supply 983.5 GWh/annum to meet the various end use energy requirement. System installation and commissioning could be decentralised and resources shall be harvested depending upon the availability. Nevertheless, the work illustrates the availability of 983.5 GWh energy from locally available resources. Model implementation could significantly reduce the GHG emission while reducing the stress on central grid. It would also generate employment in the village level which could also enable entrepreneurship opportunities. This model (Regional Integrated energy Plan: RIEP) is replicable in all taluks or cluster of villages, which highlights the flexibility and strength of the approach. Integrated renewable energy planning has the potential to minimise the operating cost while exploiting sustainable, reliable and environmental friendly renewable energy sources. This transforms rural India to self-reliant and self-sustained systems with energy sufficiency, which helps in realising the dream of total electrification in the country and scope for employment and education opportunities at local levels.

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References

1. T.V. Ramachandra and Ganesh Hegde (2014). Scope for Distributed Renewable Energy Systems in South India, IEEE Global Humanitarian Technology Conference - South Asia Satellite (GHTC-SAS), 26-27 September 2014.
2. R.P. Behnke, J.L. Cecda, L.S. Vargas, and A. Jofre (2005), A Distribution Company Energy Acquisition Market Model with Integration of Distributed Generation and Load Curtailment Options. IEEE Transactions on Power Systems, Vol. 20, Issue 4, pp. 1718-1727.
3. Central Electricity Authority (CEA), Government of India. (http://www.cea.nic.in/reports/monthly/dpd_div_rep/village_electrification.pdf).
4. S. Chakrabarti and S. Chakrabarti (2002). Rural electrification programme with solar energy in remote region—a case study in an island. Energy Policy Vol. 42, pp. 33–42.
5. Ministry of Power, Government of India.
6. Pathomthat Chiradeja and R. Ramakumar (2004). An Approach to Quantify the Technical Benefits of Distributed Generation. IEEE Transactions on Energy Conversion, Vol. 19, pp. 764-773.
7. Muhammad Ibrahim, M. Anisuzzaman, S. Kumar and S.C. Bhattacharya (2002). Demonstration of PV Micro-Utility System for Rural Electrification, Solar Energy, Vol. 72, pp. 521-530.
8. A.B. Kanase-Patil, R.P. Saini and M.P. Sharma (2009). Integrated renewable energy systems for off grid rural electrification of remote area, Renewable Energy, Vol. 35, pp. 1342-1349.
9. G.D. Kamalapur and R.Y. Udaykumar (2010). Electrification in rural areas of India and consideration of SHS, 2010 5th International Conference on industrial and Information Systems, ICIIS 2010, Jul 29 - Aug 01, 2010, India.
10. Mel George and Rangan Banerjee (2011). A methodology for analysis of impacts of grid integration of renewable energy, Energy Policy, Vol. 39, pp. 1265-1276.
11. T.V. Ramachandra, Ganesh Hegde and Gautam Krishnadas (2014), Scope for Solar Energy in Uttara Kannada, Karnataka State, India: Roof Top PV for domestic electricity and standalone systems for irrigation. Productivity, Vol. 55, No. 1, pp. 101-119.
12. T.V. Ramachandra, Ganesh Hegde and Gautham Krishnadas (2014). Potential Assessment and Decentralized Applications of Wind Energy in Uttara Kannada, Karnataka. International Journal of Renewable Energy Research, Vol. 4, Issue. 1, pp. 1-10.
13. T.V. Ramachandra, Rishabh Jain and Gautham Krishnadas (2011). Hotspots of solar potential in India. Renewable and Sustainable Energy Reviews, Vol. 15, pp. 3178–3186.
14. T.V. Ramachandra (2009). RIEP: Regional Integrated Energy Plan. Renewable and Sustainable Energy Reviews, Vol. 13, pp. 285-317