Implement Relevant Renewable Energy Harvesting In Rural India to Achieve Sustainability Goals – an Attribute Selection Model

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Abstract: With an ever-growing and developing world, rise in energy demand is inevitable. In many circumstances, this is not possible as many rural areas lack access to electricity. The main culprit for this is the demand in urban areas. As the population density in metropolitan cities is high, the citizens consume most of the energy produced by the power plants, for instance, residential, commercial buildings, and industries. This dependency causes intermittent electricity flow as there is variation in demand daily, monthly, seasonally and yearly, which in turn causes an unnecessary variation in power plant output. As a result, organizations requiring urgent / continuous electricity cannot have stable access due to the fluctuations. Abiding by Goal 7 of United Nations Sustainable Development Goals (Affordable and Clean Energy), it is required that producing clean energy and having a stand-alone (off-grid) system is desirable to tackle this intermittency. Consequently, in case of excess electricity produced, it is returned to the grid or to any nearby area where there is demand. In the case of an independent / isolated University Campus, surplus electricity can be given to the nearby rural area. This position paper discusses and explains the methods and ways to use renewable sources and grid power to counter such effects depending upon that specific region. It includes two case studies with a need to imbibe and construct a mathematical model including all the concerned parameters and their application.

Keywords: Affordable and Clean Energy; Energy Consumption; United Nations, Sustainable Development Goal 7

1 Introduction

India is a developing country. A crucial constituent of the Indian economy is the Agriculture sector which covers 16% of the national GDP [1]. Agriculture, at scale, requires huge portions of land for farming and livestock management. Agriculture is a, labor intensive industry, with regular man-power requirement. As a result, the farmers tend to settle near their farms, away from the urban cities. It also mitigates the effect of pollution produced in metropolitan cities. However, the farmers lack access to a reliable and continuous energy source. Many State Electricity Boards are not very keen to extend their Electricity Grid Connections to remote

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areas as it is not economically viable and does not produce enough revenue. Hence villagers tend to explore alternative sources of energy that contribute to global warming and climate change, which are not in tune with the standards laid down for the United Nations Sustainable Development Goals.

Approximately 74.3% of India's population resides in rural areas, thus aggravating the problem [2]. Due to lack regular and reliable availability of electricity, tools used for farming are deemed void, like water pumps and electrical machinery. Therefore, renewable sources of energy become imperative for sustainability. As the prime population experiences this Energy drought, it is required to address this issue, without causing any adverse effects on the environment.

2 Literature Survey

In 2019, India achieved a milestone with 100% electrical connectivity in the rural areas under the *Saubhagya* scheme, but a hundred percent electrification is still not attained. A village is declared electrified when 10% of the households have access to power [3]. It still leaves a large chunk of the village population not having access to electricity. Hence off-grid electricity is the preferred alternative for their daily electrical needs. It gives rise to many micro-grids. Micro-grids are self-sufficient energy systems that produce their own energy [4].

Grid-connected households are dependent on the power plant that predominantly runs on fossil fuel. There can be electrical shortages due to load shedding and maintenance. But, the grid gives stable energy and can handle heavy loads. Having a grid connection involves time and investment, which are not guaranteed to be profitable in the long run.

Whereas, Off-grid households are not dependent on the grid and provide clean energy but are dependent on factors like irradiance in case of Solar Photo Voltaics (PV) and wind velocity in case of Wind turbines. Hence the energy is intermittent and cannot take heavy loads.

Various existing models were studied in the domain of Sustainable Energy. The models intended to determine the energy demand and the energy production capacity for a nation and its contribution towards the GDP of the country. They are:

LEAP Model [5, 6]

The Stockholm Environment Institute developed the model LEAP (Long-range Energy Alternatives Planning System). It is a static energy-economy-environment model. The energy demand, consumption, and environmental impact are treated as objects, and the energy demand, consumption, and environmental impact of each sector are forecasted by the model and the economic benefits of each energy scenario is analyzed. The model is an end-use energy consumption model. It includes scenarios like BAU (Business As Usual), RET (Renewable Energy Technology), and ARET (Accelerated Renewable Energy Technology).

PAT Model [7]

Perform, Achieve and Trade (PAT) are designed to enhance energy efficiency in industries with the basic green energy concept to comply with international policy. To improve targets on specified Specific Energy Consumption (SEC) in a cost-effective manner, the PAT mechanism was designed to be adopted by the industry. For a successful delivery PAT model needs improvement to give its operational mechanism scale, complexities, and timelines.

DSM Model [8, 9] **–**

Demand Side management (DSM) consists of two mechanisms namely, price responsive demand and demand response program. This model aims to decrease the demand during peak consumption while avoiding additional energy production to provide an eco-friendly standard of living. It encourages the energy load demand when the real-time price is low and discourages it when the price is high.

LUT Model [10] **-**

The LUT energy model is created using the linear optimization of the parameters on the given energy system. The model takes into consideration the previously defined constraints. It is applied to the given energy system with the assumptions for the future Renewable Energy (RE) power generation and forecasted demand. The primary aim is to minimize the Total Annual Energy System Costs (TAESC). The TAESC is the sum of the costs of installed capacities of the different technologies and energy generation. It also includes the energy system in self-generation mode and consumption of energy for residential, commercial, and industrial sectors.

3 Renewable Energy Sources [11]:

India is geographically diverse, with the Himalayas in the North and the Thar Desert in the North West. It gives rise to a multitude of sources of energy. At the very North of the Country, Ladakh consists of high amounts of Geothermal Energy prospects, while the Coastal regions have accessibility to Ocean and Wind Energy. The Government of India has set a target of installing 175 GW of renewable energy capacity by 2022. The following are all the types of renewable energy prospects across the country:

1. Solar
2. Wind
3. Geothermal
4. Ocean and Tidal
5. Hydroelectric
6. Biomass

3.1 Solar:

India lies in the Solar Belt with the Tropic of Cancer running through its mid-region and above the Equator. The country is in a Solar energy-rich zone. India receives an average irradiance of approximately 4 kWh/m2/ day. In recent times, Solar has proved to be beneficial and profitable, courtesy to the technological advancements at the advent of the 21st Century, with cheaper modules due to their widespread usage. Solar serves as a huge possibility to meet the demands of the entire country's power requirements due to its abundant availability.
For rural electrification, off-grid decentralized applications have been advantageous to meet energy demands like cooling and heating in the villages and the urban areas with the lowest tariff rate of Rs.2.4/kWh in July 2018. National Solar Mission targets the installation of 100 GW grid-connected solar power plants by 2022.

3.2 Wind:

India consists of numerous hilly terrains that give rise to wind energy harvesting. With a 7600 km long coastline, the prospects of utilizing this energy are imminent. The wind energy sector is the most promising, with the country placed fourth highest in installed capacity of wind energy in the World with a power capacity of 39.25 GW. The Ministry targets an expansion of this sector to 60 GW by 2022. India does not have any offshore wind energy harvesting, hence a target of 5 GW capacity by 2022 and 30 GW by 2030 has been set.

3.3 Biomass:

Biomass is an important energy source for the country. It has benefits like availability and carbon-neutral form of energy. It also has the potential to provide significant employment in rural areas. Biomass is also capable of providing firm energy. About 32% of the total primary energy use in the country is still derived from biomass. More than 70% of the country's population depends upon it for its energy needs, majorly by the villagers. A total capacity of 10.2 GW is installed in Biomass Power. The nation targets to install a further 10 GW of capacity by 2022.

3.4 Geothermal [12]:

Geothermal Energy has the potential to provide clean and reliable energy. It is mainly used for power generation and direct heating/cooling. It can be utilized for electrical power production as well as space/ direct heating applications, for instance, space or district heating by Ground Source Heat Pump or generating hot water for domestic/ industrial use. Implementation of this technology in India is still in the initial stages with no geothermal power plant set up in the country due to high upfront cost.

3.5 Ocean and Tidal [12]:

Tidal energy has the potential to produce an extensive capacity of 12.5 GW according to a study conducted by IIT Madras. Since it is possible to implement them only in the coastal region, it is suitable for only off-grid electricity generation, especially in remote locations where fossil fuel-based electricity is still used and with no other alternative.

3.6 Hydroelectric:
Hydroelectric power generation is the most famous renewable source of energy with many countries accepting it as well as implementing it on a large scale. The rise of this source of energy has made it one of the favorite nominees for base load operations in the future. As a result, the Ministry is giving special emphasis on mechanical and electricity generation by promoting the use of new and efficient designs of water mills. It also plans for remote village electrification by setting up micro hydro projects with a capacity of up to 100 kW. India has an installed capacity of 46 GW of Hydroelectric energy, as on March 2020.

4 Characteristics of the Indian subcontinent

India has six geographical divisions, namely, the Himalayas, the Indo Gangetic Plains, the Deccan Plateau, the Thar Desert, the Eastern and the Western Coast. Each of these regions has differences in attributes like temperature, rainfall, wind velocities, elevation, etc.
Energy consumption depends on all these factors. People living in colder regions use energy for heating purposes while energy is used for cooling in the hotter regions. Another factor that plays an important role is the population density and the related energy demand. Demand Side Management is vital, as the system must not be over-modeled, causing unwanted expenses and waste of clean energy while being sufficient for the required demand. The excess energy can be given back to the grid. It eventually acts as another opportunity for the State Electricity Boards to extend their grid lines for the excess electricity that will even out the Supply and Demand, followed by the Renewable Integration into the system.

5 Mathematical Model

With the above indicated attributes, it is evident that certain energy sources are present in particular regions as clean sources. These factors help to find the best source for that specific region. Hence, formulating a mathematical model to find the best source and its utilization is paramount. Having these variables to play with a threshold values will give the preference of the source with the best possible outcome, depending on energy and investment. Having such a model will solve a layman’s problem of choosing the best alternative/s.

Developing a model that can be replicated in every situation and gives the best outcome for that region acts as a catalyst for better understanding which in turn gives better results. Importantly, it aims to mitigate the energy crisis faced by the villagers by helping them know the best alternative for them and also creating a sustainable environment. The model considers the necessary design parameters and current constraints required for it.

6 Variables and their dependency

The basic parameters should be analyzed and the energy source with the highest availability should be taken into design, according to the local demand and the population density. As energy demand is directly proportional to the population in that region, along with variation in the region, for instance, urban areas will consume more energy per capita than rural. The variables that play a vital role in determining the best source are as indicated in Table 1.

Table.1. Sources and their respective Parameters

Source	Parameter	
Solar Thermal	Daily Solar Irradiance	Moderate to High
	Temperature	Moderate to High
	Wind	NA
	Rainfall	Scarce
	Water Source	NA
	Elevation	NA
Solar Photo Voltaic (PV)	Daily Solar Irradiance	Moderate to High
	Temperature	Low to Moderate
	Wind	NA
	Rainfall	Scarce
	Water Source	NA
	Elevation	NA
Wind	Daily Solar Irradiance	NA
	Temperature	NA
	Wind	High
	Rainfall	Moderate
	Water Source	NA
	Elevation	Moderate to High
Hydro	Daily Solar Irradiance	NA
	Temperature	NA
	Wind	NA
	Rainfall	Moderate to High
	Water Source	High
	Elevation	High
Ocean and Tidal	Daily Solar Irradiance	NA
	Temperature	Moderate to High

	Wind	NA
	Rainfall	Moderate to High
	Water Source	High
	Elevation	Low

If more than one source has a better edge than the others, the following criteria will be taken into consideration:

1. Total annual energy prospects.
2. Investment cost
3. Energy Demand
4. Return On Investment (ROI)

6.1 Case Study I:

Thar Desert, Western Rajasthan, consists of high daily solar irradiance averaging approximately 6.1 kWh/m^2/day as in Fig. 6, scarce rainfall as in Fig. 5 and water source as in Fig. 1, moderately strong winds with power density of 200-225 W/m^2 as in Fig. 7 as well as moderate population density as in Fig. 2, and average annual temperature of 27.5^{o}C as in Fig. 4. Thus, the best renewable source of energy is Solar Thermal and Solar PV, followed by Wind.

6.2 Case Study II:

The Maharashtra district of Satara is situated along the hilltops, with an elevation in the range of 500-100m as in Fig. 3, moderate population density as in Fig. 2, and approximately 2000 mm of rainfall as in Fig. 5. It also receives a daily average solar irradiance of 5.8 kWh/m2 as in Fig. 6 and an average annual temperature of 25^{o}C as in Fig. 4 combined with a high wind power density of 250 W/m2 as in Fig. 7. But at higher altitudes, the occurrences of stronger winds are evident. Thus the best source of energy, in this case, is a Wind turbine. Solar does seem possible, but since Satara is located in hilly terrain with many slopes, it is inadvisable to implement solar in this region.

7 Conclusion

The villages can employ technology with the best prospective outcome for that region. As India lives in the villages, this technique can ensure that local electrical needs are satisfied. Many State Electricity Boards refrain from extending their lines to many villages as they are non-profitable. The proposed model provides an opportunity to extend the lines to add surplus energy to the grid quota, whenever required by the grid.

India is power-hungry as it is a developing country. It would need all the resources to provide for the overall development of the country. It would not only impact the energy sector but also help employment, where the people in villages are provided with jobs to maintain their respective local energy systems and ensure electrical transmission.

Importantly, Academic Institutions are the best option for this as they can provide learning experiences and technical knowledge in this sector which will benefit the nation in the long run.

Moreover, organizations can also look for village adoptions under the Corporate Social Responsibility (CSR). It involves the steps needed to adhere to the United Nations Sustainable Development Goal 7, Affordable and Clean Energy. It is beneficial for any company to take responsibility for any underprivileged village and improve the local standards as per the clauses laid down in United Nations Sustainable Development Goal 7.

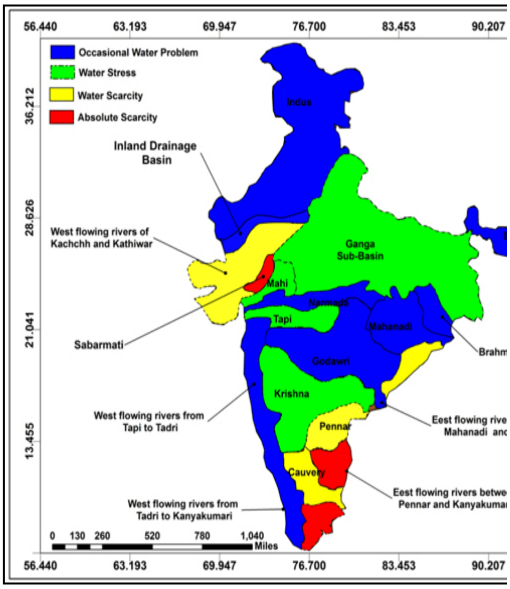

Fig. 1 Water Table Map of India [13]

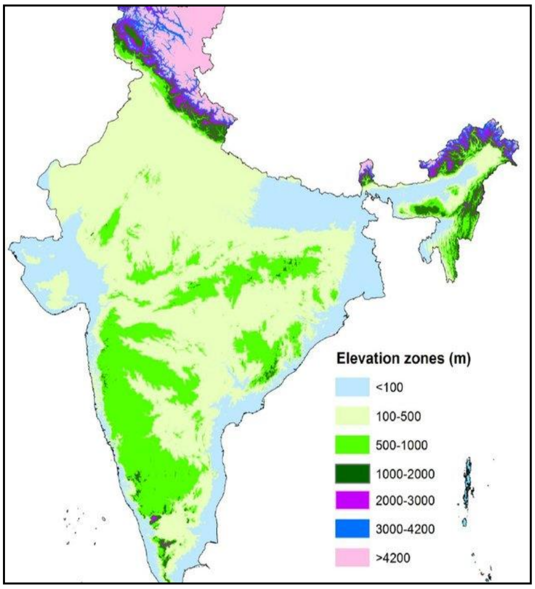

Fig. 3 Elevation map of India [15]

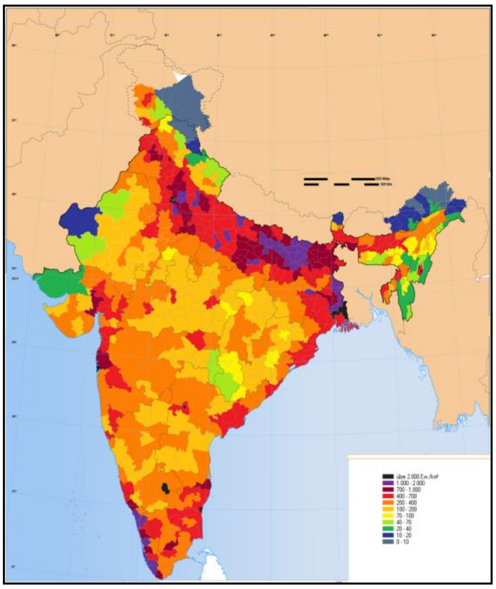

Fig.2 Population Density Map of India [14]

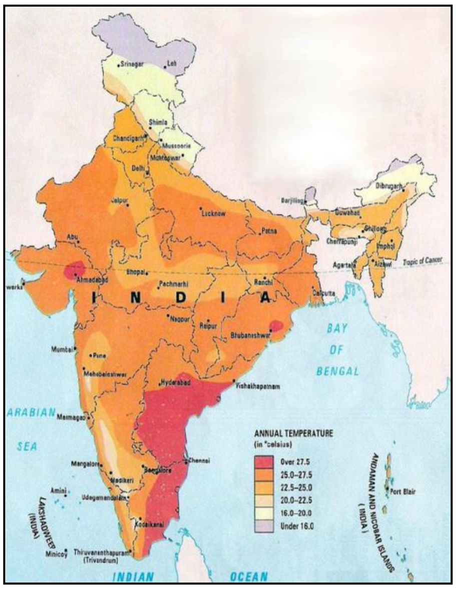

Fig.4 Temperature Map of India [16]

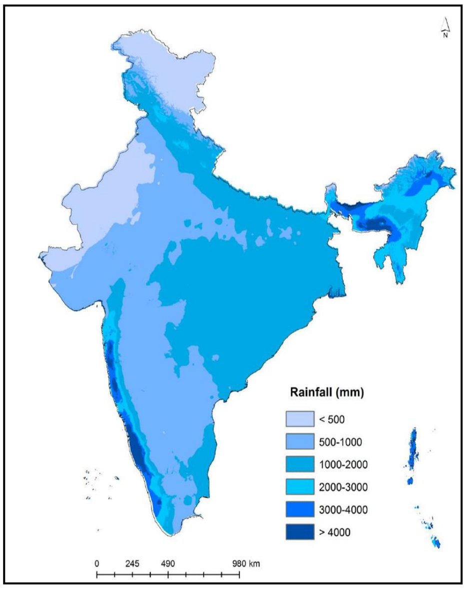

Fig. 5 Rainfall Map of India [17]

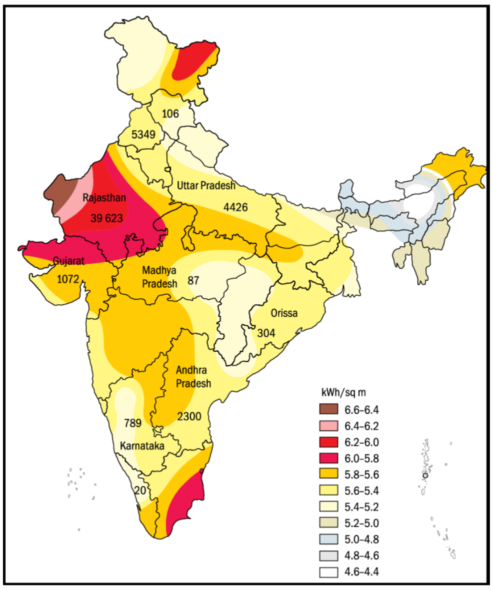

Fig. 6 Solar Map of India [17]

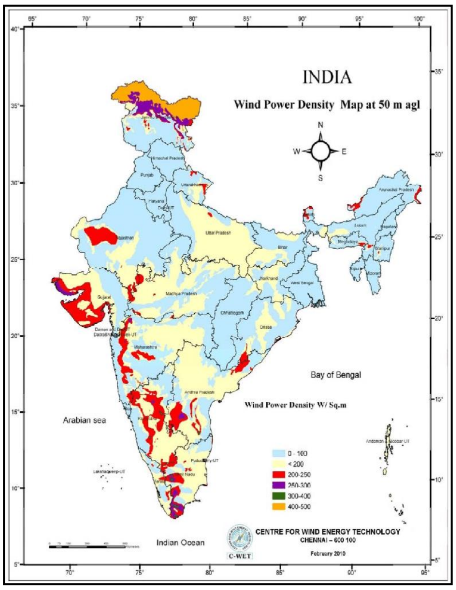

Fig. 7 Wind Map of India [18]

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