Mathematical Model To Implement Relevant Renewable Energy Harvesting In Rural India To Achieve Sustainability Goals

Harsh Malapur[1], Mangesh Bedekar[2]

1. *Student, School of Mechanical Engineering, Dr. Vishwanath Karad MIT-World Peace University*
2. *Professor, School of Computer Engineering Technology, Dr. Vishwanath Karad MIT-World Peace University*

Abstract:

With an ever-growing and developing world, a 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 plant, for instance, residential, commercial buildings, and industries. Alternatively, this dependency causes intermittent electricity flow as the demand varies daily, monthly, yearly, and seasonally, which in turn causes an unnecessary variation in power plant output. As a result, organizations requiring urgent power cannot have stable access due to the fluctuations. Abiding by Goal 7 of United Nations Sustainable Development Goals (Affordable and Clean Energy), it is empirical that producing clean energy and having a stand-alone system (off-grid) is beneficial to tackle intermittency. This paper explains the methods and ways to use renewable sources and grid power to counter such effects depending on that specific region. It includes two case studies with a need to imbibe and construct a mathematical model including all the dependent variables and their application. Consequently, in case of excess energy produced, it is returned to the grid or any nearby demand. In the case of an isolated university, surplus energy can be given to the rural area.

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 requires huge land at its disposal for farming and livestock management. As a result, the farmers tend to settle 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 refuse to extend their Electricity Grid Connection as it does not produce enough revenue. Hence villagers move towards other sources of energy that contribute to global warming and climate change, opposing the standards of United Nations Sustainable Development Goals. 74.3% of the nation's population resides in rural areas, thus alleviating the problem [2]. Due to lack of electricity, tools for farming deem void, like water pumps and machinery. Therefore, solutions in terms of finding renewable sources of energy become imperative for sustainability. As the major population experiences this Energy drought, it is empirical to do the needful, without adverse effects on the environment.

2. Grid and Off Grid:

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 leaves us with a large chunk of the 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. Microgrids are self-sufficient energy systems that produce their 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 provides clean energy but limited by factors like irradiance for Solar PV and wind velocity for Wind turbines. The energy provided is intermittent and cannot take heavy loads.

3. Literature Survey:

LEAP Model [5,6]-

The model LEAP (Long range Energy Alternatives Planning system), was developed by the Stockholm Environment Institute and is a static energy-economy-environment model. It treats energy demand, consumption, and environmental impact as objects, and the model forecasts the energy demand, consumption, and environmental impact of each sector and analyzes the economic benefits of each energy scenario. 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) is designed to enhance energy efficiency in industries with the basic green energy concept to comply with international policy. The PAT mechanism is designed to be adopted by industry to improve target on specified specific energy consumption (SEC) in a cost-effective manner. Perform, Achieve and Trade (PAT) needs improvement to give its operational mechanism scale, complexities and timelines for successful delivery.

DSM [8,9] –

Demand side management (DSM) includes mechanisms of both price responsive demand and demand response programs [9]. The first one refers to those changes applied by consumers to their electric load profile in response to energy market price signals for improving the economic efficiency of their energy consumption. This mechanism aims to decrease the peak demand 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 discouraging it when the price is high.

LUT model [10]-

The LUT energy model is based on a linear optimization of the energy system parameters under previously defined constraints, applied to the system with the assumptions for the future RE power generation and demand. The main target of system optimization for the model is to minimize the total annual energy system costs, which is calculated as sum of the costs of installed capacities of the different technologies, energy generation and generation ramping. In addition, included in the energy system is the self-generation and consumption of energy for residential, commercial and industrial sectors.

4. Renewable Energy Sources [12]:

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 Head of the Country, Ladakh consists of high amounts of Geothermal Energy prospects, while the Coastal regions have 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

4.1 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 purposes 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 the year 2022.

4.2 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 promise ng, 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 harvesting facility, hence a target of 5 GW capacity by 2022 and 30 GW by 2030 has been set.

4.3 Biomass:

Biomass is an important energy source for the country. It has benefits like being widely available, carbon-neutral, and 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 and more than 70% of the country's population depends upon it for its energy needs. A total capacity of 10170 MW is installed in Biomass Power. The nation targets to install a further 10 GW of capacity by 2022.

4.4 Geothermal [13]:

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.

4.5 Ocean and Tidal [13]:

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 the remote locations where fossil fuel based electricity is still used and with no other alternative.

4.6 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 favourite nominee 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 hydel projects with capacity up to 100 kW. India has an installed capacity of 46 GW of Hydroelectric energy as of March 2020.

5. Characteristics of the Indian subcontinent-

India has six regions, 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 particular attributes like temperature, rainfall, wind velocities, elevation, etc.
Energy consumption depends on all these factors. Since people living in colder regions use energy for heating purposes, while it is used for cooling in the hotter zones. 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 can always be given to the grid. This eventually acts as an another opportunity for the State Electricity Board 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.

6. Mathematical model:

With the information, 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 particular region. Hence, formulating a mathematical model to find the best source and its utilization is paramount.

Having these variables to play, with a threshold value, 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. Constructing a model that can be replicated in every situation and give the best outcome for that region acts as a catalyst for the better understanding, in-turn giving 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 create a sustainable environment. It will not only provide the best but also give the designing parameters required for it.

6.1 Variables and their dependency:

The basic parameters should be compared to each other and the source with the higher chance should be then taken forwards to design it according to the demand and population density. As demand will be 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 certain variables that play key role in determining the best source are as follows-

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 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. ROI

6.2 Case Study I:

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

6.3 Case Study II:

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

7. Conclusion:

The villages can employ the method with the best prospective outcome for that region. As India lives in the villages, this technique can ensure the people of the nation are regarded equal in terms of the electricity needs met. As many State Electricity Boards refrain to extend their lines to many villages as they are non-profitable, it provides an opportunity to extend the lines to add surplus energy in the grid quota, which is also required by the grid. India is power-hungry as it is a developing country. It would need all the resources it has 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 the village are provided with jobs to maintain their respective systems and ensure electrical transmission. Importantly, Academic Institutions are the best option for this as this can provide a learning experience along with educational knowledge in this sector which will benefit the nation in the long run.

Moreover, organizations can also look for village adoption as a way to fulfill Corporate Social Responsibility (CSR). As this method involves the steps needed to adhere according to the United Nations Sustainable Development Goal 7, Affordable and Clean Energy, it would be beneficial for any company to take responsibility of any underprivileged village and improve the standards according to the Goal 7.

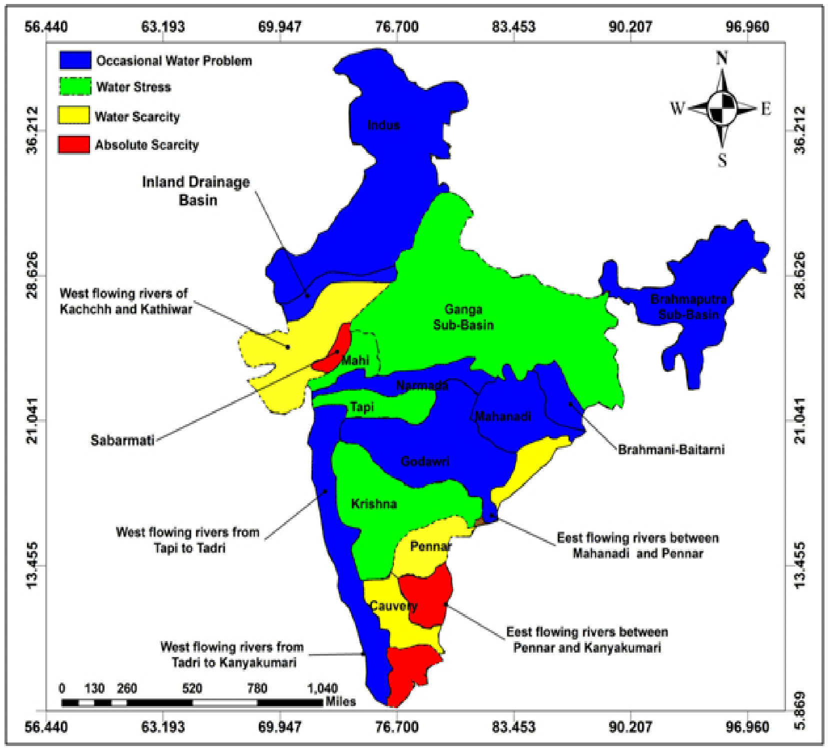

Fig. 1 Water Table Map of India [14]

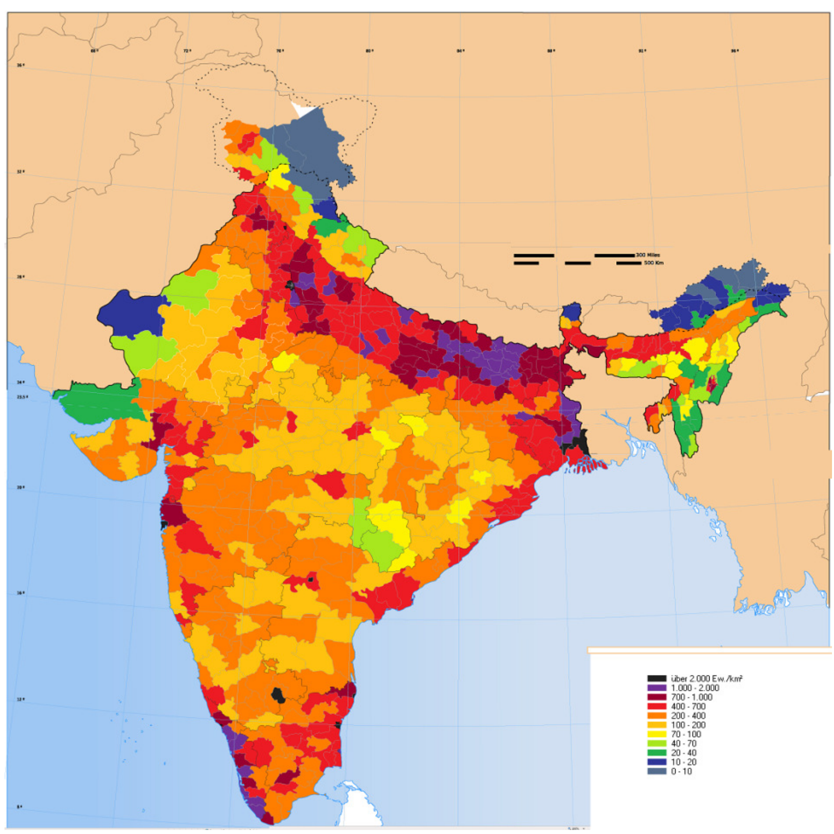

Fig.2 Population Density Map of India [15]

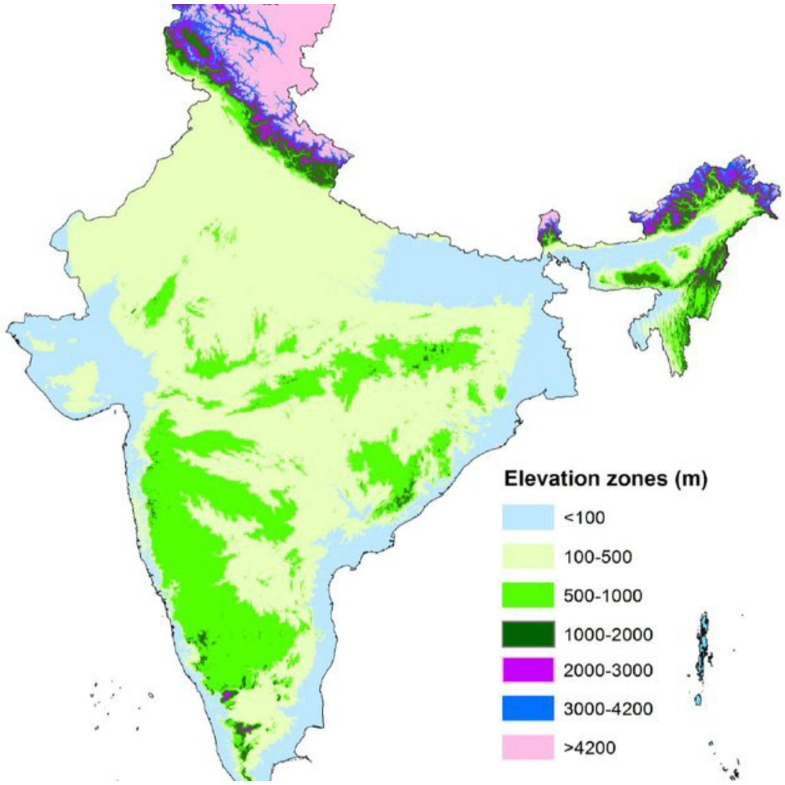

Fig. 3 Elevation map of India [16]

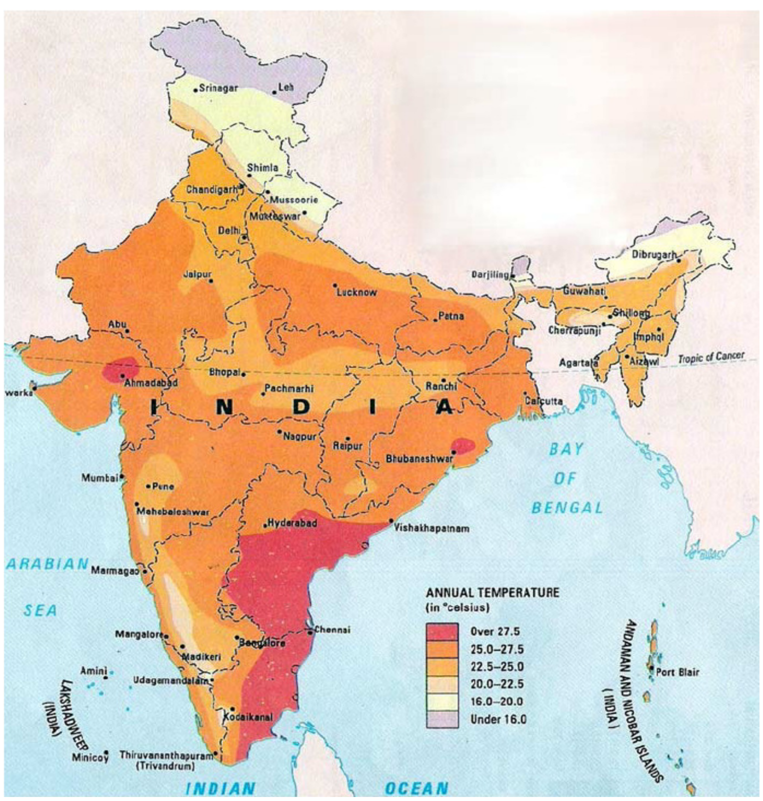

Fig.4 Temperature Map of India [17]

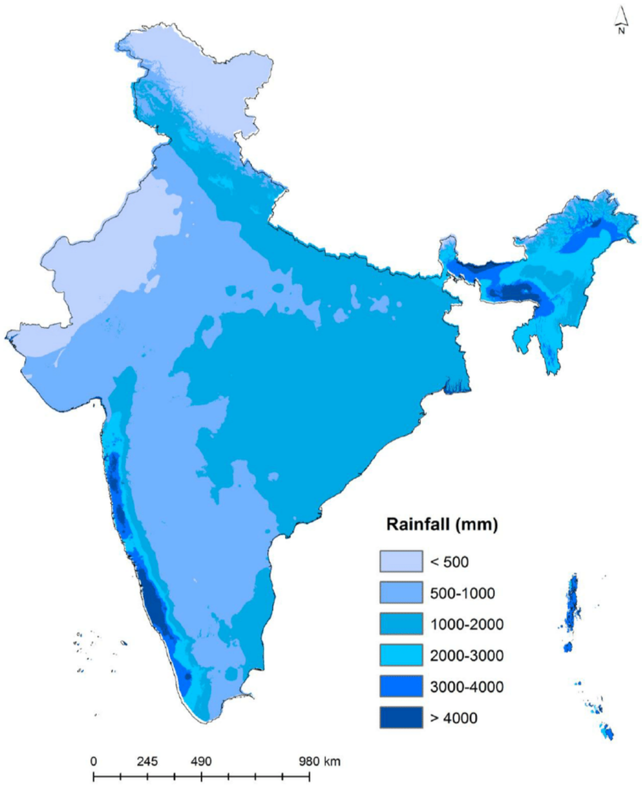

Fig. 5 Rainfall Map of India [16]

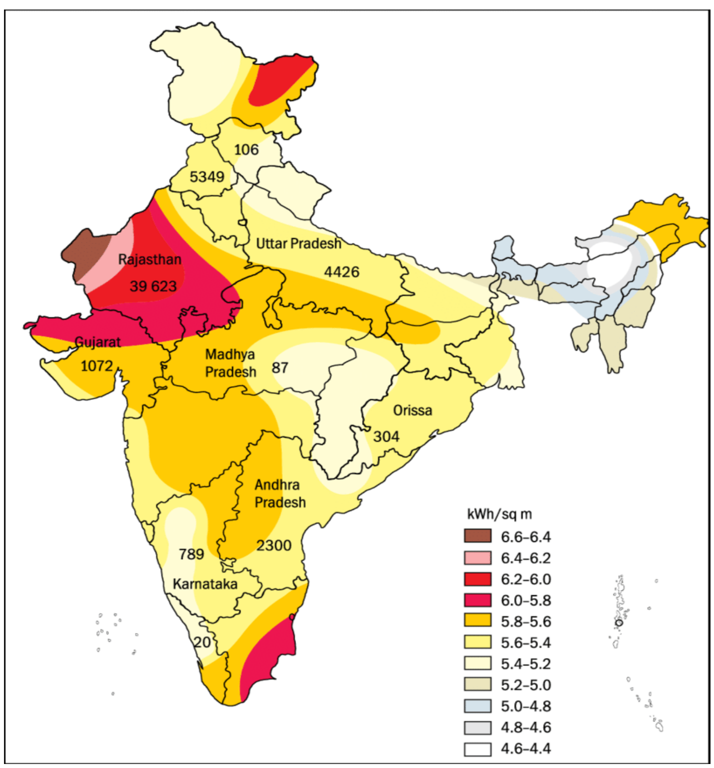

Fig. 6 Solar Map of India [18]

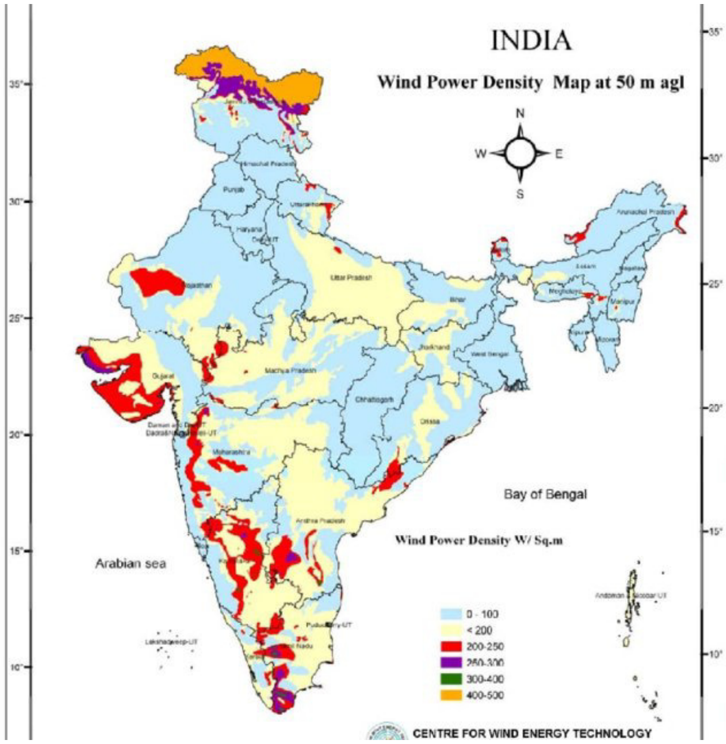

Fig. 7 Wind Map of India [19]

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