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Table of Contents

List of Tables

List of Figures

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Glossary

BSRN	Baseline Surface Radiation Network
CDM	Clean Development Mechanism
CERC	Central Electricity Regulatory Commission
CGWB	Central Ground Water Board
CIGS	Copper indium gallium diselenide
CIS	Cadmium-Indium-Gallium-Selenide
CLFR	Compact Linear Fresnel Reflector
CSP	Concentrated Solar Power
CST	Concentrated Solar Thermal
C-WET	Centre for Wind Energy Technology
DNI	Direct Normal Insolation
DSS	Deep Seismic Sounding
FRU	Field Research Unit
FSD	Full Supply Depth
GDP	Gross Domestic Product
GEBA	Global Energy Balance Archive
GEDA	Gujarat Energy Development Agency
GEOS	Goddard Earth Observing System
GETCO	Gujarat Energy Transmission Company
GHI	Global Horizontal Insolation
GIDC	Gujarat Industrial Development Corporation
GIS	Geographical Information System
GLCF	Global Land Cover Facility
GoI	Government of India
GSI	Geological Survey of India
GW	Giga Watt
Ha	Hectare
HAWT	Horizontal Axis Wind Turbines
IITM	Indian Institute of Tropical Meteorology
IMD	India Metrological Department
IREDA	Indian Renewable Energy Development Agency
ISCCP	International Satellite Cloud Climatology Project
JNNSM	Jawaharlal Nehru National Solar Mission
LULC	Land Use Land Cover
MAST	Mean Annual Surface Temperature
MNRE	Ministry of New and Renewable Energy
MT	Metric Tonne
MToE	Million Tonnes of Oil Equivalent
MVC	Maximum Value Composite
MVC	Maximum Value Composite
MW	Megawatt
NAL	National Aerospace Laboratories

NGRI	National Geophysical Survey of India
NLSE	National Laboratory for Sustainable Energy
NWRAP	National Wind Resource Assessment Program
PF	Protected Forests
PTC	Parabolic Trough Collector
PV	Photo Voltaic
RE	Renewable Energy
REE	Rare Earth Element
RF	Reserved Forests
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
SDSS	Spatial Distribution Support System
SERC	State Energy Regulatory Commission
SNA	State Nodal Agency
So-Na-Ta	Son-Narmada-Tapi
SPV	Solar Photo Voltaic
TWh	Trillion watt hour
VAWT	Vertical Axis Wind Turbines
WMO	World Meteorological Organization

Executive summary

Introduction

The sources of energy from the conventional sources like coal, oil, natural gas, etc. are limited in quantity and if they were depleted at the present rate of consumption, they will be going to exhaust in the coming few decades. With the development of the mankind, in the present life style, it is very difficult to imagine the life without energy or more precisely without electrical energy. What can be the solution to this? The only answer came to anyone's mind is to think of sources which are non-exhaustible, i.e. renewable sources of energy. Solar, wind, biomass, tidal, geothermal, ocean thermal etc. are the main names in the list of Renewable Energy (RE) sources. Energy security has become more important in the case of developing countries like India because most of such countries heavily depend on the oil imports for their energy demand, and this contributes a lot in terms of the money outflow from the country. The solution for nation like India to overcome such problem if seen in longer time span is to become self-sustainable in terms of energy and too from the sources which are renewable in nature. India is a big country having different climatic zones in different part of the country, and it is very difficult to point out that this renewable energy source is best for India. As the potential of renewable energy sources are heavily dependent on the geography of the location. Beyond this, the government of India is committed for "Power for all by 2012"and to provide all households with electricity at an affordable price by 2012. The only sustainable solution is to increase the contribution of renewable energy sources in the total energy mix. At present, RE contribution is very less (7.7%) in overall energy mix (Installed capacity 167 GW)[1] as on November 2010. Government of India (GoI) is putting a lot of efforts in increasing RE share and targets set as 20 GW under national solar mission for 2022 clearly shows government willingness to this. Gujarat is one of the biggest states of the country having a large amount of waste land along with good solar radiation for most of the year. Apart from solar, there are winds, biomass, tidal, geothermal resources are also available in the state. Proper estimation of potential of any renewable energy technology is essential for planning and promotion of the technology. There has been some state level potential assessment of these resources under the Government of India programs for renewable energies. In the present study a focus has been made to go beyond the previous approaches and an integrated approach for Renewable Energy Potential assessment has been made at the district level, considering the availability of the waste land, water potential, existing electrical transmission network, gas grid network etc. Geographical Information System (GIS) has been used in finding out the waste land and in analysing the biomass and wind potential and mapping the solar and wind power potential sites over the state.

Objective of study

The broad objective of the study is

- To carry out the Integrated Renewable Energy potential assessment for the state of Gujarat,
- To develop a Renewable Energy atlas which can give user a bird's eye view of relative potential of these RE sources at the district level in coordination with existing network of electrical transmission, gas grid network, and Narmada water canal network

[1] http://www.powermin.nic.in/JSP_SERVLETS/internal.jsp accessed on 2010-12-27

Methodology of study

For the renewable energy resource assessment of Gujarat, a logical approach has been adopted. The methodology includes data collection on the previous estimates of Renewable energy potential in the state, analysing those data, finding out the shortcoming and need for improvements that can be made on potential assessment methods, including the impact of technology development in to the actual potential. Various government agencies like GEDA, GIDC, GETCO, CGWB, IMD, etc have been contacted for collection of the data and information required for the study. The land use and land cover (LULC) data of Gujarat were collected for the present year and analysed through the Geographic Information System (GIS). The lands that are appropriate for the installation of solar and wind power projects and the lands having potential for producing biomass had been identified based on the LULC map of the state. The available data for all the RE resources, collected from the secondary sources has been mapped and used for the assessment of district wise RE potential.

For solar energy potential assessment the solar resources for each of the district from NASA satellite data has been used for developing the District wise GHI and DNI. This data along with the suitable wasteland data has been used to estimate the total solar power potential, both for solar photovoltaic plant and concentrated solar thermal power plants. In the case of wind energy, the wind power density map at 80 m height from the Indian Wind Atlas developed by Centre for Wind Energy Technology (C-WET), Chennai has been used and digitised using GIS and then potential estimation for the wind is done by the identification of suitable wasteland in those areas where the wind power density is above 200 W/m2. In the case of biomass, database of cultivated crops, woody biomass available from forest and trees outside forests is collected. The estimation of theoretical potential of biomass from crop residues has been estimated using the formula which is a function of area under agricultural crops and cropping pattern, agricultural crop residue production, current use of crop residues, and availability of crop residue for energy generation. The residue consumed as fodder is subtracted to estimate the quantity of surplus biomass available for the energy production. The estimates of woody biomass under forest cover (7.51% of the geographical area of Gujarat) was estimated at the district level by taking the details of very dense forest, moderately dense forest, open forest and scrub available. An average productivity is estimated taking the methodology available in the literature to find out the biomass potential from the forest.

Some land parcels can have both solar and wind potential, so hybrid potential estimation is carried out using the shadow analysis method adopted (detailed in the integrated section). For the Solar power plants water and resource requirements is estimated and the ground water availability and the canal network are linked to find the possible availability of water resources for solar power generation.

Grid substation network, canal network and gas grid available in the Gujarat state is also integrated in the methodology of the RE potential estimation from the perspective of the infrastructure available in terms of transmission, water, and gas hybrid power plants possibility. Apart from this, tidal and geothermal resources available in the state have also been discussed in this report and an estimate of tidal power potential at Gulf of Kachchh and Gulf of Khambat has been made. Detailed methodology adopted for the individual Renewable Energy Resource and for the integrated assessment of Renewable energy potential is described in the relevant chapters.

1. Introduction

1.1 Importance of renewable energy resources

The resources for generating power by conventional methods by exploiting coal, petroleum and natural gas are fast depleting. There is every possibility of energy starvation to occur in many places in the near future. Besides, the pollutants added to the environment by these methods have already made the ecological balance nearly fragile. Thus there is an urgent need for the entire humanity to tap other resources which will at the same time be ecologically friendly. Some of such resources (non-conventional) are the sun, the wind, the biomass, and the tidal and geothermal sources. The nuclear power resources do provide a very large potential but it requires a great attention due to larger capital cost because of emergency, containment, radioactive waste and storage systems, resolution of the long-term high level waste storage issue in most countries, and issues related to potential nuclear proliferation.

Renewable energy represents an area of tremendous opportunity for India. India has already supported the growth of renewable energy technologies, the impact this has had on utilization of various technologies, and the enormous remaining potential.

1.2 Energy scenario of India

In 2008, India accounted for 17.7% of the world population but was the fifth-largest consumer of energy, accounting for 3.8% of global consumption. India's total commercial energy supply is dominated by coal and largely-imported oil with renewable energy resources contributing less than 1% (this does not include hydro > 25 MW) of the total generated electricity. The current power-generating capacity is insufficient to meet current demand, and in 2009–2010, India experienced a generation deficit of approximately 10% (84 TWh) and a corresponding peak load deficit of 12.7% (over 15 GW). India's frequent electricity shortages are estimated to have cost the Indian economy 6% of gross domestic product (GDP) in financial year 2007–2008. The states with highest deficits included Maharastra, which is India's strongest state economically, and Punjab, both with peak deficits of 24%[1].These figures do not take into account the large un-electrified parts of the country. As per the latest data available, 16% of villages in the country are remaining un-electrified[2].

India's continued economic growth and success in lifting hundreds of millions of its citizens out of poverty will depend on a rapid expansion of the power sector. The government is aware of the size and importance of the challenge and that success will depend on structural changes in the industry and new technologies and business models. Despite increasing electrification at the village level, approximately 35% of the total population or 400 million people still remained without access to electricity in 2008[3].

A snap shot of the India's power sector in terms of percentage contribution in total installed capacity is shown in the figure 1.1.

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[1] Central Electricity Authority.Monthly Reports, March, April 2010, http://www.cea.nic.in/power_sec_reports/reports.htm. Accessed September 2010

[2] Central Electricity Authority."Progress Report of Village Electrification as on 30-06-2010." http://www.cea.nic.in/god/dpd/village_electrification.pdf. Accessed October 2010

[3] "Electricity Access in 2008 - Developing Asia" International Energy Agency, http://www.iea.org/weo/database_electricity/electricity_access_database.htm.Accessed September 2010.

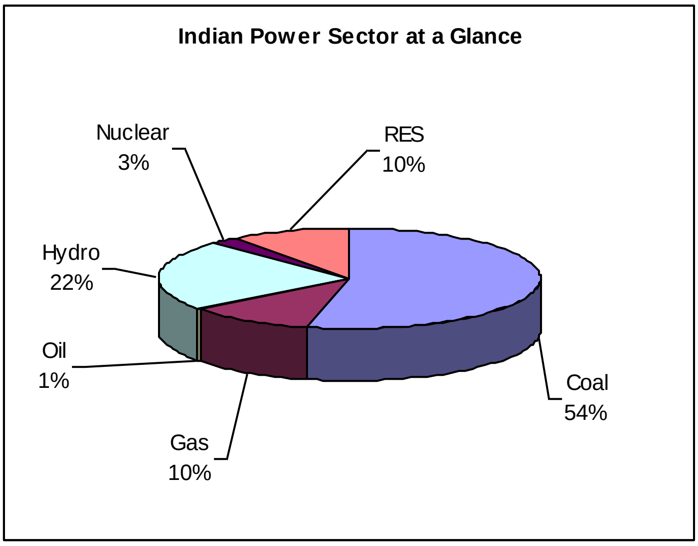

Figure 1.1 Indian power sector at a glance

The electricity intensity of the Indian economy—the percentage growth of electricity consumption that correlates with 1% of economic growth—fell from approximately 3.14% in the 1950s to 0.97% in the 1990s[1]. In 2007, it was at 0.73%. The main reason for this reduction is that India's growth until now was based more on the service sector (with an electricity intensity of only 0.11%) than on growth in industrial production (with an electricity intensity of 1.91%)[2]. Today, for each 1% of economic growth, India needs around 0.75% of additional energy[3]. The Planning Commission of India, which coordinates Indian long-term policy, analyses different scenarios and in one of them assessed that this value could fall to 0.67% (by 2021-22 to 2031-32)[4].

India is facing a great challenge to build up its energy infrastructure fast enough to keep pace with economic and social changes. Energy requirements have risen sharply in recent years, and this trend is likely to continue in the foreseeable future. It is driven by India's strong economic and population growth as well as by changing lifestyle patterns. Growth and modernization essentially follow the energy-intensive Western model of the 19th and 20th centuries, in which economic growth correlates with a comparable growth in the energy use.

For GDP growth to continue at 7–8%, the Planning Commission estimates that primary energy supply would increase at the very least by 3 to 4 times by 2031-2032 and the electricity generation capacity by 5 to 6 times, based on 2003-2004 levels[5]. In 2031-2032, India will require approximately 1,500 to 2,300 million tonnes of oil equivalent (MTOE) to cover its total commercial primary energy needs[6]. The Indian government by itself does not have sufficient financial resources to solve the problem of energy shortages. It must rely on

[1] Indiacore."Overview of Indian Power Sector."http://www.indiacore.com/power.html.Accessed August 2010.
[2] McKinsey& Company India."Powering India—The Road to 2017." 2009., page 90
[3] BP."Statistical Review of the World Economy, 2009." Calculation based on the figures of 2000-2008.
[4] GOI Planning Commission. "Integrated Energy Policy - Report of the Expert Committee 2006.", August 2006; pages 18-19. The study indicates that the international average value is 0,83%, whereby countries with a higher GDP (over USD 8,000 per person per year) tend to have a lower average energy elasticity of 0.76% (see page 19).
[5] ibid.;page xiii (Overview).
[6] ibid.; page 20.

cooperation with the private sector to meet future energy requirements. This opens up interesting market opportunities for international companies.

One of the key missions of Government of India is "The exploitation and development of various forms of energy and making energy available at affordable rates". For the growth of economy and for socio-economic development of all strata of society, the commensurate growth of India's energy sector is crucial. Meeting the goal of full energy access will require India to add new electricity generation capacity at an even faster speed, most likely to reach 300 GW by 2017. Against this backdrop, expansion of reliance on renewable energy (RE) resources would increase India's energy security by way of lessening dependence on both imported fuels. RE is not subjected to escalating prices like fossil fuels. Further, RE has significant environmental benefits, including zero carbon emissions.

RE has made a strong case in addressing the above challenge for the following reasons:

- While the costs of fossil fuels increase, the costs of solar and other RE technologies are decreasing owing to technology advancement.
- The dependence on local energy sources and scalability of RE technologies make them well-suited to meet the need for power in remote areas that lack grid and road infrastructures.
- Opportunity for India to play a leadership role in the emergent global green economy leading to increased investments in RE field.

The potential for RE in India is enormous given its large land mass that receives among the highest solar irradiation in the world; its long coastline and high wind velocities that provide ample opportunities for both land-based and offshore wind farms; its significant annual production of biomass; and its numerous rivers and waterways that can be tapped for hydropower. There are the needs for policy interventions to tap these vast renewable energy resources at a sustainable way. Some of the major initiatives taken by the country in the forms of policy and regulations are described below:

In 1992, Government of India established the world's first Ministry committed solely to the development of RE sources and in 1987, the Indian Renewable Energy Development Agency (IREDA), to provide financial assistance for RE and energy efficiency projects, Central Electricity Authority, Central Electricity Regulatory Commission, the Power Finance Corporation and the Rural Electrification Corporation Ltd, have together planned and implemented many RE laws and regulations in order to realize the enormous RE potential in India, such as:

- **Electricity Act 2003**[1] was one of the major steps towards liberalizing the power market in India and encouraging competition and attracting investment. The promotion of cogeneration and electricity generation from renewable sources is identified as a consideration in the establishment of tariff regulations, allowing for the Central Electricity Regulatory Commission to establish a preferential tariff for renewable energy.
- **National Electricity Policy 2005**[2] stipulates the need for increasing the share of electricity from non-conventional sources and allows for the State Energy Regulatory Commission (SERC) to establish a preferential tariff for electricity generated from renewable sources to enable them to be cost competitive.

[1] http://www.cea.nic.in/home_page_links/ElectricityAct2003.pdf accessed on October 2010
[2] http://www.cea.nic.in/reports/national_elec_policy.pdf accessed on October 2010

- **National Tariff Policy 2006[1],** mandates each SERC to specify a renewable portfolio obligation with distribution companies in a time-bound manner. These purchases are to be made through a competitive bidding process. The objective of this policy is to enable RE technologies to compete with conventional sources.
- **Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) 2005[2],** aims to extend electricity to rural households and to households below the poverty line.

Eleventh Five-Year Plan (2007-2012), India's Planning Commission hired a new and renewable energy working group to develop plans for RE during the Eleventh Plan and prospective plans for the Twelfth and Thirteenth Plans. A 10% power generation capacity from renewable sources by 2012 was set as a target in the Eleventh Plan. To achieve this, subsidies that promote investment ensuring optimal performance (e.g. depreciation benefits) are to be phased out and replaced with incentives that emphasize performance (e.g. feed-in tariffs).

These laws and regulations together with various policy instruments and programmes dedicated to specific renewable technologies have supported Government of India to expand its RE power generation in the past decade.

Despite all efforts of GoI, RE generation has not developed as expected. But it is clearly seen from over the years; wind power has developed significantly in many states, and now by the announcement of Jawaharlal Nehru National Solar Missions, it is expected that the solar power will develop at the faster pace. The state like Gujarat, Rajasthan, Tamil Nadu, Karnataka and others will see the RE growth not only due to resource availability but also due to conducive environment and supportive infrastructure development in these states.

1.3 Energy overview of Gujarat

Power, a key factor for the overall growth of the economy and the state of Gujarat has attracted a large number of private players in the sector in recent past. The total installed capacity[3] of the State was 14110 MW as on 30th April 2010, of which 6152 MW by State, 5514 MW by private sector and 2445 MW by the Central sector. The Renewable Energy resources accounts for 1656 MW. Despite this it has remained scarce across the country. On an average, Gujarat has witnessed a peak power generation capacity deficit at 25.5% during 2009, which is only next to Maharashtra, which had a power deficit of 25.9% for the same period against India's total peak deficit of 13.8% for the year 2009.

The state aims to become a hub for power generation activities with its focus on doubling the power generation policy during the XIth five year plan in order to keep pace with the rising energy demand, which is poised to grow at a rate of 10% every year.
The power-generation companies and electricity boards of various States are incurring huge losses. Gujarat is the shining exception; it has successfully converted losses to the tunes of Rs.2500 Crores in to the profits of Rs. 400 Crores. Gujarat has almost separate power grid for industrial and residential and agricultural purpose, which has been done under Jyotigram scheme[4], making it unique state for Power producing private sector companies to have their power evacuation done easily. Gujarat has highest number of power substations of 66kv and

[1] http://www.powermin.nic.in/whats_new/pdf/Tariff_Policy.pdf. Accessed on October 2010
[2] Rajiv Gandhi Grameen Vidyutikaran Yojana. http://rggvy.gov.in/rggvy/rggvyportal/index.html. Accessed August 2010.
[3] http://www.wrpc.gov.in/htm/apr10%5CCapacity.pdf accessed on 05th January,2011
[4] http://guj-epd.gov.in/epd_jyotiyojna.htm

above in India. All the 18000 villages of Gujarat are getting un- interrupted quality electricity-supply.

The coming years will witness Gujarat emerging as a hub not only for power generation from conventional sources but also from the more environmentally friendly renewable sources.

The government's draft for power policy states, Gujarat is endowed with lignite, oil &gas reserves and renewable sources of power generations like solar power, water-based power, wind and geo thermal power generation. The State has an atomic power plant situated in the southern part of the State at Kakrapar near Surat.

Looking ahead with concerns about the carbon footprints, the State is proactively considering development of renewable energy sources. For this, the State has also declared a separate Solar Power Policy so as to encourage solar power generation projects as a means for socio-economic development of these backward regions through livelihood creation for the local population.

The solar power policy entails objectives of promotion of green and clean power, to create an environment to leverage the clean development mechanism, productive use of wastelands, and promotion of local manufacturing facilities and creation of environmental consciousness among the citizens.

According to the Socio-Economic Review of the State Government for 2009-10, investments will happen in the field of wind energy for 4000 MW, biomass for 1000 MW and solar power for 716 MW. Already 34 national and international project developers have shown interest to set up 365 MW solar Photovoltaic and 351 MW solar thermal power projects in the State. As estimated nearly 2-3% of the total power requirements of the State are expected to be met through solar power alone.

In the wind energy-front, Gujarat once again has a benefit of its geographical position for having the longest coastal belt. Gradually, the State has evolved itself into a rapidly adopting renewable energy sources over past few years. Gujarat has the maximum capacity additions in wind power generation in recent years with an annual growth rate of 97.7%, as the total wind power installed capacity grew from 352.6 MW in 2005-06 to 2076.41 MW in 2010-11. The total installed capacity for wind farms in Gujarat is 2076.41 MW (as on 31st March 2011).

The power sector of Gujarat as a whole in terms of percentage contribution of power projects in total installed capacity of the state is shown below in the figure 1.2.

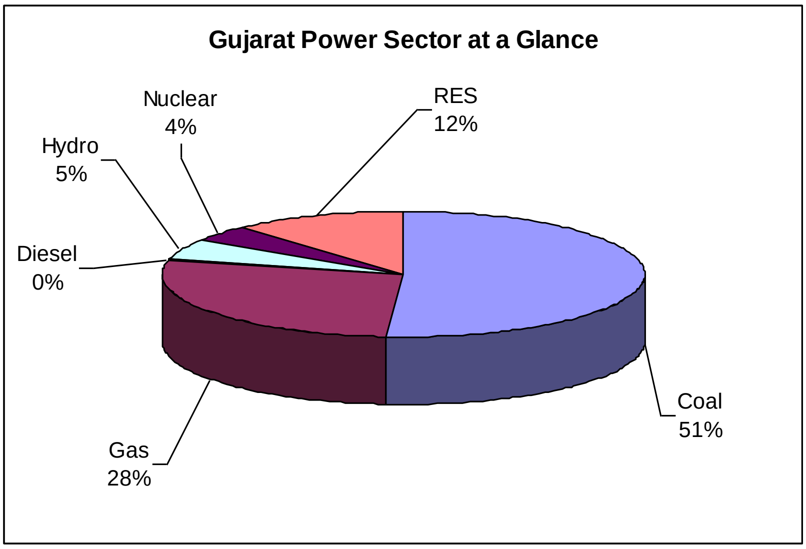

Figure 1.2 Gujarat power sector at a glance[1]

It is clearly seen from figure that Gujarat is already having almost 12% of Renewable energy installed and it is very ambitious to feed more and more power from renewable into its grid.

[1] http://www.wrpc.gov.in/htm/apr10%5CCapacity.pdf accessed on 05th January,2011

2. Potential assessment of different renewable energy resources

2.1 Land use land cover analysis of Gujarat

Introduction to geoinformatics

Geoinformatics is generally described as the science and technology dealing with spatial structure or character of any entity (resource) including its classification, qualification, quantification though capturing, storing, processing, updating, retrieving, disseminating, visualizing and portraying its attribute for an effective and efficient decision making, including the infrastructure and support necessary to secure its usage. In a very broad sense, remote sensing ad Geographical Information System (GIS) are the terms often taking about in this. Remote Sensing is "remotely acquire territorial and environmental data and to combine methods and techniques for subsequent processing and interpretation

(this definition also fits digital photogrammetry)" and GIS is "to make use of a powerful combination of instruments capable of receiving, recording, recalling, transforming, representing, and processing georeferenced spatial data" (Gomarasca, 2010). The amalgamation of these technologies with some more support tools (eg. GPS< computer hardware and software, programming skills and other) can help to develop a Spatial Decision Support System (SDSS). SDSS refers to a relatively powerful set of tools for handling spatial attributes of any entity so as to supply the decision makers with objective elements of problems related to resource, energy and environment.

The fundamental essence of out university, Energy is such an entity, which has been described in different ways. Among all, matter (quanta) and its exploitation have defined the progress of human civilization. In the social and economic terms it has become much more important in the governmental policy and securing existence of one above another. The externalities of the current usage of energy limits, environmental problems, climate change issues, there is a consistent motivation towards use of alternate sources and very precisely focus is towards renewable energy resources. Development of these renewable sources of energy is one of the most important ways of mitigating problems of shortage of global energy demand and supply, and minimizing the effects usage of fossil sources. In this, Geoinformatics can aid in realizing the potential of renewable energy resource. This has nothing to do with the generation but providing information on determining the optimal supply locations, generating facility, operational usage and distribution network. Increased usage of such a tool is in favour of the economies and essential in the interest of sound and sustainable policies, both energy and the space.

The earlier work done in this aspect is more on utilization of satellite-based information in resource assessment. The resources ranged from forest, agriculture other land use to retrieving information on solar energy (intensity), meteorology, wind and others. There are many existing satellite remote-sensing programs to inform about the distribution of such energy sources efficiently. There are a few new programs aimed towards providing information on the solar energy distribution and intensity. An opposed the exploiting the potential of remote sensing satellite data, the present work focuses on the usage of geospatial tools (geoinformatics) for enhancing the knowledge about the distribution of renewable resource, value addition using field records and providing a platform (SDSS) to visualize the available information for better decision making.

Land use land cover mapping

Spot vegetation – 1: 1 000 000

To meet the primary objective of uniform mapping of the state, data from the SPOT-VEGETATION (VGT) Earth observing system was used. The VGT sensor on-board the SPOT-4 satellite delivers daily acquisitions with a swath width of 2200 km and a spatial resolution of about one kilometre. The sensor records data from four channels, located in the blue (0.43–0.47 µm), the red (0.61–0.68 µm), the near-infrared (NIR, 0.78–0.89 µm) and the short-wave infrared (SWIR, 1.58–1.75 µm) range of the electromagnetic spectrum. Dataset of year 2009 and 2010 were used to map and monitor the temporal changes.

The SPOT Vegetation S10 (VGT-S10) data product is the Maximum Value Composite (MVC) syntheses downloaded from http://www.vgt.vito.be/. VGT-S10 products (ten day synthesis) were compiled by merging segments (data strips) acquired in a ten days. The data was corrected for system errors (error registration of the different channels, calibration of all the detectors along the line-array detectors for each spectral band) and re-sampled to UTM projection. Auxiliary data supplied with the products allow users to process the original reflectance values using their own algorithms. The pixels selected for the syntheses are based on the selection of the maximum NDVI value [NDVI = (Infrared–Red)/(Infrared+Red)], to ensure coverage of all landmasses worldwide with a minimum effect of cloud cover (http://www.vgt.vito.be/).

For the classification of the satellite sensor data, stack of maximum NDVI dataset was taken for Kharif, Rabi and Zaid seasons. The cloud classes were masked out. The mapping step involves using unsupervised classification based on the K-means algorithm run on the three sets. Each cluster was assigned a preliminary cover type label taking care of the spatial pattern and spectral or multi-temporal statistics of each class and on comparison with ancillary data and extensive ground data. Related 'single category' classes were then grouped using a convergence of evidence approach (Lillesand and Kiefer 1999). Finally all the three datasets were integrated to produce a Land use Land Cover Map. The classification was followed by post-classification refinement for a coherent set of classes. On the final output, median filtering was carried out for image smoothing.

Landsat TM/ETM – 1: 250 000

To meet the primary objective of uniform mapping of the state, different scenes of Landsat TM/ETM were used. LANDSAT TM/ETM data with a spatial resolution of 30m and the spectral wavelength of seven bands (B1 0.45-0.52, B2 0.52-0.60, B3 0.63-0.69, B4 0.75-0.90, B5 1.55-1.75 and B6 10.4-12.5, B7 2.09-2.35 □m are with 60m). Landsat has a temporal resolution of 24-25 days and swat of 188 km. With this spatial, spectral and temporal resolution, it is found suitable for land use land cover mapping. Landsat series dataset were geometrically and radiometrically corrected as per the specification of Global Land Cover Facility (GLCF) network.

Datasets of Kharif, Rabi and summer season were used to map the different crop type. Maximum likelihood classification algorithm of supervised classification technique was used to prepare LULC maps. The class specific well distribution sample/training set were used to train the computer for this. Finally the three maps with Kharif, Rabi and summer crop were summarized to prepare the detailed land use/land cover map (Figure 2.1).

Description of the land classes shown in the map and the district wise land area covered under these classes are given in Annexure-1

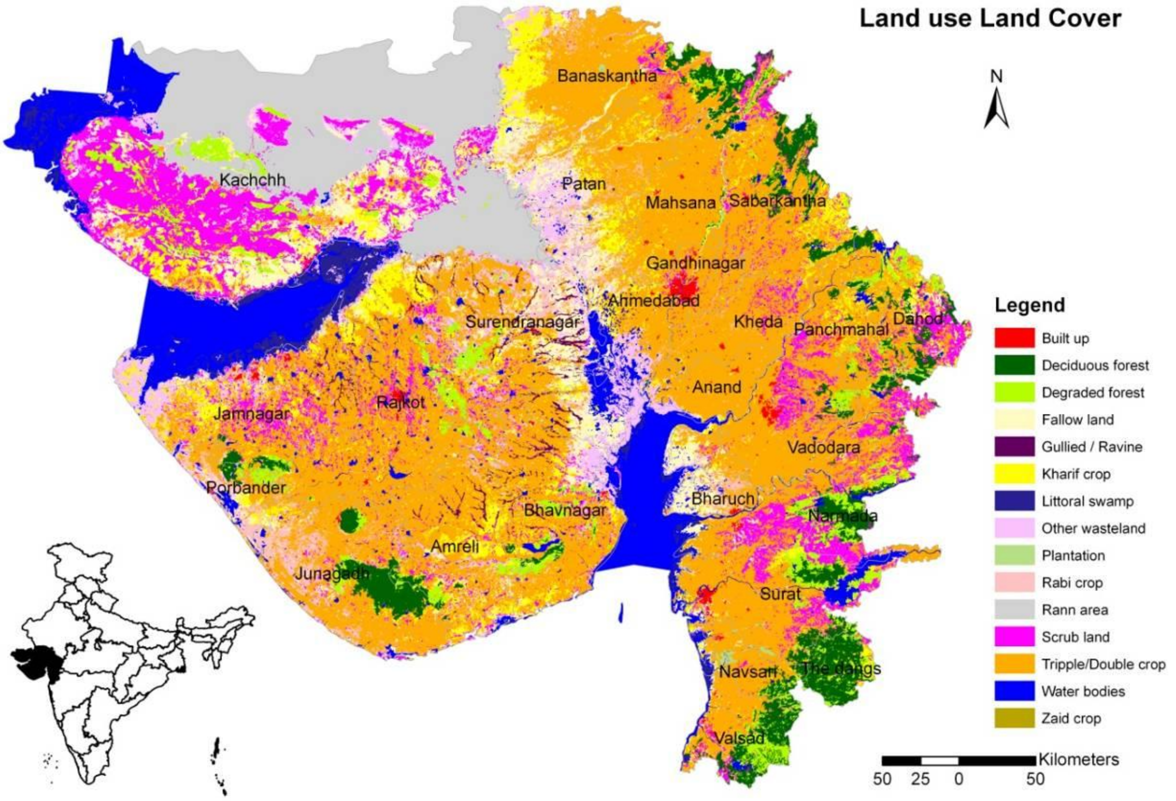

Figure 2.1 LULC map of Gujarat

2.2 Solar energy

Basic introduction

India is located in the sunny belt of the earth, thereby receiving abundant radiant energy from the sun. This solar potential exists for the most of the parts of the country. Its equivalent energy potential is estimated at about 6,000 million GWh of energy per year. The daily average global radiation varies from 5 .0 (north-eastern and hilly areas) to about 7.0 (western regions and cold dessert) kWh/m^2 with the sunshine hours ranging between 2300 and 3200 per year. In most parts of India, clear sunny weather is experienced for 250 to 300 days a year. The annual global radiation varies from 1600-2200 kWh/m^2. Apart from this, the locations which are having these good solar potential is sparsely populated and with abundance of barren land, which favours the development of solar power plants in such regions. In the western part of the country, in the states of Rajasthan and Gujarat, Thar desert and Rann of Kutcch is located. An estimate says that if alone 35,000 km2 region of the Thar desert can be utilized for solar power generation, it would suffice in generating 700 to 2,100 GW of solar power, which is far beyond India's present installed capacity. So the proper estimation of the suitable land availability in the state for solar power projects will give better idea about the

There are various technologies available for converting solar energy into electricity and researches are continuing to improve the efficiency of these solar power technologies. With the improvement in the efficiency, the total potential for the solar power project will also be increased. Basic solar power technologies are described in detail in the Annexure 2.

Previous estimates of solar power potential

The Gujarat government encourages solar power generation projects as a means of socio economic development. The Solar Power Policy 2009 aims to generate 716 MW of power. Allocations of 365 MW of SPV and 351 MW of CSP have already been made to 34 developers. Gujarat Energy Development Agency (GEDA) established by the Government of Gujarat disseminates energy information and play a catalytic role in development and promotion of renewable energy technologies in the state. It undertakes on its own or in collaboration with other agencies, programmes of research and development, applications and extension as related to various new and renewable energy sources. GEDA plays a key role in facilitation and implementation of the solar power policy 2009. It facilitates and assists project developers through a number of activities. These include identifying suitable locations for solar projects, preparing a land bank, assessing the connecting infrastructure, arranging right of way and water supply, obtaining clearances and approvals under the purview of state government etc. Based on the information received from GEDA, Gujarat has solar power potential of 10000 MWe.

Scope of refinement/improvement in potential estimation

The above potential estimate is based on the assumption of 300 sunny days in a year with the solar radiation of 5.6-6 kWh/m^2/day. This estimate also shows that it has the potential of reducing the CO2 emission 16.13 Million tonnes /year. Based on the current industry practices for the solar power plant installation worldwide, the land area requirements[1] for CSP plants varies from 16000m2/ MW to 84000 m^2/ MW and for solar PV it varies from 20000 – 40000 m2/ MW depending on the type of technology selected. When a reverse calculation is made for the land area requirement for this much capacity, it comes out to be around 836km2 of land for solar power plants, which is far less (4.1% only) than the total wasteland available in the state of Gujarat. There is another doubt whether suitability of wasteland type has been considered for the solar power plant installation. Apart from this ground water resources and grid infrastructure available in the state were not considered while making such estimates as water is one of the challenges for the installation of big solar thermal power plants and huge electrical grid infrastructure is required to evacuate the power from such remote areas.

In the present study, the following were considered

- Suitable land in each district for solar power
- Solar radiation analysis, based on satellite data for each of the district
- Ground water potential of each district
- Information on the grid infrastructure

The detailed methodology for arriving at the solar potential based on the existing infrastructure and available solar technologies is described in the following section.

Approach and methodology for current study

In the present study, realistic estimate of the land use and land cover were made for the Gujarat state using GIS software as described in above section. This has projected the

[1] "Global Concentrated Solar Power Industry Report", CSP Today, 2010-2011, page 19

different type of land available in a particular district (Annexure 1). Wastelands have following further classifications available based on the Gujarat Wasteland Atlas

- Gullied and/or Ravenous land
  - Shallow
  - Medium
- Scrub Land
  - Land with scrub
  - Land without scrub
- Waterlogged and Marshy land
- Land affected by salinity/alkalinity (moderate))
- Under Utilized/Degraded Notified Forest Land
- Under Utilized/Degraded Notified Forest Land (agricultural)
- Degraded Pastures/ Grazing Land
- Degraded Land under plantation crop
- Sands (Coastal)
- Barren Rocky Area
- Steep sloping area

Based on above wasteland classification, the land which can be best suited to solar application is the land without scrub (mostly, the barren land which does not have any capability to grow vegetation or the fallow land covered with grass is called land without scrub). These features are also found usually at relatively higher topography like uplands or high grounds without scrub. These lands are generally prone to degradation or erosion.

Although other type of land cannot be neglected for the development of solar power plant but the land without scrubs will require least land development or improvement from the perspective of the solar power plants, hence justifies from the overall cost reduction perspective.

In the present study for the solar power projects the land with scrubs class has been considered to map the solar power potential of Gujarat in the GIS platform. This scrub land category has been considered only because the fact that the scrub land being almost flat terrain, with no vegetation/trees in it can also be considered very much suitable for solar power projects, but only thing is that the cost of land development may be comparatively higher than the land without scrub category. Again only those land with scrubs which have slopes less than 3% has been considered more suitable for the solar power projects and the potential mappings have been done based on these scrub lands with slope less than 3%.

Solar radiation over Gujarat

The solar radiation analysis was made for each of the district in the state. For this, NASA satellite data were obtained (see Annexure 3) and Annual values of Global, diffuse and direct normal incidence radiation were calculated based on the monthly average of daily radiation. This data source has it's own limitations but due to unavailability of any other solar radiation data source for the entire districts has forced to use this data set. A comparison of solar radiation data available for various locations of Gujarat has been made in the Annexure 3.

The district wise Global Horizontal Insolation (GHI) and Direct Normal Insolation (DNI) data (as shown in Figure 2.2a and figure 2.2b) has been used for the estimation of total solar power potential in Gujarat.

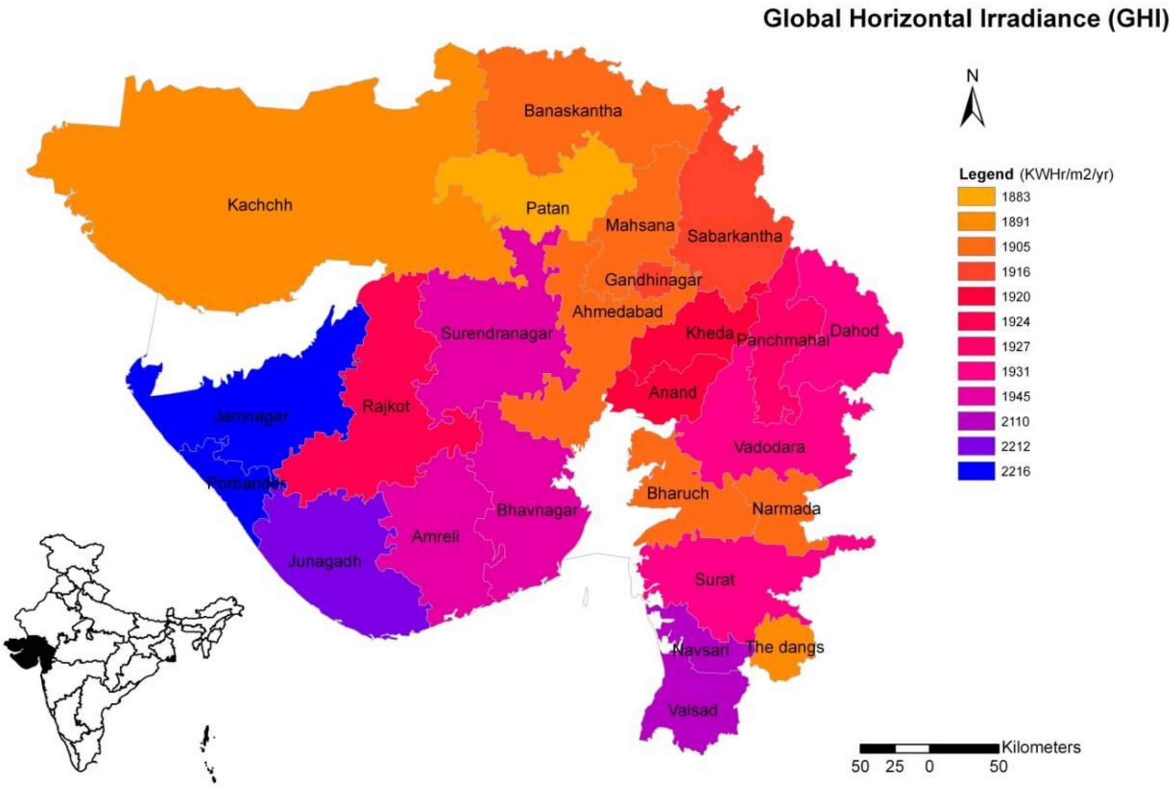

Figure 2.2a District wise GHI data for Gujarat

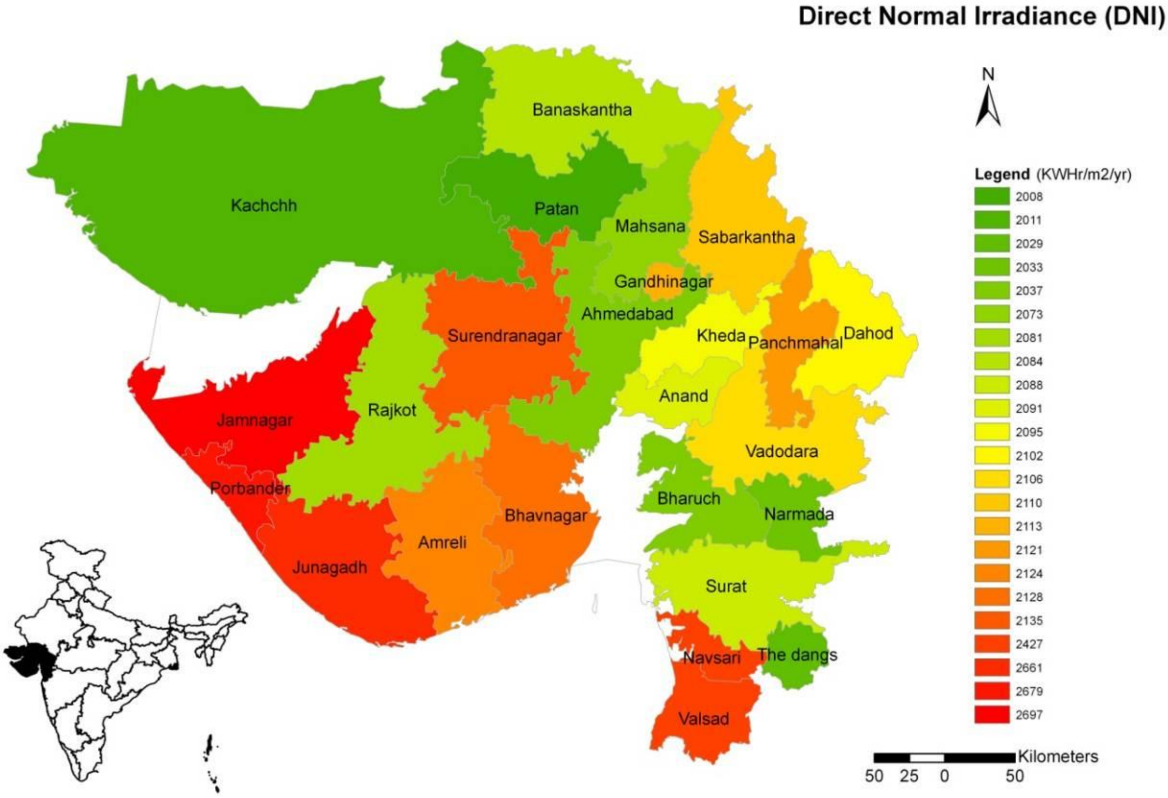

Figure 2.2b District wise DNI data for Gujarat

Mapping of Solar power potential areas

As stated above the scrub lands with slope less than 3% has been considered suitable for solar power projects. Considering the distribution and size ranges of these land polygons, following minimum sizes of land polygons have been considered for the solar power potential mapping

- For CSP the minimum land polygon size considered is 200 Ha, which corresponds to minimum 50 MW CSP project capacity
- For SPV the minimum land polygon size considered is 20 Ha, which corresponds to minimum 5 MW SPV project capacity

Based on the above considerations the total available scrub lands in Gujarat has been mapped using GIS and it is assumed that CSP projects would be more preferred over SPV projects looking at their efficiencies etc. First the total scrub land with polygon size above 200 Ha has been marked for identification of total CSP potential in the state as shown in the Figure 2.3.

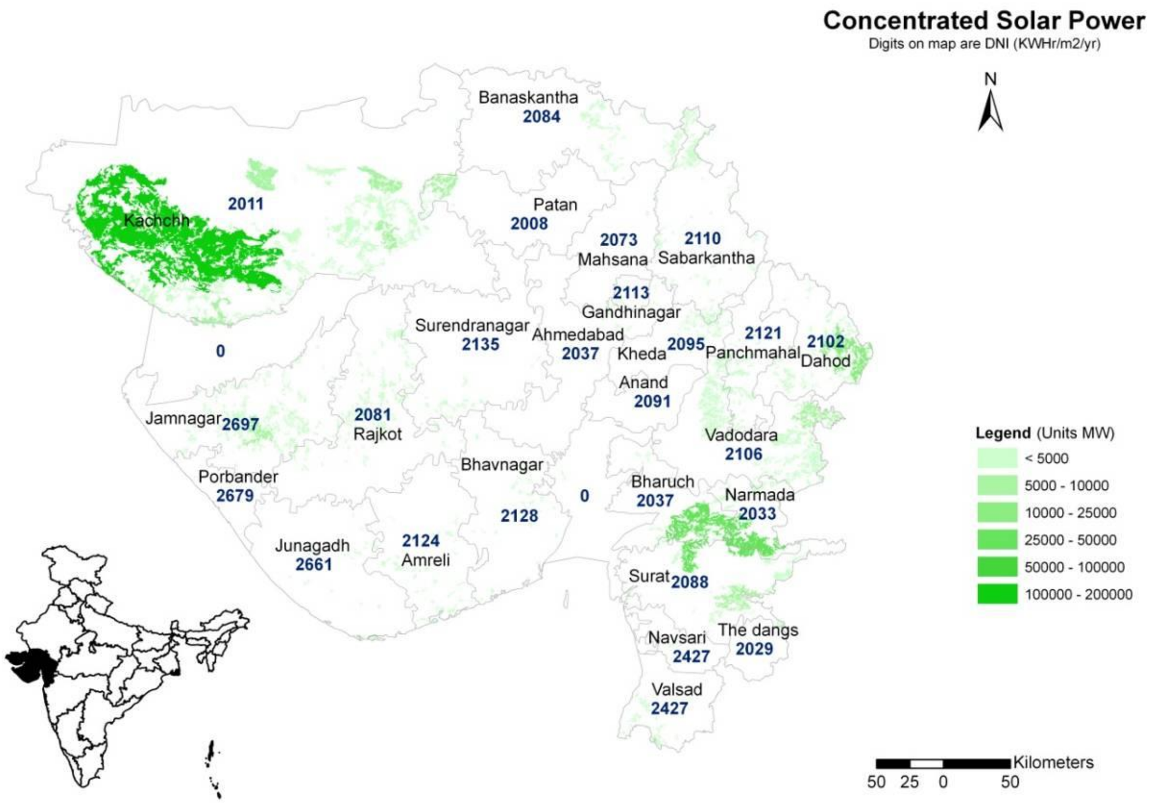

Figure 2.3 Map showing all scrub lands suitable for CSP project in Gujarat

The Solar power plant selection is further having criteria of the availability of water in the area. CSP project require lot of water for the steam and cleaning of surfaces. For the identification of most suitable CSP project location based on the water availability analysis, the Groundwater resource data for the Gujarat has been collected and also the route map of Narmada Canal Network in the state has been digitised using GIS. Land parcels of CSP which are in the district with surplus ground water availability or which are within 25 km distance from Narmada Canal has been considered as suitable sites for CSP with water availability. These lands are shown in the figure 2.4.The detailed description of the ground water availability and an analysis for solar power, based on the availability of ground water is given in section 3.2 "Ground Water Availability" and the description of Narmada Canal Network is given in Section 3.3.

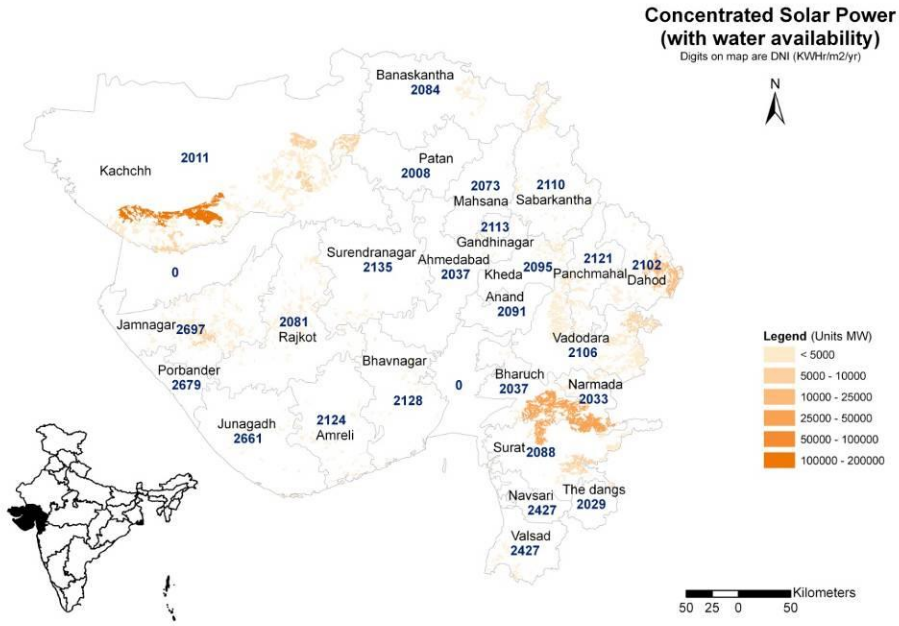

Figure 2.4 Map showing lands suitable for CSP project based on water availability in Gujarat

Further as stated above the CSP projects have been preferred over SPV projects based on their overall efficiency. The net potential for SPV power projects has been estimated based on the land parcels remaining after the land being utilised for CSP projects including water availability. Figure 2.5 is the map showing the land areas considering if all the lands suitable for solar power projects would be utilised for SPV and Figure 2.6 is the map showing the lands which will be remaining for SPV after utilisation of the land by CSP projects where the water is available.

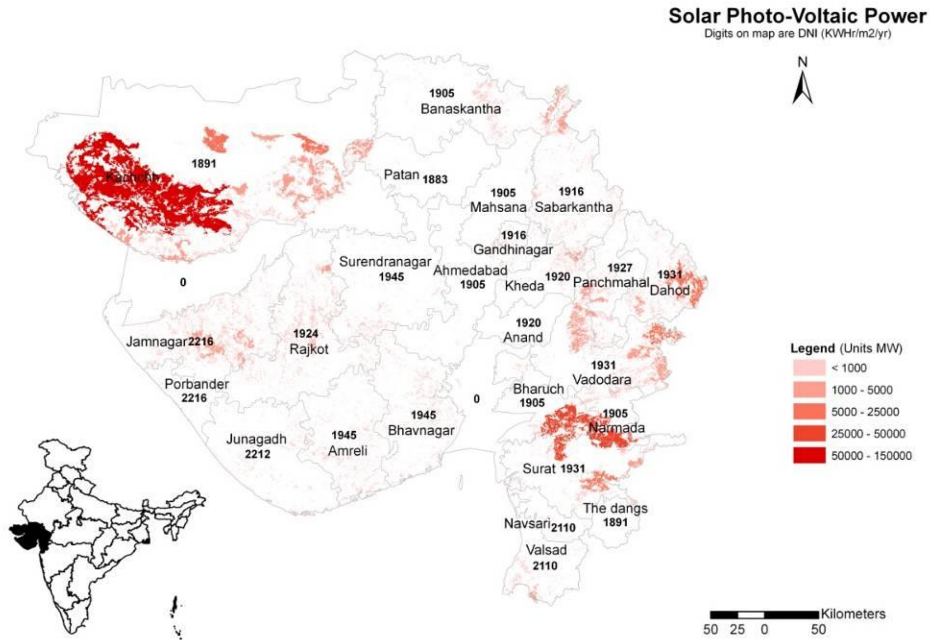

Figure 2.5 Map showing total lands suitable for SPV project in Gujarat

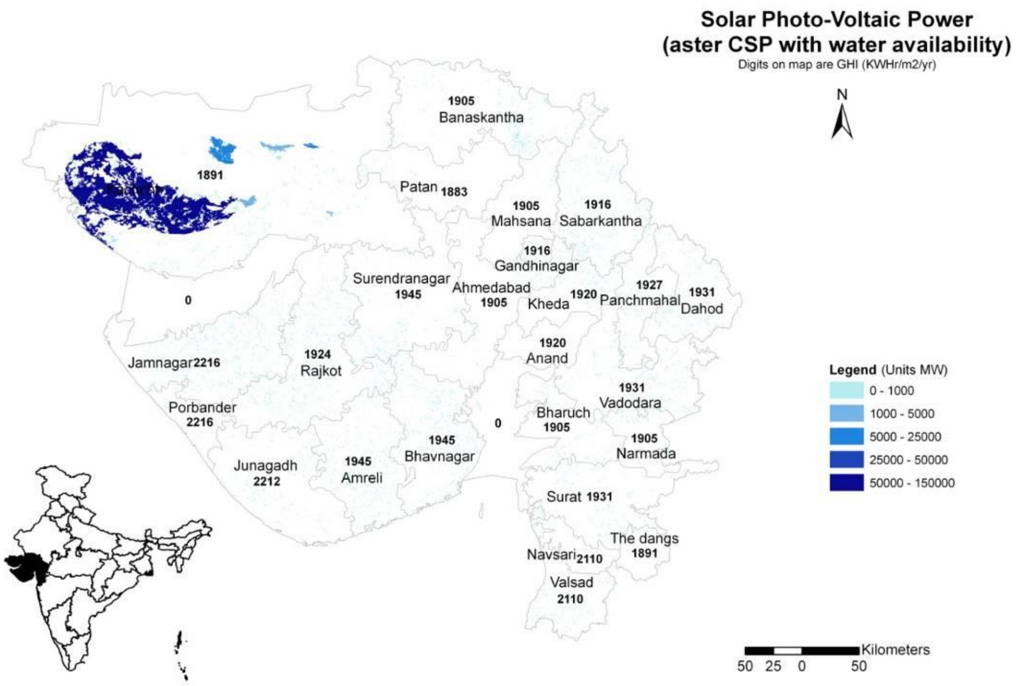

Figure 2.6 Map showing total lands suitable for SPV project in Gujarat after utilisation of CSP suitable lands based on water availability

Estimation of total solar power potential

The ground cover ratio i.e. ratio of actual solar collector area over total used land area, for different mode of tracking is different, (For fixed installation at latitude: 0.5, single axis tracking: 0.35, and for double axis tracking: 0.2). The solar potential has been estimated by considering an intermediate approach by considering the single axis tracking i.e. ground cover ratio of 0.35.

For the calculation of the theoretical solar potential in terms of MWe, solar to electrical conversion efficiency of 12% for solar PV and 14% for solar thermal is assumed.

With the methodology adopted above, a solar power potential of approximately 581 GWe has been estimated in the state of Gujarat considering the land availability of 100%, in the category of land with scrubs with slope less than 3%, energy conversion efficiencies of 12% for Solar PV and 14% for solar thermal power. Further the daily sunshine hours of 8.5 hours has been considered. Table 2.1 gives the district wise total land areas and the scrub land areas suitable for either solar PV or for CSP projects (i.e. scrub land parcels larger than 20 ha size). A summary table for the estimates of the solar power potential distribution over the districts based on these considerations is shown in the table 2.1. Details of the estimates of district wise total suitable area and the MW potential estimates for SPV and CSP with different land utilisation scenarios are given in Annexure 4.

Table 2.1 Solar power potential of Gujarat, District-wise

Sr. No.	District	Total Area (km²)	Scrub Land Area (km²)	Latitude (N)	Longitude (E)	DNI (kWh/m²/yr)	GHI (kWh/m²/yr)
1	Ahmedabad	8087	130	21.70	72.25	2037	1905
2	Amreli	7397	416	21.35	71.03	2124	1945
3	Anand	2951	0	22.68	72.67	2091	1920
4	Banaskantha	10400	449	23.79	72.03	2084	1905
5	Bharuch	5253	772	21.65	72.80	2037	1905
6	Bhavnagar	8628	432	21.47	71.15	2128	1945
7	Dahod	3733	939	21.80	73.73	2102	1931
8	Gandhinagar	2163	47	23.30	73.00	2113	1916
9	Jamnagar	14125	1284	22.00	69.47	2697	2216
10	Junagadh	8846	264	20.92	70.23	2661	2212
11	Kachchh	45652	8378	22.74	72.85	2011	1891
12	Kheda	3959	262	23.43	70.17	2095	1920
13	Mahsana	4393	48	23.34	72.17	2073	1905
14	Narmada	2755	613	21.62	72.78	2033	1905
15	Navsari	2196	37	20.54	72.72	2427	2110
16	Panchmahal	5083	334	22.77	73.95	2121	1927
17	Patan	5668	265	23.98	71.76	2008	1883
18	Porbander	2295	30	21.33	69.90	2679	2216
19	Rajkot	11203	969	21.83	70.80	2081	1924
20	Sabarkantha	7390	736	23.03	73.39	2110	1916
21	Surat	7761	921	21.12	73.31	2088	1931
22	Surendranagar	10489	276	22.52	70.80	2135	1945
23	The Dangs	1764	18	20.72	73.40	2029	1891
24	Vadodara	7555	1510	21.99	73.34	2106	1931
25	Valsad	2939	201	20.56	72.87	2427	2110
	Total	192685	19329				

District wise total land area suitable for solar PV power projects and the estimated potential for solar PV power projects are given in Table 2.2. It is estimated that if 100% of the scrub land (polygons larger than 20 ha) with slope less than 3% can be utilised then the estimated potential for Solar PV power projects will be about 506 GW.

Table 2.2 Total solar PV power potential of Gujarat

District	Total SPV land area (km²)	GHI (kWh/m²/yr)	Total SPV Potential (MW)
Ahmedabad	130	1905	3355
Amreli	416	1945	10955
Anand	0	1920	0
Banaskantha	449	1905	11579
Bharuch	772	1905	19907
Bhavnagar	432	1945	11378
Dahod	939	1931	24547
Gandhinagar	47	1916	1223

District	Total SPV land area (km²)	GHI (kWh/m²/yr)	Total SPV Potential (MW)
Jamnagar	1284	2216	38509
Junagadh	264	2212	7895
Kachchh	8378	1891	214469
Kheda	262	1920	6797
Mahsana	48	1905	1228
Narmada	613	1905	15803
Navsari	37	2110	1048
Panchmahal	334	1927	8718
Patan	265	1883	6744
Porbander	30	2216	896
Rajkot	969	1924	25229
Sabarkantha	736	1916	19093
Surat	921	1931	24063
Surendranagar	276	1945	7263
The dangs	18	1891	468
Vadodara	1510	1931	39476
Valsad	201	2110	5750
Total	**19329**		**506393**

District wise total land area suitable for CSP projects and the estimated potential for CSP power projects are given in Table 2.3. It is estimated that if 100% of the scrub land with slope less than 3% can be utilised then the estimated potential for Solar PV power projects will be about 506 GW. Further the minimum polygon size considered is 200 Ha, which corresponds to about 50 MW of CSP project.

Table 2.3 Total CSP power potential of Gujarat

District	Total CSP land area (km²)	DNI (kWh/m²/yr)	Total CSP Potential (MW)
Ahmedabad	50	2037	1611
Amreli	175	2124	5872
Anand	0	2091	0
Banaskantha	288	2084	9484
Bharuch	707	2037	22739
Bhavnagar	117	2128	3931
Dahod	752	2102	24957
Gandhinagar	24	2113	802
Jamnagar	871	2697	37115
Junagadh	94	2661	3940
Kachchh	8068	2011	256247
Kheda	166	2095	5482
Mahsana	10	2073	332
Narmada	553	2033	17760
Navsari	13	2427	479
Panchmahal	215	2121	7208
Patan	222	2008	7033

District	Total CSP land area (km²)	DNI (kWh/m²/yr)	Total CSP Potential (MW)
Porbander	3	2679	131
Rajkot	536	2081	17609
Sabarkantha	435	2110	14486
Surat	785	2088	25880
Surendranagar	126	2135	4261
The dangs	0	2029	0
Vadodara	1323	2106	44003
Valsad	123	2427	4706
Total	**15655**		**516070**

But as discussed above CSP projects require lot of water so the analysis for the lands where there could be water availability shows the CSP potential of about 345 GW. District wise details of these land areas with water availability and the CSP potential is given in Table 2.4

Table 2.4 Total CSP power potential of Gujarat considering water availability

District	Total land area for CSP based on water availability (km²)	DNI (kWh/m²/yr)	Total CSP Potential (MW), based on water availability
Ahmedabad	50	2037	1611
Amreli	175	2124	5872
Anand	0	2091	0
Banaskantha	235	2084	7735
Bharuch	707	2037	22739
Bhavnagar	117	2128	3931
Dahod	752	2102	24957
Gandhinagar	24	2113	802
Jamnagar	871	2697	37115
Junagadh	94	2661	3940
Kachchh	2763	2011	87764
Kheda	166	2095	5482
Mahsana	10	2073	332
Narmada	553	2033	17760
Navsari	13	2427	479
Panchmahal	215	2121	7208
Patan	222	2008	7033
Porbander	0	2679	0
Rajkot	536	2081	17609
Sabarkantha	435	2110	14486
Surat	785	2088	25880
Surendranagar	126	2135	4261
The dangs	0	2029	1
Vadodara	1323	2106	44003
Valsad	123	2427	4706
Total	**10294**	**54497**	**345706**

Above analysis presents the solar power potential if all the suitable area considered is either used for Solar PV projects only or for CSP projects only. But considering the higher efficiencies of CSP projects it is assumed that CSP projects will be preferred over SPV projects in the areas where there will be good water availability and other infrastructure availability. With this assumption it is then estimated that after utilising the CSP potential areas for CSP projects there would be a potential for about 235 GW of solar PV projects in the remaining land areas. District wise land area and solar PV potential are given in Table 2.5.

Table 2.5 SPV power potential remaining after CSP potential utilisation based on water availability

District	Total SPV land area after excluding CSP land (km^2)	GHI ($kWh/m^2/yr$)	Total SPV Potential excluding CSP (MW)
Ahmedabad	80	1905	2064
Amreli	241	1945	6347
Anand	0	1920	0
Banaskantha	214	1905	5518
Bharuch	65	1905	1680
Bhavnagar	315	1945	8298
Dahod	187	1931	4895
Gandhinagar	23	1916	599
Jamnagar	412	2216	12370
Junagadh	170	2212	5088
Kachchh	5615	1891	143732
Kheda	96	1920	2491
Mahsana	37	1905	967
Narmada	60	1905	1539
Navsari	24	2110	691
Panchmahal	119	1927	3105
Patan	43	1883	1091
Porbander	30	2216	896
Rajkot	433	1924	11274
Sabarkantha	301	1916	7818
Surat	136	1931	3548
Surendranagar	149	1945	3935
The dangs	18	1891	467
Vadodara	187	1931	4893
Valsad	79	2110	2243
Total	**9035**		**235548**

As it may not be really feasible to utilise all the scrub land for the solar power. different scenarios have been developed assuming that only 10%, 25%, 50%, 75% and 100% of such type of land is available for solar power plants. The results of this scenario analysis are given in Annexure 4. Further the above potentials are based on the scrub land areas and as stated above the land without scrubs would be more preferable as it will require less land development work. An assessment of these lands has also been collected from the Gujarat

Wasteland Atlas and the analysis has been done for different possible scenarios to estimate the solar power potential. These potentials based on the land without scrubs area are given in the Annexure 4.

2.3 Wind energy

Introduction

Wind energy is kinetic energy associated with movement of atmospheric air due to uneven heating of atmosphere by solar radiations, irregularities in the earth surface and rotation of the earth. Wind has considerable amount of kinetic energy when blowing at high speeds. This kinetic energy when passing through the blades of the wind turbines is converted into mechanical energy and rotates the wind blades and the connected generator, thereby producing electricity. Even though the wind turbines look simple the technology is fundamentally unique as it has to function like a standalone power plant with highly variable fuel (wind energy).

Wind power is the most widely utilised renewable source of energy. One of the best things with the technology is that it is well matured technology to be implemented in various wind power potential sites. Among all renewable energy sources being developed worldwide, the largest component is wind power which has a year-on year growth of 31.7% with global installed capacity of 158.5 GW in 2009[1]. India too is a leading country and ranks fifth in the world in the wind power installation with total wind power installed capacity of 14989 MW as of August 2011[2]. Figure 2.7 shows the progress of annual and cumulative wind power installation capacity in India

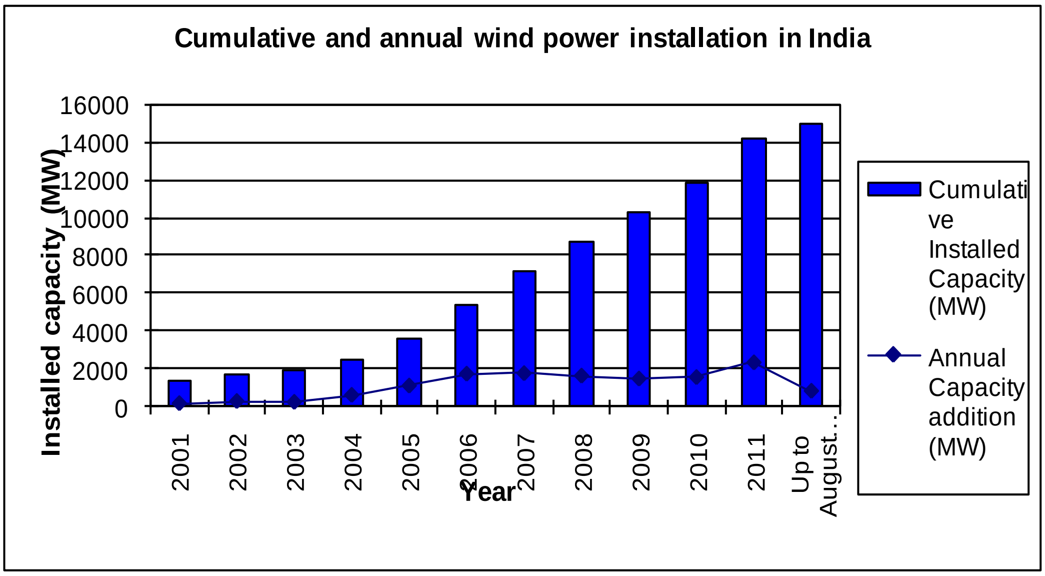

Figure 2.7 Cumulative and annual wind power addition in India

Wind turbine industry is a continuously growing industry with various technological advancements for improving the efficiency of wind turbines and extraction of energy from wind at low windy sites. Though there has been no major change in the overall architecture

[1] "Global Wind 2009 Report" Global Wind Energy Council, Brussels, Belgium
[2] Centre for Wind Energy Technology, Chennai "http://www.cwet.tn.nic.in/html/information_yw.html"

of the modern wind turbines there have been many technological improvements in the design of the wind turbines worldwide resulting in improved performances, optimal land use and better grid integration. The areas in which development work is being targeted are large size wind turbines with higher rated generating capacity, development of powerful and larger blades, improved power electronics and taller towers. The developments in these fields are as following. The wind turbine technology, it's technological advancements and the wind turbines available in Indian market are discussed in detail in Annexure 5.

Multi MW capacity wind turbine (2 MW to 2.5 MW) are now entering into the Indian wind market, though very few turbines of these ratings have been installed till now. The challenges involved for these turbines are the availability of high windy sites, roads and infrastructure/other facilities for the transportation and installation of large towers and blades etc. But once these challenges overcome, the wind energy in India can achieve the potential installation more than what has been estimated now based on the available resources.

The most important thing is to carry out the wind resource study in detail for the planning and decision making of the wind power project implementation. Without proper wind resource analysis of an area it is unwise to invest in any wind power project. The subsequent sections describe the approach and considerations made for the previous estimates of the wind power potential and then the approach used based on the latest wind resource data, wind turbine technologies and the suitable land availability. The study is carried out for the district wise wind power potential in the state of Gujarat.

Previous estimates of wind power potential

In India the wind resource assessment has been carried out under the Ministry of New and Renewable Energy's (MNRE's) Wind Resource Assessment Program which started way back in 1984 by the involvement of Field Research Unit (FRU), Bangalore of the Indian Institute of Tropical Meteorology (IITM), Pune in association with National Aerospace Laboratories (NAL), Bangalore. First the Wind Energy Data for India was prepared and published in 1983[1] which was used as base for few demonstration projects. The results of the demonstration project showcased the very much need of extensive wind resource assessment program with number of dedicated wind monitoring stations to identify the wind farmable sites in the country. Under the wind resource assessment program till now over Six hundred wind monitoring stations have been installed in 28 states and 3 union territories[2] out of which 71 stations are in Gujarat. The list and the description of these 64 locations of Gujarat is given in Annexure-6. The FRU of IITM had collected the data from 448 monitoring stations and after the establishment of Centre for Wind Energy Technology (C-WET) Chennai the National Wind Resource Assessment Program (NWRAP) have been transferred to C-WET and since 2001 the NWRAP is being executed by C-WET. The wind speed and direction data from all these stations have been analysed and the wind monitoring stations where the Wind Power Density (WPD) has been found above 200 W/m2 at 50 m height above ground level were declared as wind farmable sites (fig 2 shows the wind power density map of India at 50 m level). The data from all these wind farmable sites have been published in seven volumes of Wind Energy Resource Survey of India. The wind resource assessment program is an ongoing program and is now being taken up by Centre for Wind Energy Technology (C-WET) Chennai which under this MNRE program identify the locations in association with various State Nodal Agencies (SNAs) and

[1] Indian Wind Atlas-2010

[2] http://www.cwet.tn.nic.in/Docu/List%20of%20wms%20on%2030.11.10.pdf

commissions wind monitoring stations to monitor the wind power potential all over the country. The installation of individual wind monitoring stations all over the country is very expansive and the wind data monitored at a single location can represent the wind flow pattern over only the small area around the location point of wind monitoring station.

To help analyse the overall country wind power potential and to help identifying the potential areas where detailed study can be done C-WET in association with Riso DTU National Laboratory for Sustainable Energy (NLSE), Denmark, developed the Indian Wind Atlas which has been published in April 2010. In the wind atlas mesoscale models have been used to develop the wind resource map of India for 50 m and 80 m level. The results of these mesoscale models have been correlated with the actual measured data from various wind monitoring stations to arrive at certain accuracy of the mesoscale wind mapping. Figure 2.8 shows the wind power density of India at 80 m height above ground as given in Indian Wind Atlas. Map shows that most of the areas in Gujarat are having wind power density between 200-300 W/m^2 and above at 80 m above ground level and there are very less areas with wind power density lower than 200 W/m^2.

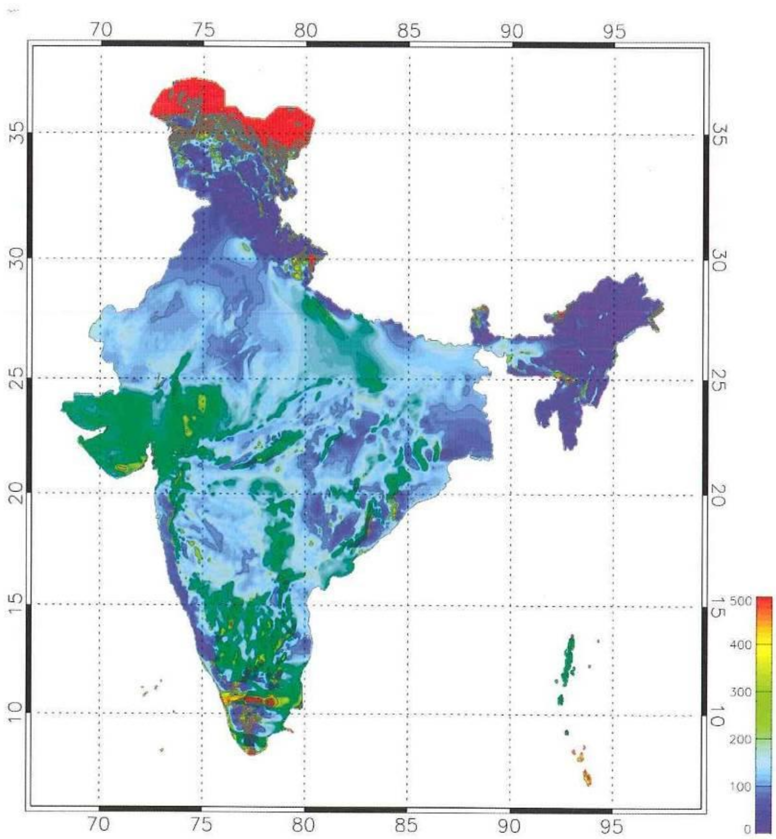

Figure 4.90. All India Mean simulated wind power density at 80 m a.g.l. The contour interval is 100 W/m^2.

Figure 2.8 All India mean simulated wind power density at 80 m height above ground level

Source: Indian Wind Atlas-2010

The Indian Wind Atlas also describes the estimation of wind power potential at different wind power density levels at 50 m level. The basic assumption for potential estimation is the land requirement as 9 MW wind power per km^2 area (average of 5Dx7D, 4Dx8D and 4Dx7D spacing where D is the rotor diameter) and the availability of 2% of the total land in the respective wind power density zone. Based on this consideration the Potential for the wind power in Gujarat has been estimated to 10,609 MW of which the 9758 MW is in the WPD zone of 200-250 W/m2 and 851 MW is in the zone of 250-300 W/m2 at 50 m level above ground.

The consideration of 2% area only may be very less/un representative and the wind power potential may have been underestimated considering the present status of development in the wind power technology such as higher capacity rating wind turbines with just a small increase in hub height and rotor diameter. Further the suitable waste land utilization shall be the focus for wind power development instead of acquiring any agricultural or forest land. The next section describes the approach used in this study and results for the estimation of the wind power potential according to the wasteland categories which falls around the identified wind farmable sites with the criteria of WPD>200 W/m2 at 80 m above ground level.

Approach and methodology for current study

In this wind resource mapping approach the district wise wind power potential in Gujarat has been mapped in terms of wind power density at 80m height above ground level based on the available wind resource data from Wind Energy Resource Survey data-books and Indian Wind Atlas published by C-WET and has been projected with the different category of wasteland in all the districts of Gujarat using GIS and remote sensing technique. The WPD map at 80 m height as given in Indian Wind Atlas has been used and digitised using GIS to locate those areas which have the WPDs more than 200 W/m2 at 80 m above ground level. Figure 2.9 shows the WPD map in Gujarat as arrived based on Indian Wind Atlas map using GIS.

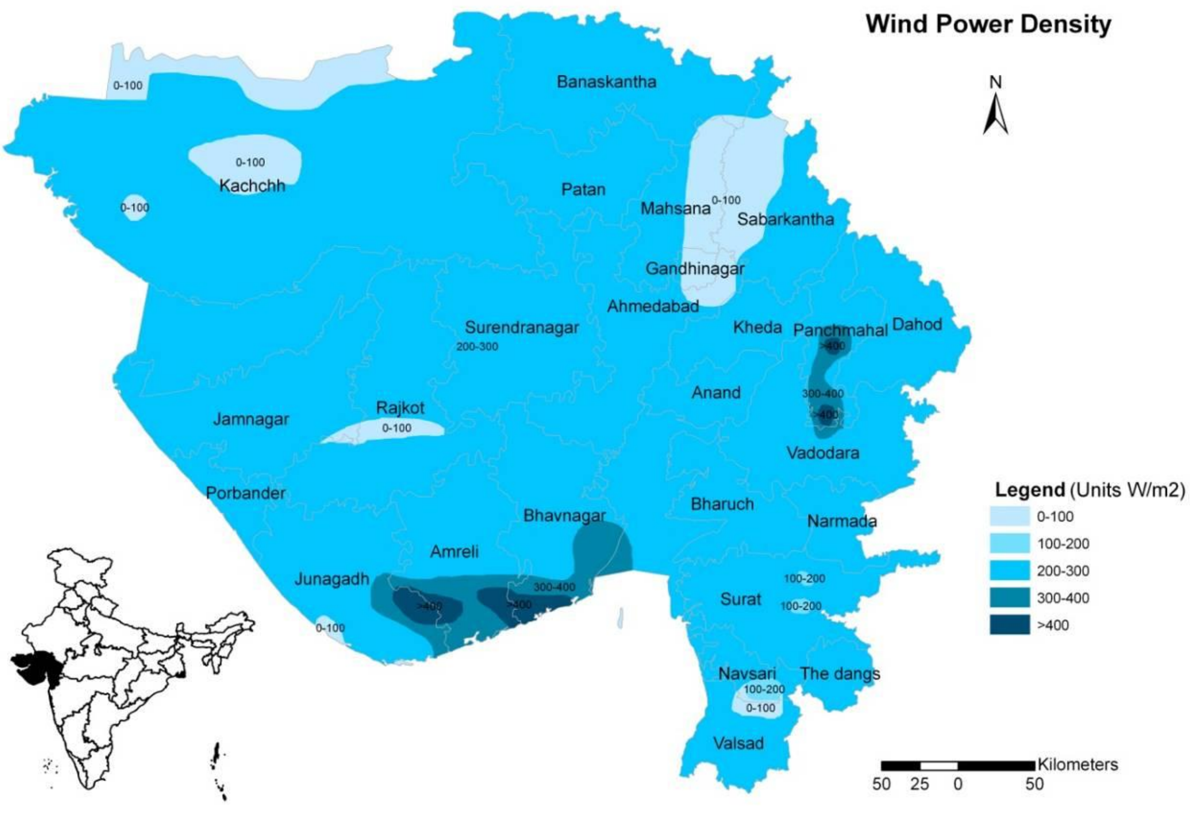

Figure 2.9 Mean simulated wind power density of Gujarat at 80 m level above ground

Further as stated above the wind resource survey of India gives the WPD data for the wind monitoring masts installed in Gujarat under the Wind Power Program of the GoI, at up to 50 m level above ground, projections for 80 m level has been made based on the wind speed frequency distribution data, power law index values and energy pattern factors as available in the data published by C-WET using WAsP software (A sample wind frequency distribution data of one location is given in Annexure- 7). The Wind power Densities at 50 m and 80 m for the wind measurement locations in Gujarat are given in Annexure-6.

The sites which are having the WPD equal to or greater than 200 W/m2 are to be considered as the potential wind farmable sites as per the guidelines of MNRE, and also the state nodal agencies approve only those sites for the development of wind farms which are having WPD greater than 200 W/m2. Considering this fact the locations with WPD >200 W/m^2 has been considered for the study and the land use land cover data has been calculated using GIS.

The final assumptions made for the estimation of MW potential are

a. The Land requirement of 11.2 Ha/MW

b. The type of land considered suitable for the wind farm development are

- Land with scrubs
- Other wastelands (It contains barren land, degraded grazing land, Rann area or saline land)

c. As the foot print area of wind turbine installation is comparatively less, i.e. approximately 1-2 Ha/WTG it is assumed that the Agricultural lands may also be considered for the wind farm installation with the provision that the agricultural activities can be continued in the lands lying between the WTGs.

d. For the land mapping purpose in GIS, the minimum land polygon size of 20 Ha has been considered.

Separate mapping has been done for both the cases i.e. a) Only crop land considered for wind farms b) Crop land not considered for wind farms and c) Both crop land and non-crop land considered for wind farms. Figure 2.10, Figure 2.11 and Figure 2.12 respectively shows the wind potential areas with only crop land, non-crop land and for both crop as well as non-crop land combined.

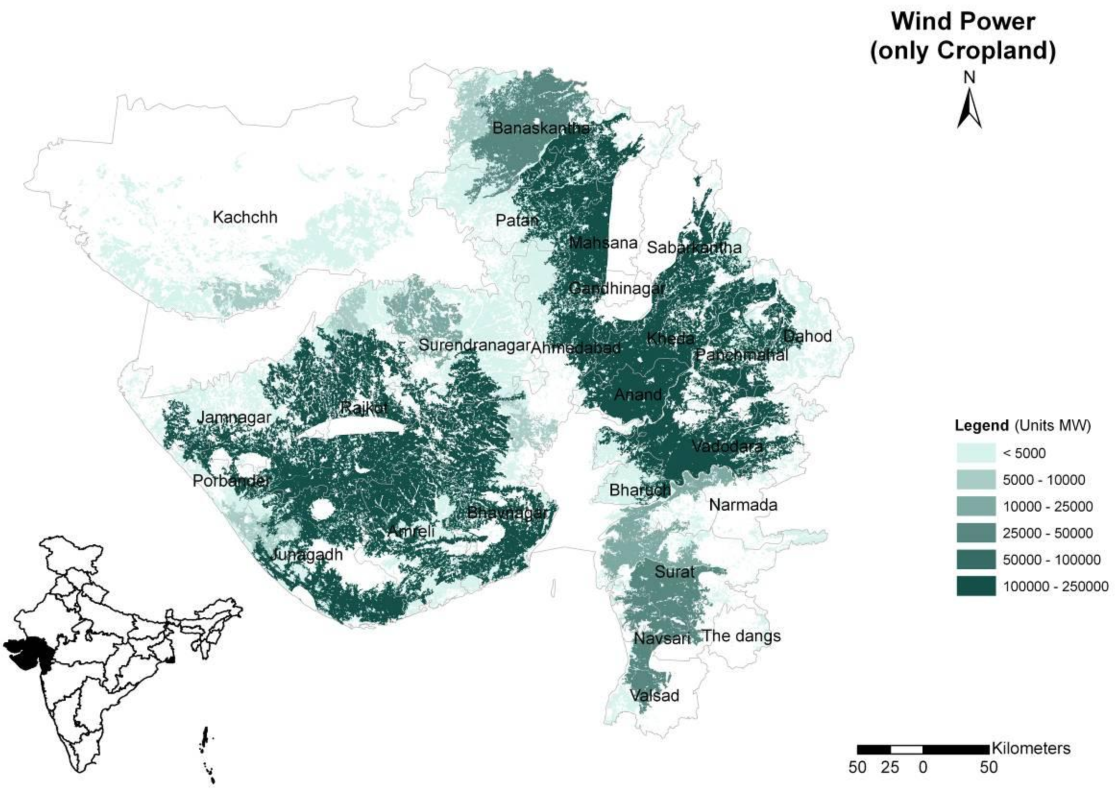

Figure 2.10 Crop lands under Wind power potential areas in Gujarat

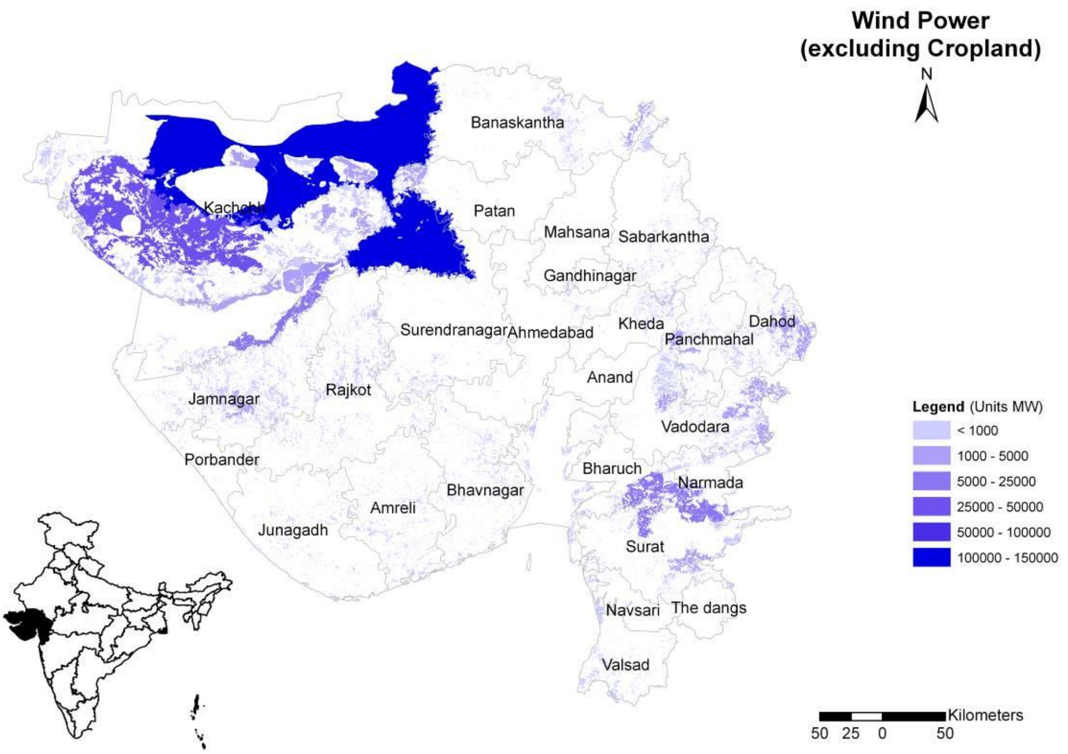

Figure 2.11 Non-Crop lands under Wind power potential areas in Gujarat

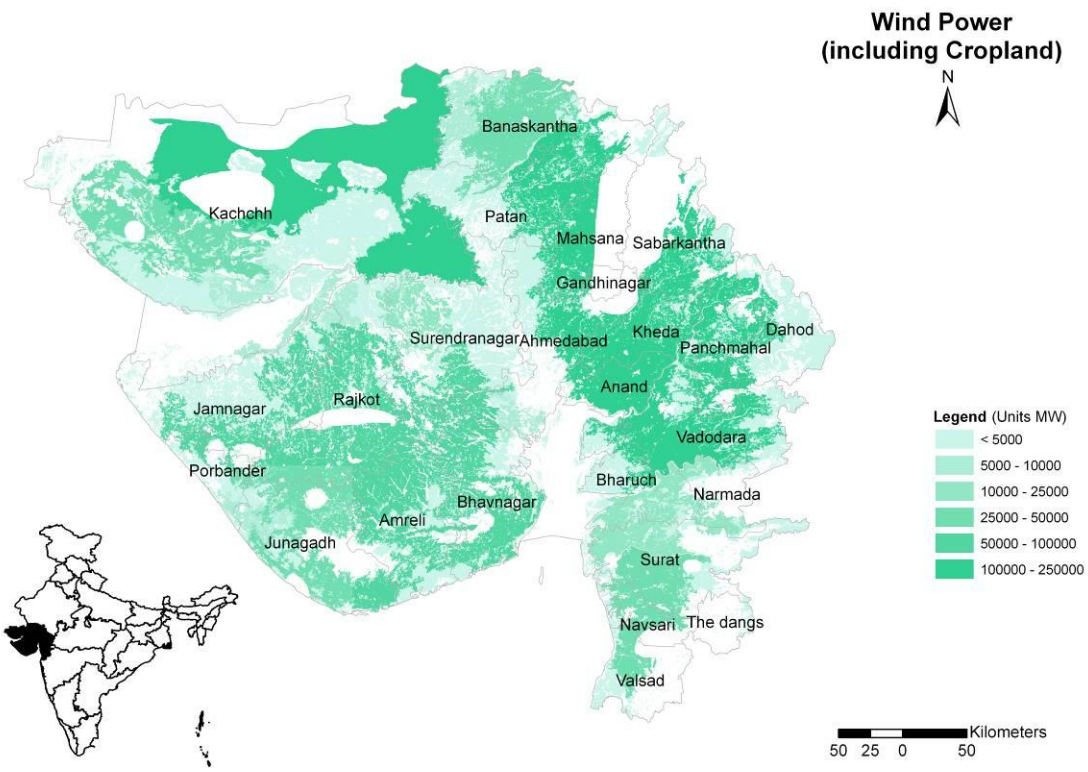

Figure 2.12 Both Crop land and Non-Crop lands under Wind power potential areas in Gujarat

Estimation of total wind power potential

The land requirement per MW of wind turbines depends on the actual spacing made between the wind turbines in a wind far. Generally the practice is to use the array spacing of the 5Dx7D, 4Dx8D and 4Dx7D, 3Dx5D depending on the wind strength of the site, where D is the rotor diameter. Now a days the research are being carried out to develop the high capacity wind turbines with higher hub heights and lower rotor diameter with increased efficiency for the optimisation of the energy generation as well as the better land utilisation. For the higher hub height wind turbines which can absorb the high wind power densities available at their hub height level the land area requires per MW for these turbines are comparatively less than the low hub height wind turbines. As stated above that based on the minimum spacing requirement, array arrangement and the rotor diameters of modern Multi MW scale wind turbines the average land requirement for wind power projects has been estimated as 11.2 Ha/MW. Using these land requirement criteria and the land areas available under the selected land classes the district wise wind power potential has been estimates. Total wind power potential in Gujarat is estimated at about 304 GW considering only non-crop lands and 858 GW considering only crop land. District wise wind power potential are given in Table 2.6.

Table 2.6 District wise wind power potential based on LULC analysis for the wind power potential sites in Gujarat

District	Total suitable area (non crop land)for Wind (km2)	Total potential for wind power in non-crop land (MW)	Total suitable area (only crop land)for Wind (km2)	Total potential for wind power in only crop land (MW)
Ahmedabad	91	812	4968	44356
Amreli	428	3821	5801	51793
Anand	0	0	2349	20972
Banaskantha	545	4869	8128	72574
Bharuch	799	7135	3210	28657
Bhavnagar	433	3866	5533	49405
Dahod	939	8384	2631	23487
Gandhinagar	9	78	62	553
Jamnagar	1386	12379	5968	53288
Junagadh	251	2240	6320	56430
Kachchh	22955	204951	6489	57938
Kheda	262	2335	3066	27372
Mahsana	18	162	2608	23288
Narmada	613	5471	592	5286
Navsari	43	385	1043	9316
Panchmahal	334	2984	2815	25134
Patan	474	4236	4889	43647
Porbander	30	267	1401	12506
Rajkot	883	7883	8072	72074
Sabarkantha	533	4758	2886	25766
Surat	899	8027	4104	36639
Surendranagar	400	3568	6703	59845
The dangs	18	163	151	1351
Vadodara	1510	13483	5087	45419
Valsad	244	2182	1254	11195
Total	**34097**	**304440**	**96128**	**858290**

Further the 100 % land may not be utilised for the wind farm development only so a scenario has been developed considering that only, 10% 25%, 50%, 75% and 100% of the land could be utilised for the wind farm development. The analysis results are shown in Annexure 8

Also the analysis for the wind power potential as per the different Wind Power Density areas has been carried out using GIS. District wise details of wind power potential based on different wind power density areas are given in Annexure 9.

This GIS based approach for estimating the LULC pattern in the identified sites and then estimation of wind power potential is then used for the integration of this potential along with the solar power potential which again was estimated based on the district wise land use land cover pattern and solar radiation analysis in Gujarat. Detailed integrated potential assessment is given in section 3 of this report

Repowering potential for wind energy systems in Gujarat

Gujarat is one of the states where the very first demonstration wind power projects were installed. Since then there are many wind turbines have been installed by the private sectors. As in the earlier times the wind turbines of smaller capacities (less than 500 kW rating) were installed, and has been operating since long, their performance might not be optimal as compared to the real wind power potential in those good windy sites of Gujarat. Thus, there exists a good potential for the repowering of the wind energy systems in Gujarat, using state-of-the art wind turbines. Table 2.7 gives the list of the installed smaller capacity rating wind turbines in Gujarat, before year 2000.

Table 2.7 District wise wind repowering potential in Gujarat

District	Rating (kW)	No. of turbines	Capacity (MW)
Jamnagar	200	53	10.6
	225	98	22.05
	230	8	1.84
	250	63	15.75
	300	15	4.5
	320	35	11.2
	350	54	18.9
Rajkot	90	99	8.91
	140	4	0.56
	200	51	10.2
	225	95	21.375
	230	3	0.69
	250	24	6
	270	2	0.54
	300	36	10.8
	350	12	4.2
Total Capacity		652	148.115

It is difficult to assess the actual land area covered by these wind turbines without having a detailed survey on the wind farm locations where they have been installed. Assuming that each of these smaller capacity wind turbines can be replaced by the modern wind turbine of rating of 1500 kW on an average at the same location, the total wind energy re-powering potential is estimated to be about 978 MW. That means an enhancement in the installed capacity of about 830 MW. But the repowering of wind turbines has various technical, economical and policy related issues which are out of the scope of this study.

2.4 Biomass energy

Biomass is an important source of energy accounting for about one third of the total fuel used in our country. The current availability of biomass in India is estimated at about 120-150 million MT per annum covering agricultural and forestry residues corresponding to a potential of 16,000 MW. The energy obtained from biomass is a form of renewable energy and, in principle, utilizing this energy does not add carbon dioxide, a major greenhouse gas, to the atmosphere, in contrast to fossil fuels. As per an estimate, globally photosynthesis produces 220 billion dry tonnes of biomass each year with 1% conversion efficiency (Ashwani et al, 2010).

The major sources of biomass in India are agricultural residues and wood from forest lands. The study done on agro residues indicate that about 15-20% of the agriculture residue can be made available for power generation without affecting the present usage.

In India, there is high dependence on biomass in the rural area, about 90% of the rural households use biomass for cooking and heating as it is the cheapest and the most widely available fuel. In an effort to lessen dependence on burning fossil fuels and utilise renewable sources of power generation instead, the government of Gujarat State is now turning towards biomass waste for generating electricity. Gujarat Energy Development Agency that promotes renewable and green fuels has chalked out a plan to generate 400 MW of power in next few years through biomass (Pathak et al, 2008).

Objective

The objective of the section is to estimate the biomass power potential in Gujarat using GIS atlas data of Gujarat.

Methodology

The Biomass resources are generated as wood residues from forests and agricultural residues, generated by crops.

The theoretical biomass potential is defined as the total annual production of biomass resource from agricultural, forest and other lands in a region. This potential represents the total quantity of biomass generated in a region. For biomass assessment, a database needs to be prepare on cultivated crops and biomass generated from biomass. This would be subsequently used for the estimation of biomass potential in any given geographical region.

The data on cultivated crop areas and production have been collected from Agriculture and Cooperation department, Gujarat. The crop to residue ratio has been derived from biomass atlas of India (2004). The forest data is taken from FSI, 2009 report. Figure 2.13 shows the land areas covered with forest (i.e. the source of forest biomass) and the land area covered under agriculture (i.e. the source of agriculture biomass) in Gujarat.

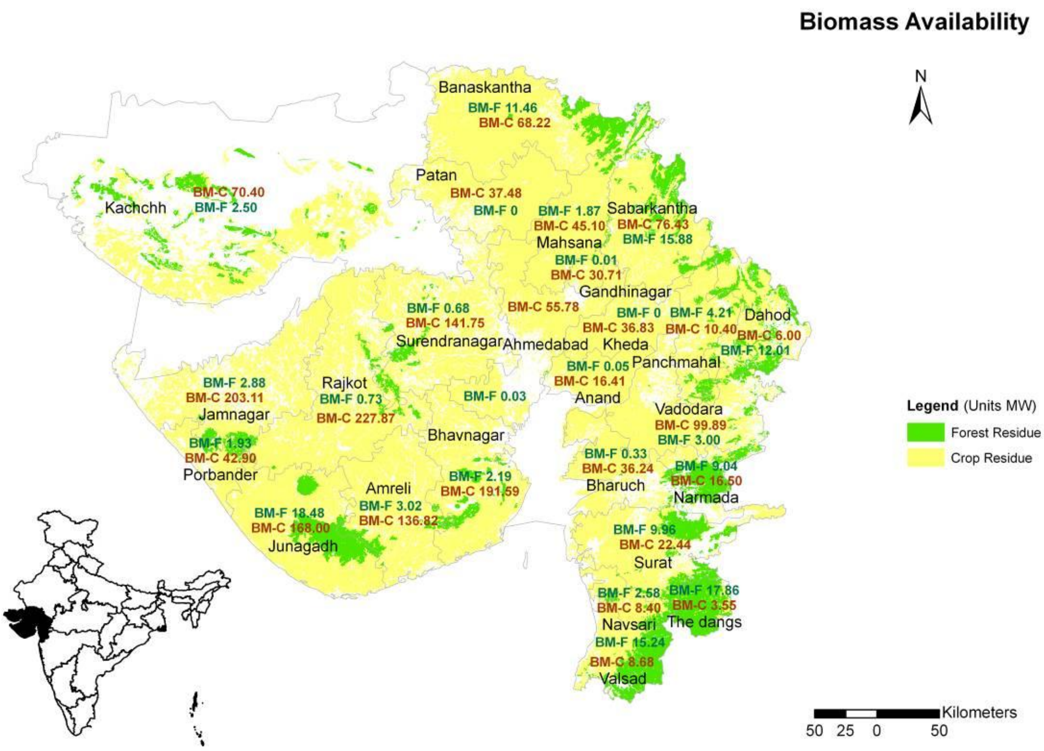

Figure 2.13 Map showing the forest land and agriculture land distribution in Gujarat

Estimation of biomass generation potential

The following section summarizes the methodology adopted for the estimation of theoretical potential of biomass from the agricultural and forest land.

Estimation of biomass potential from agricultural residues

In Gujarat, out of the total geographical area of 19.6 million hectares (2008-09) the net cropped accounts for an area of 11.6 million ha.The major crop residues are paddy straw and stalk, wheat straw, agro- stalks, sugarcane leaves and thrash, pulses stalks, Cotton waste, wastes from oilseeds etc. These varieties of biomass are essentially produced in kharif and rabi seasons and hence, available around the year

The agriculture crop production data of year 2008-09 has been sourced for all major crops in the State. The agricultural residue availability depends mainly on harvesting practices prevalent in a particular region. There is sufficient data on agricultural output and there are studies on the amount of residues generated (Ravindranath et al., 2005). The method, often used for crops, is to use a residue to crop ratio (CRR). With this method, the amount of residues is calculated from the crop production using an average CRR value.

The available agro- residue potential is specific to the region and based to the competing uses of biomass in that area. The various uses where biomass is used in India area food, fuel, fodder, etc. Other agro residues such as sugarcane bagasse, rice husks are used for cogeneration. Hence, in order to develop a real estimate of surplus biomass it becomes imperative to study the alternative uses of biomass. Therefore, estimation of potential of biomass from crop residues has been estimated as a function of - Agricultural crop residue production, Current use of crop residues, and availability of crop residues for power generation.

To estimate the surplus biomass, quantitative analysis of agro residues was done. The agro – residue that can be used as fodder because of the nutrient content required for cattle were selected. For estimating the consumption of agro residue for fodder use, the selected species of agro residues was subtracted from the total residue generated. The residue selected for the same are straw of cereal crops such wheat, rice, bajra, small millet, jowar and wheat stalk. Thus, surplus biomass was calculated using the equation

Surplus biomass (metric ton (MT)/yr): Biomass generation (MT) –(Crop residue used as fodder (MT) *

* There is large amount of biomass is used in industries for captive power generation and in boilers. For that industry – survey has not done. Therefore, actual biomass consumption in the state will be more than what is calculated in the study

Estimation of biomass potential from forests

According to SFR, forest cover constitutes land cover > 1 ha in area, with a tree canopy density of more than 10%, indicating the presence of trees over any land; whereas, the term forest area denotes the legal status of land as per government records. Further, recorded forest areas has been further split into reserved forests (RF) and protected forests (PF).

Forest area or biomass potential from sustainable harvest of trees under recorded forest area has not been considered in the estimation of biomass potential because of the following reasons:

- In India, the harvest of trees for commercial reasons from RF and PF is prohibited under the provisions of Indian forest act 1927.
- These primary forests are maintained for their ecological roles, such as conservation of biodiversity and watersheds
- Periodic harvesting of wood, even it sustainable, could damage biodiversity and forest succession, due to mode of cutting, transportation and trampling.
- Further, even if a sustainable rate of harvesting is determined, there are chances of it being undermined, and as a result of forest reserves being exploited due to over-harvesting, leading to degradation.

Hence, in the context of the study, the estimates of woody biomass under forest cover assume importance. The forest cover of the state Gujarat based on satellite data of 2004 is 14715 km2, which is 7.51% of the geographical area. The district wise details of very dense forest, moderately dense forest, open forest and scrub is available. Regarding the productivity, it has been documented that from forest land on an average 2.6T/ha/yr can be harvested on a sustainable basis, while from the open forest (with 10-40% tree crown), the average productivity comes out to 0.25t/ha/yr and from the degraded lands , it is around 0.5t/ha/yr (Ravindranath and Hall, 1995).

Power generation potential from biomass

For calculating the annual power generation, formula worked out by MNRE was used as follows (MNRE, 2001):

Annual power generation potential= (Total surplus biomass) * (collection efficiency)/ (365days* 24hrs* power factor for biomass)

Where, it is assumed 2.2 tons of agro residues and 1.5 tons of woody biomass can produce 1MW of electricity and the collection efficiency has been kept as 75% of total surplus on a conservative scale.

Forest resource

Forest, including scrub lands and other degraded lands are important source of biomass generation. The area under the forest land is 7.51% of the geographical area of Gujarat. The estimated biomass potential from open forest area, tree twigs and branched and scrub land is approximately 2.39 million tonnes. District wise forest biomass residue is given in table 2.8.

Table 2.8 Biomass residue from forest

District	Deciduous forest area (km^2)	Deciduous forest residue (tons)	Degraded forest area (km^2)	Degraded forest residue (tons)	Total biomass from forest (tons)
Ahmedabad	1.76	456.35	0.42	10.55	466.90
Amreli	179.13	46573.46	252.75	6318.70	52892.16
Anand	3.01	783.00	1.51	37.83	820.82
Banaskantha	753.62	195941.47	190.78	4769.55	200711.02
Bharuch	11.91	3095.49	105.48	2637.02	5732.50
Bhavnagar	110.65	28769.75	384.01	9600.37	38370.12
Dahod	751.94	195504.47	596.43	14910.80	210415.27
Gandhinagar	0.69	179.38	0.05	1.21	180.58
Jamnagar	184.00	47839.71	101.40	2534.93	50374.65
Junagadh	1220.97	317451.57	250.21	6255.33	323706.91
Kachchh	0.00	0.00	1748.68	43717.09	43717.09
Kheda	0.00	0.00	0.00	0.00	0.00
Mahsana	123.32	32064.07	28.30	707.61	32771.68
Narmada	562.03	146127.14	491.83	12295.76	158422.90
Navsari	233.35	60671.28	78.88	1971.88	62643.16
Panchmahal	267.08	69441.52	173.37	4334.31	73775.83
Patan	0.00	0.00	0.00	0.00	0.00
Porbander	115.85	30121.83	144.58	3614.46	33736.28
Rajkot	18.48	4805.26	317.40	7934.89	12740.15
Sabarkantha	1041.58	270812.04	297.03	7425.77	278237.81
Surat	608.77	158280.62	645.61	16140.27	174420.90
Surendranagar	0.00	0.00	477.71	11942.80	11942.80
The dangs	1179.27	306609.58	251.65	6291.36	312900.94
Vadodara	177.16	46060.85	261.49	6537.24	52598.09
Valsad	967.01	251421.88	625.45	15636.34	267058.21
Total	**8511.58**	**2213010.71**	**7425.04**	**185626.05**	**2398636.76**

Agriculture sector

In the agriculture sector, crop residues of paddy, wheat, maize, cotton and the mixture of other crops cultivated was the major source of biomass in Gujarat, as a whole. The total estimated annual residue production from crops is approximately 54 million tonnes. The analysis indicated that Gujarat is rich in oilseed and cotton production.

Biomass consumption

The major portion of agro residues utilized as fodder and in industries. Therefore, excluding the agro residues used in fodder, the surplus quanta of biomass was calculated. The available surplus biomass is approx 45 million tonnes from agro residues and 2.3 million tonnes from forest. The district wise surplus agro residue detail is given in table 2.9

Table 2.9 Biomass from agriculture residue

District	Agricultural area (ha)	Agriculture production (metric ton/ yr)	Agriculture residue generation (metric ton/ yr)	Residue consumption (metric ton/ yr)	Surplus residue (metric ton/yr)
Ahmedabad	547700	738600	2100172	666822	1433350
Amreli	838700	1174500	3728128	212448	3515680
Anand	229700	309400	806802	385242	421560
Banaskantha	724100	923600	2097158	344218	1752940
Bharuch	306900	512100	1098091	166751	931340
Bhavnagar	737500	1603500	5183048	259933	4923115
Dahod	256300	297500	629350	475100	154250
Dang	61000	71200	150000	58750	91250
Gandhinagar	165100	374400	996874	207644	789230
Jamnagar	1083900	2119800	5442752	223667	5219085
Junagad	1157800	2520900	5330796	1013791	4317005
Kutch	463200	723000	1922635	113715	1808920
Kheda	351200	610800	1620203	673843	946360
mehsana	355600	608100	1478101	319161	1158940
Narmada	109500	170100	507942	84032	423910
Navsari	94700	351100	413310	197380	215930
Panchmahal	285000	310600	704577	437287	267290
Patan	323400	427900	1114771	151701	963070
Porbander	5450	2520900	1138729	36409	1102320
Rajkot	12119	2247100	6553055	697628	5855427
Sabarkantha	545000	991500	2657948	693938	1964010
Surat	2442	1039600	687263	313393	373870
Surendranagar	774000	774000	3855882	213462	3642420
Tapi	124400	291500	364490	161660	202830
Vadodara	486000	1038900	3017538	450713	2566825
Valsad	97100	215600	420220	197160	223060
Total	**10137811**	**22966200**	**54019835**	**8755848**	**45263987**

Power generation potential

It is estimated that from agriculture and forestry sectors about 47 million tonnes of biomass is available as surplus, of which maximum comes from the agricultural sector. Using the formula worked out by MNRE, and assuming collection efficiency of biomass about 75%, MW potential was estimated. District wise biomass power potential is given in table 2.10.

Table 2.10 Power potential from biomass in Gujarat

District	Surplus agro residue (metric ton/yr)	Power potential (MW)	Total Biomass from forest (tons/year)	Power potential Forest Biomass (MW)	Total power potential from biomass (MW)
Ahmedabad	1433350	55.78	466.90	0.03	55.81
Amreli	3515680	136.82	52892.16	3.02	139.84
Anand	421560	16.41	820.82	0.05	16.46
Banaskantha	1752940	68.22	200711.02	11.46	79.68
Bharuch	931340	36.24	5732.50	0.33	36.57
Bhavnagar	4923115	191.59	38370.12	2.19	193.78
Dahod	154250	6	210415.27	12.01	18.01
Gandhinagar	789230	30.71	180.58	0.01	30.72
Jamnagar	5219085	203.11	50374.65	2.88	205.99
Junagad	4317005	168	323706.91	18.48	186.48
Kutch	1808920	70.4	43717.09	2.50	72.90
Kheda	946360	36.83	0.00	0.00	36.83
mehsana	1158940	45.1	32771.68	1.87	46.97
Narmada	423910	16.5	158422.90	9.04	25.54
Navsari	215930	8.4	62643.16	3.58	11.98
Panchmahal	267290	10.4	73775.83	4.21	14.61
Patan	963070	37.48	0.00	0.00	37.48
Porbander	1102320	42.9	33736.28	1.93	44.83
Rajkot	5855427	227.87	12740.15	0.73	228.60
Sabarkantha	1964010	76.43	278237.81	15.88	92.31
Surat incl. Tapi	576700	22.44	174420.90	9.96	32.40
Surendranagar	3642420	141.75	11942.80	0.68	142.43
The Dang	91250	3.55	312900.94	17.86	21.41
Vadodara	2566825	99.89	52598.09	3.00	102.89
Valsad	223060	8.68	267058.21	15.24	23.92
Total	**45263987**	**1761.52**	**2398636.76**	**136.91**	**1898.41**

Annually about 1900 MW of electricity could be generated from the surplus biomass. Surendranagar, Rajkot, Jamnagar, Junagad, Bhavnagar, Amreli are the districts with high potential for biomass energy. Figure 2.14 gives the district wise total Biomass power potential in Gujarat.

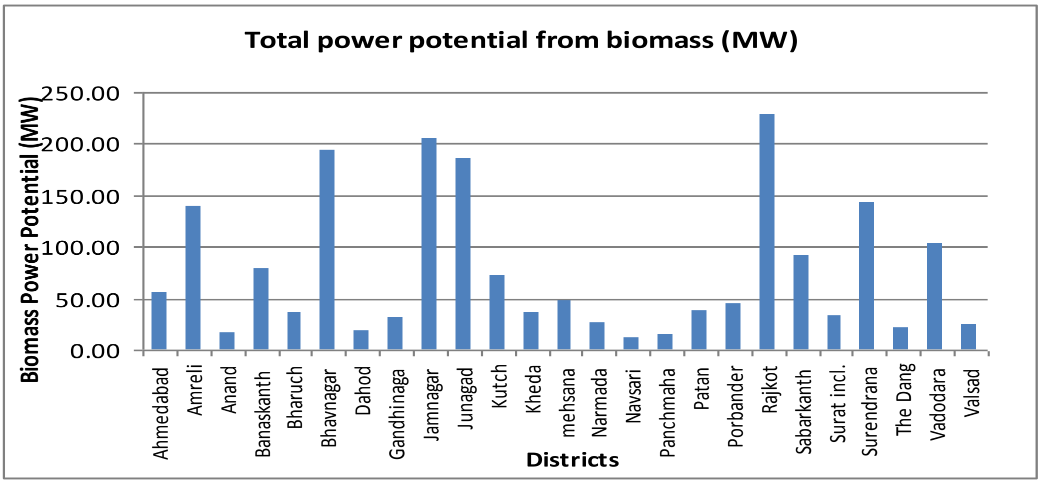

Figure 2.14 District wise total biomass power potential in Gujarat

Biomass utilization in briquetting industry

Gujarat is leading state in briquette production. There are approx 150 briquette manufacturers in the state and all of them use binder- less piston press machines. The units have more than 5 to 6 machines of capacities in the range of 750kg/hr to 1000 kg/hr. (source: Bioenergy India, Issue 2, Dec 2009)

Therefore, based on these figures, biomass consumed for this sector is calculated as

Briquetting units	150
Machines in each unit	6
Capacity	1000 Kg/hr
If machine run for 20hrs in a day	7300000 kg/yr
Total biomass consumption by machines in the state	6.57 MT/yr

Net surplus biomass and Power generation

Deducting 6.5 Million tonnes of biomass (used in biomass briquetting industry) from total 47 million tonnes of biomass (obtained as surplus biomass from agro and forest sector, shown above). The net surplus biomass for the state is (24.25-6.57) 40.5 million tonnes/ yr. Using the above mentioned formula, the net biomass power potential estimated in the state is about 1522 MW.

2.5 Tidal energy

Introduction

The coastal line of Gujarat is endowed with huge tidal potential and is one of the world's few high tidal potential sites. Thus; harnessing tidal energy can help in meeting energy demands of the coastal cities. It would reduce expenditure on the fuel and would help in meeting the energy demands through locally and abundantly available resources. Tidal energy can play great role in supporting and boosting the development of the state. There are two potential sites for harnessing tidal energy in Gujarat, namely Gulf of Kachchh and Gulf of Khambat (Figure 2.15).

Figure 2.15 Potential tidal sites in Gujarat[1]

[1] Source:http://www.eosnap.com/public/media/2008/11/rann_of_kutch/20081105-rann-full.jpg [Accessed 14 January 2011]

A description of tidal energy and re

Methodology for tidal power potential assessment

This analysis completely based on the secondary research and complemented with data collected from research publications of National Institute of Oceanography (NIO), Goa,[1] Tidal range data which is important for calculating potential of the site is not available for the sites at Gulf of Khambat, however, tidal range for some sites in Gulf of Kachchh is available. Ranges considered for calculation purposes are the average tidal ranges. Thus, potential energy measurement at several sites in both the gulfs has not been done. Potential energy has been estimated for the gulf, on the whole. It is important to note that since the research is purely secondary in nature, therefore, results obtained are to be validated by ground truthing and on-site measurements.

Detailed information on tidal energy resource and the properties of tides in Gulf of Kachh and Gulf of Khambat of Gujarat state are given in Annexure10.

Tidal Energy Potential from Gulf of Kachchh

With average tidal range of 5.5 m (Deshmukh, Nayak, Mahaguna&Dev, 2005) and basin area of 170 km2 (Khaligh and Onar, 2010), using (1), the total theoretical tidal potential of the gulf comes out to be 503 MW.

Tidal energy potential from Gulf of Khambat

With an average tidal range of 7 m and basin area of 1970 km2 (Khaligh&Onar, 2010), the total theoretical tidal potential of the gulf comes out to be 6303 MW.

Hence the total tidal potential for the state of Gujarat is as tabulated in table 2.11.

Table 2.11 Tidal energy potential for Gujarat

Potential site	Tidal energy potential (MW)
Gulf of Kachchh	503
Gulf of Khambat	6303
Total	6806

2.6 Geothermal energy

India's geothermal resources are mostly unutilized or unknown. The current estimates of the country's geothermal power generating potential[2] stands between 10,000 to 10,600 MW. These estimates are now outdated as new methods of estimating geothermal potential have become available. However, there has been no attempt at the national level to recalculate the gross national geothermal potential in light of new methods and data becoming available. In this study, an attempt has been made to collect the latest data and perform some analysis in order to produce some map-able data for geothermal potential for the state of Gujarat.

The Gujarat state has many thermal springs and sufficient geological evidence of the existence of geothermal energy resource beneath its crust. Detailed description of Gujarat's geothermal resources and its assessment methodologies is given in Annexure 11. The extent

[1] Digital Repository Service of National Institute of Oceanography (CSIR), India.Weblink: http://drs.nio.org/drs/index.jsp

[2] Prof. Chandrasekharam, Dept. of Earth Sciences, IIT Bombay, and MNRE sources

of this resource is more or less known as per inferences made in the methodologies given in the Annexure, from location of thermal springs, well data, and fault lines. The estimation of this resource in quantifiable terms (for examples kilocalories, BTUs, or MWh) would be nearly impossible at the moment with the available data. Even with significant data availability, quantifying the amount of heat contained in a thermal reservoir is difficult to predict. Even more difficult to predict is the thermal energy content of hot dry rocks located close to fault lines since their ultimate heat supplier is magmatic processes inside of the earth.

However, from the analysis, it can be inferred that certain regions in Gujarat have a higher potential for geothermal energy development than other areas. Such regions are located within the Cambay graben, Kutchgraben and Narmadagraben. Within these grabens, spots with higher surface temperatures and heat flow values would be most ideal for drilling and further examination. Due consideration should also be given to proximity to thermal springs/surface manifestation sites as these present ready samples for geochemical analysis and reservoir calculations. Proximity to fault lines is also an important factor while planning an actual project.

Heat flow (measured in mW/m^2) quantities are important to geothermal potential estimates as they indicate the amount of heat conducting through the crust from inside the earth. The map of Gujarat state and the old heat flow maps of India[1], (see figure 2.16) can be used as a baseline to make further estimates and improve the map with advanced GIS techniques. Superimposing the borehole information, fault lines and thermal springs would be the first step in this direction.

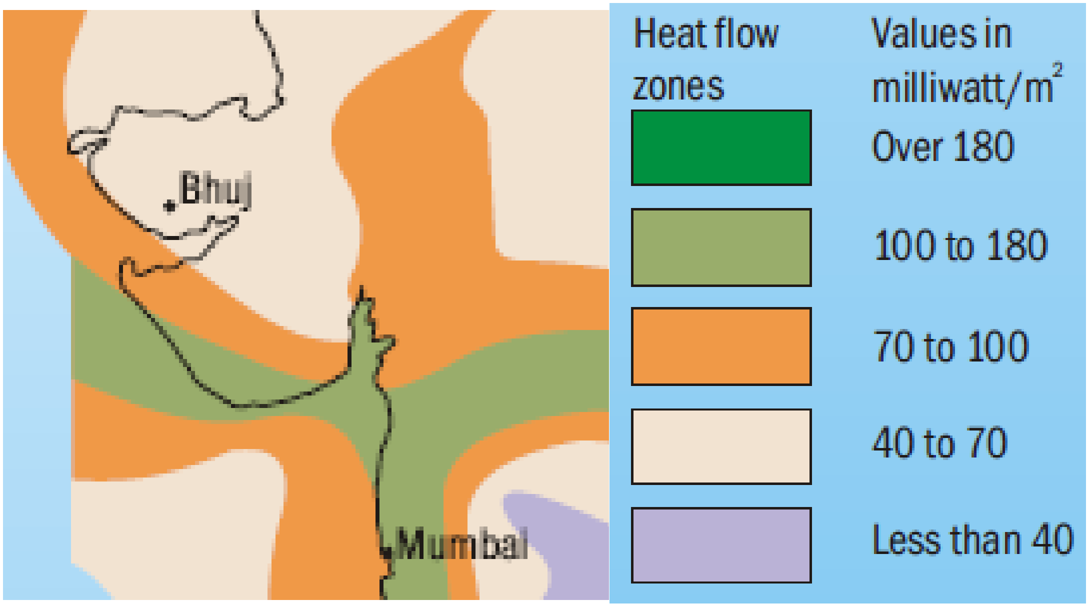

Figure 2.16 Heat flow map of Gujarat state[2]

For further work, borehole data would have to be collected from oil and gas companies and other agencies (such as GSI and NGRI) that have bore-well data for wells located in Gujarat state. Given the sensitive nature of the data it was not be possible to get all of this information. Hence alternate approaches outlined in the Annexure (tectonic-fault line

[1] Source: References 2 and 8 from reference list given at end
[2] Source: Taken from TERI report no. 2008RT09

analysis, etc.) may be adopted in the modeling studies for estimating the geothermal energy resource potential in Gujarat. Overall it can be concluded that there is good geothermal potential exist in the state which need to be assessed and framework has to be developed for proper utilisation of these resources. However it was not possible to map these resources in current study along with other renewables and infrastructure details using GIS.

3. Integrated approach for RE assessment

3.1 Solar and wind integration

Concept

Gujarat is one of the state which has not only good solar potential sites but also have good wind regimes. There are some regions which can have both solar and wind potential. In a wind farm, wind generators are sparsely placed and they don't block too much sun light. This in between space of wind generators can be utilized for the installation of the solar PV projects. From this perspective, it is very much necessary to find out the hybrid or integrated potential for such sites. It needs a proper shadow analysis, so that at no point of time in the year, shadow fall on the solar PV farm and they can work at their best efficiency. The installed cost of wind generators is almost half of the solar electric generations. Hence, if there are such districts available having both resources well, then wind is given preference and the solar PV field can be optimized around it by doing the shadow analysis for the whole year. This will lead to better utilization of the land or maximization of the power /acre of land using both the resources solar and wind at their best level of efficiencies.

Methodology

The location of Ahmedabad was selected for the shadow analysis purpose,

Wind turbines in a wind farm are arranged in arrays with a spacing of 3D*5D, 4D*8D, 4D*10D, 5D*7D etc between two wind turbines, where D is the rotor diameter. This array arrangement is made to minimize the wake loss effect and to maximize the energy generation. The current practice in the Indian Market with 82m diameter wind turbine is to have 5D*7D.

Hence an array of 5 wind turbines of 1.5 MW capacities with 82 m rotor diameter is simulated using ECOTECT[1] software for shadow analysis.

The area which is shadowed throughout the year is excluded for solar PV installations. The MW capacity for solar PV for that area is calculated as under:

Total area covered by the field consists of 5 turbines	954500 m^2
Shaded area of each turbine in the month of January	54413 m^2
Shaded area of each turbine in the month of July	7865 m^2
Shaded area of each turbine over the year	62278 m^2
Shadow area of 5 turbines	311390 m^2
Effective shadow area on the field	186834 m^2
Effective un-shaded area	767666 m^2

The potential of solar in this un-shaded area adopting the same methodology earlier in solar section is about 24 MWe.

Hybrid potential for solar and wind for this land area is 31.5 MW, hence the combined land area requirement is about 3.0 ha/ MW.

[1] http://usa.autodesk.com/adsk/servlet/pc/index?id=12602821&siteID=123112

For the estimation of total MW potential for integration of wind and solar PV systems, it has been assumed that wherever wind power potential is available the preference shall be given to wind farm installation, then SPV systems in between the wind farms. Figure 3.1 shows the common land area and potential for wind and solar PV systems.

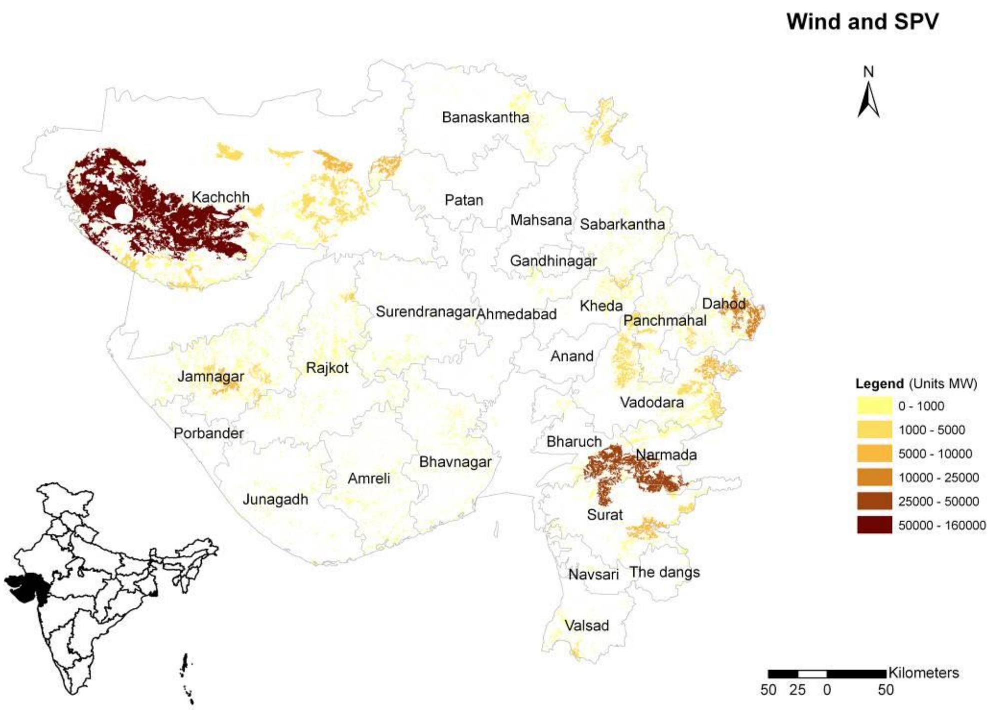

Figure 3.1 Wind and Solar PV common land areas

Further an analysis has been carried out for the case when all the CSP suitable land with water availability will be utilised first and then in remaining lands wind farms will be installed and in between the wind farms solar PV systems will be installed. Figure 3.2 shows the common wind and solar PV land remaining after utilisation of CSP potential lands based on water availability.

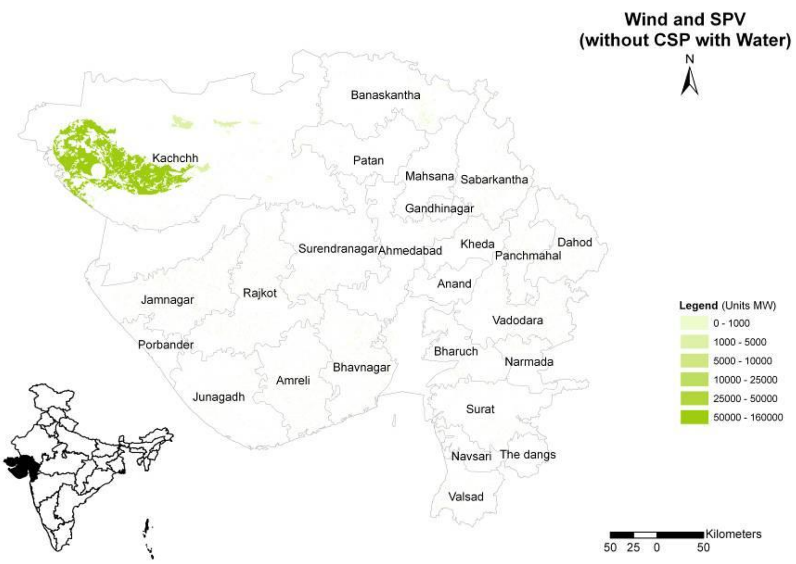

Figure 3.2 Wind and Solar PV common land areas remaining after CSP land utilisation

On combining the CSP potential and the Wind solar PV combined potential we can get the total wind solar integrated power potential. Figure 3.3 shows the combination of CSP land and the Wind-Solar PV common land areas

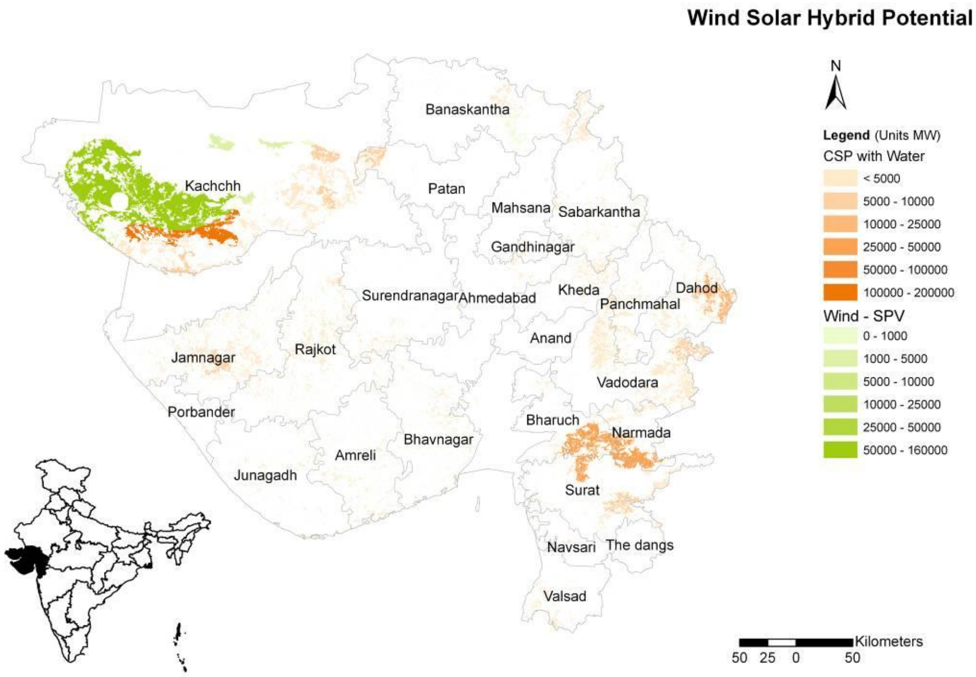

Figure 3.3 Combined views of Wind and Solar PV common land areas and CSP suitable land based on water availability

Now there are two more cases which are as follows

1. As there are some areas where the WPD is less than 200 W/m^2 and there is a possibility that there could be some scrub land where solar PV potential exists. So these would be the lands where only solar PV potential will exist and no wind power potential as shown in Figure 3.4
2. For wind power, in the non-crop land category, apart from scrub lands the Rann area and other wasteland has also been considered suitable. So these will be the land areas where no solar power potential is considered and these will be only wind power potential areas. These areas are shown in figure 3.5

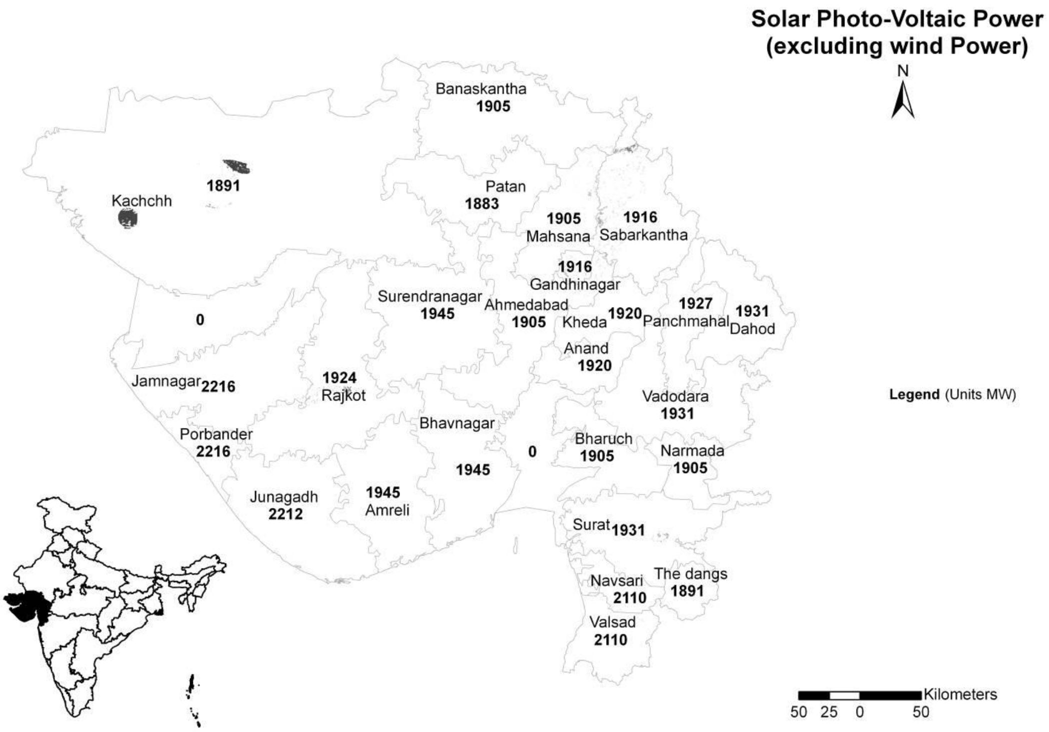

Figure 3.4 Land areas with only Solar PV potential

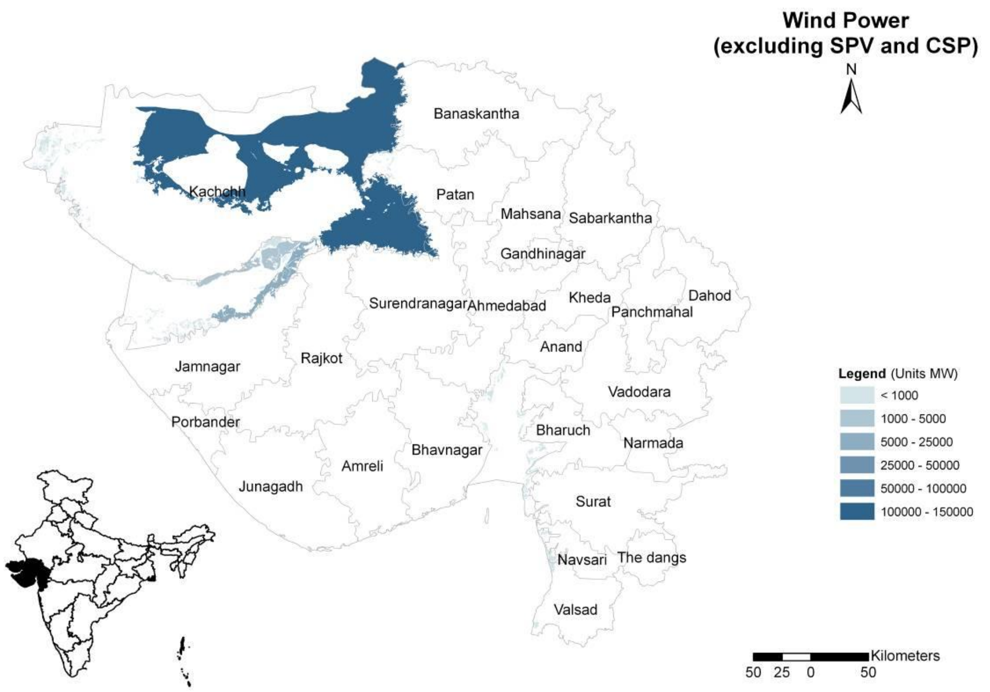

Figure 3.5 Land areas (non-crop land) with only wind power potential

Estimated solar and wind integrated power potential

Based on the common wind and solar power potential area analysis as detailed above the power potential in MW has been estimated. For this the wind power potential is estimated considering 11.2 ha land requirement per MW and for solar PV power potential in the land between wind turbines, based on the shadow analysis it is estimated that out of total land about 75% of the land will be remaining totally unaffected from shadow in which solar PV power can be installed. Solar PV efficiency is considered as 12%. Table 3.1 gives the estimated potential values for wind and solar PV system in common suitable land areas.

Table 3.1 Wind and solar PV potential in common suitable land areas

District	Total Wind-SPV common area (km²)	Potential for only SPV in this common area (MW)	Potential for only wind in this common area (MW)	Combined wind and SPV potential in the common area (MW)
Ahmedabad	91	2340	810	2566
Amreli	416	10955	3715	11932
Anand	0	0	0	0
Banaskantha	439	11313	3917	12402
Bharuch	772	19907	6892	21823
Bhavnagar	432	11378	3858	12392
Dahod	939	24547	8384	26794
Gandhinagar	9	227	78	249
Jamnagar	1270	38095	11338	39909
Junagadh	251	7513	2240	7875
Kachchh	8029	205548	71691	225852
Kheda	262	6797	2335	7433
Mahsana	18	467	162	512
Narmada	613	15803	5471	17324
Navsari	32	913	285	970
Panchmahal	334	8718	2984	9522
Patan	265	6744	2362	7420
Porbander	30	896	267	939
Rajkot	874	22765	7804	24877
Sabarkantha	533	13823	4758	15125
Surat	897	23460	8013	25608
Surendranagar	276	7263	2463	7910
The dangs	18	468	163	514
Vadodara	1510	39476	13483	43091
Valsad	197	5617	1756	5969
Total	**18506**	**485035**	**165231**	**529007**

Table 3.2 gives wind solar PV potential in common suitable land areas remaining after CSP land utilisation

Table 3.2 Wind and solar PV potential in common suitable land areas remaining after CSP land utilisation

District	Total Wind-SPV common area after CSP land utilisation (km^2)	Potential for only SPV in this common area (MW)	Potential for only wind in this common area (MW)	Combined wind and SPV potential in the common area (MW)
Ahmedabad	51	1322	458	1449
Amreli	241	6347	2152	6912
Anand	0	0	0	0
Banaskantha	208	5355	1854	5870
Bharuch	65	1680	582	1842
Bhavnagar	315	8298	2814	9037
Dahod	187	4895	1672	5343
Gandhinagar	2	63	22	69
Jamnagar	403	12093	3599	12669
Junagadh	167	5015	1495	5257
Kachchh	5266	134811	47019	148127
Kheda	96	2491	856	2724
Mahsana	14	356	123	390
Narmada	60	1539	533	1687
Navsari	19	555	174	590
Panchmahal	119	3105	1063	3392
Patan	43	1091	382	1200
Porbander	30	896	267	939
Rajkot	393	10236	3509	11186
Sabarkantha	206	5331	1835	5834
Surat	130	3389	1157	3699
Surendranagar	149	3935	1334	4286
The dangs	18	467	163	513
Vadodara	187	4893	1671	5342
Valsad	74	2110	660	2242
Total	8444	220274	75394	240599

Table 3.3 gives the potential values for the areas where only wind or only solar PV potential exists.

Table 3.3 Only wind and only solar PV power potential

District	SPV land area not common with wind area (km^2)	GHI ($kWh/m^2/yr$)	SPV Potential excluding common area with wind (MW)	Suitable area (non crop land) for Wind where no solar suitable land (km^2)	Potential for wind power in non-crop land where no solar suitable land (MW)
Ahmedabad	39	1905	1015	0	2
Amreli	0	1945	0	12	106

District	SPV land area not common with wind area (km²)	GHI (kWh/m²/yr)	SPV Potential excluding common area with wind (MW)	Suitable area (non crop land) for Wind where no solar suitable land (km²)	Potential for wind power in non-crop land where no solar suitable land (MW)
Anand	0	1920	0	0	0
Banaskantha	10	1905	266	107	952
Bharuch	0	1905	0	27	243
Bhavnagar	0	1945	0	1	8
Dahod	0	1931	0	0	0
Gandhinagar	38	1916	995	0	0
Jamnagar	14	2216	414	117	1041
Junagadh	13	2212	382	0	0
Kachchh	348	1891	8921	14925	133260
Kheda	0	1920	0	0	0
Mahsana	30	1905	761	0	0
Narmada	0	1905	0	0	0
Navsari	5	2110	135	11	100
Panchmahal	0	1927	0	0	0
Patan	0	1883	0	210	1874
Porbander	0	2216	0	0	0
Rajkot	95	1924	2464	9	80
Sabarkantha	203	1916	5270	0	0
Surat	23	1931	603	2	14
Surendranagar	0	1945	0	124	1105
The dangs	0	1891	0	0	0
Vadodara	0	1931	0	0	0
Valsad	5	2110	133	48	426
Total	**823**		**21358**	**15591**	**139209**

Table 3.4 gives the integrated potential for wind, Solar PV, CSP and Biomass power projects in Gujarat

Table 3.4 Integrated wind, solar and biomass power potential in Gujarat

District	CSP with water availability (GW)	SPV Wind hybrid excluding CSP land (GW)	Only SPV excluding wind and CSP	Only wind excluding solar potential land (GW)	Biomass (GW)	Total integrated potential (GW)
Ahmedabad	1.61	1.45	1.01	0.00	0.06	4.13
Amreli	5.87	6.91	0.00	0.11	0.14	13.03
Anand	0.00	0.00	0.00	0.00	0.02	0.02
Banaskantha	7.74	5.87	0.27	0.95	0.08	14.90
Bharuch	22.74	1.84	0.00	0.24	0.04	24.86
Bhavnagar	3.93	9.04	0.00	0.01	0.19	13.17
Dahod	24.96	5.34	0.00	0.00	0.02	30.32
Gandhinagar	0.80	0.07	1.00	0.00	0.03	1.90

District	CSP with water availability (GW)	SPV Wind hybrid excluding CSP land (GW)	Only SPV excluding wind and CSP	Only wind excluding solar potential land (GW)	Biomass (GW)	Total integrated potential (GW)
Jamnagar	37.11	12.67	0.41	1.04	0.21	51.44
Junagadh	3.94	5.26	0.38	0.00	0.19	9.77
Kachchh	87.76	148.13	8.92	133.26	0.07	378.14
Kheda	5.48	2.72	0.00	0.00	0.04	8.24
Mahsana	0.33	0.39	0.76	0.00	0.05	1.53
Narmada	17.76	1.69	0.00	0.00	0.03	19.47
Navsari	0.48	0.59	0.14	0.10	0.01	1.32
Panchmahal	7.21	3.39	0.00	0.00	0.01	10.61
Patan	7.03	1.20	0.00	1.87	0.04	10.14
Porbander	0.00	0.94	0.00	0.00	0.04	0.98
Rajkot	17.61	11.19	2.46	0.08	0.23	31.57
Sabarkantha	14.49	5.83	5.27	0.00	0.09	25.68
Surat	25.88	3.70	0.60	0.01	0.03	30.23
Surendranagar	4.26	4.29	0.00	1.11	0.14	9.79
The dangs	0.00	0.51	0.00	0.00	0.02	0.54
Vadodara	44.00	5.34	0.00	0.00	0.10	49.45
Valsad	4.71	2.24	0.13	0.43	0.02	7.53
Total	**345.71**	**240.60**	**21.36**	**139.21**	**1898.41**	**748.77**

3.2 Ground water potential

Water availability is a prerequisite for the deployment of solar power especially in the case of CSP as water is required for three main functions: steam generation, cooling, and cleaning of solar mirrors. It needs to be properly addressed while it comes to CSP planning. This is so important that availability of the water resource can be a limiting factor. The location which should be promoted for solar deployment must have consideration of water resources abstraction and consumption in sustainable manner for the long term. But it is really a contradicting factor as most of the location which is good for solar deployment is in desert and having shortages of water. These areas need to implement efficient water use, especially to prevent seasonal water shortages.

The solar PV plant requires water only for mirror cleaning; hence the requirement is not as huge as the CSP plants. But the deployment in large scale can adversely affect the region water resources if not considered or not planned in an appropriate manner.

Although for there is another option for wet cooling, i.e. to go for dry cooling options but it is a compromise of the efficiency and decrease in overall plant output, hence on the revenue generation.

In the context of the state of Gujarat, the similar conditions exists, the state is having shortages of ground water resources, even the quality of water is not very good in many locations.

The state is having overall annual rainfall of 1243 mm. The diverse terrain conditions have given rise to different ground water situations in the State. The rock formations ranging in age from Archaean to recent include gneisses, schists, phyllites, intrusive, medium to coarse grained sandstones, basalts and recent alluvium. The high relief area in the eastern and north eastern part occupied by Archaean and Deccan Trap have steep gradient allowing high run-off and therefore have little groundwater potential. The yield of wells in these formation ranges from 5-10m3/hr. The yield in sandstones varies from 50 to 170 m3/hr. The yield of wells tapping Quaternary alluvium in Cambay basin ranges between 75-150m3/hr. There are five major aquifers in alluvial sediments out of which the top one has dried up due to over exploitation.

Ground water being a hidden resource is often developed without proper understanding of its occurrence in time and space and threatened by overexploitation and contamination. There is an inherent linkage between development and management of ground water resources. Central Ground Water Board being the apex organization at the central level with vast experience in the ground water sector has taken the proactive role in identifying various key issues on ground water management.

The table 3.5 shows the dynamic ground water resources in the state of Gujarat.

Table 3.5 Dynamic ground water resources in the state of Gujarat[1]

Annual Replenishable Ground water Resource	15.81 BCM
Net Annual Ground Water Availability	
Annual Ground Water Draft	11.49 BCM
Stage of Ground Water Development	76 %

Annexure-12 gives an over view of the state wise ground water resource availability, utilization and stage of development in India. This gives a comparative picture of ground water availability in Gujarat vis a vis other states of India.

Availability of the ground water resources in the state of Gujarat over different districts is presented in the table in Annexure-13. A close analysis in to the table 3.3 shows that districts of Ahmedabad, Banaskantha, Gandhinagar, Mahesana and Patan are facing the problem of shortages of ground water even for irrigation, hence the development of solar power plants specially CSP, cannot depend on the ground water in these districts. Out of these districts, the Government of Gujarat is planning to develop Banaskantha and Patan as solar hub and recently the government had announced the development of Solar Park in the Charanka Village of the Patan district. The park would be home to around 500 MW solar power generation capacity. The solar park at Charanka village will be constructed on the land of 2000-hectare for the phase-1. Out of which 1000-hectare is a waste land. The solar park will house not only the solar PV plants but also for the CSP plant. So a proper linking of the water resources is required.

In the case of CSP, both wet cooling and dry cooling options were considered. The water requirement for a CSP power plant[2] with wet cooling is 10500 million cubic meter (MCM) per MW per year, whereas it reduces drastically to 1100 MCM/ MW/ year for dry cooling. There is hardly any illustration for the amount of water needed for a solar PV plant. In a Solar PV plant the water is needed for cleaning the panels, hence it is taken as the same as the amount of water needed for CSP plants for mirror cleaning (2% of the total water required). The amount comes out to be 210 MCM/ MW/ year. For interlinking the solar

[1] http://cgwb.gov.in/gw_profiles/st_Gujarat.htm, accessed onNovember 2010

[2] Report on "Global Concentrated Solar Power Industry Report, 2010-2011", published by CSP today

potential estimated earlier with the ground water resources available in each of the district, an estimation of the water requirement by considering both CSP and SPV power plants was done. A criterion based on the availability of the ground water resources for an estimation of real solar potential doesn't seems to be appropriate. Hence, this has been shown as qualitative criterion not as the GO/No-GO criterion. If the ground water resources in a specific district is sufficient to meet the demand at the present rate of exploitation, then considered indicated as Yes otherwise No. The Table 3.6 summarizes this.

Table 3.6 Suitability of solar power plants based on the ground water availability

				Water requirement calculations @ m³/MW/year (MCM/ year)			Ground Water Balance, 2004	Check of Solar Power Plant based on availability of Ground water balance		
Sr. No.	District	CSP Potential (MW)	SPV Potential, MWe	CSP Wet Cooling	Dry Cooling	SPV Cleaning	MCM/Yr	CSP Wet Cooling	Dry Cooling	SPV Cleaning
1	Ahmedabad	1611	3355	16.92	1.77	0.70	-67.93	No	No	No
2	Amreli	5872	10955	61.65	6.46	2.30	199.25	Yes	Yes	Yes
3	Anand	0	0	0.00	0.00	0.00	248.35	Yes	Yes	Yes
4	Banaskantha	7735	11579	81.22	8.51	2.43	-183.52	No	No	No
5	Bharuch	22739	19907	238.75	25.01	4.18	104.06	No	Yes	Yes
6	Bhavnagar	3931	11378	41.28	4.32	2.39	234.42	Yes	Yes	Yes
7	Dahod	24957	24547	262.05	27.45	5.15	79.82	No	Yes	Yes
8	Gandhinagar	802	1223	8.42	0.88	0.26	-302.62	No	No	No
9	Jamnagar	37115	38509	389.71	40.83	8.09	324.31	No	Yes	Yes
10	Junagadh	3940	7895	41.37	4.33	1.66	287.88	Yes	Yes	Yes
11	Kachchh	87764	214469	921.52	96.54	45.04	46.97	No	No	Yes
13	Kheda	5482	6797	57.56	6.03	1.43	190.05	Yes	Yes	Yes
12	Mahsana	332	1228	3.48	0.36	0.26	-425.85	No	No	No
14	Narmada	17760	15803	186.48	19.54	3.32	131.95	No	Yes	Yes
15	Navsari	479	1048	5.03	0.53	0.22	245.45	Yes	Yes	Yes
16	Panchmahal	7208	8718	75.68	7.93	1.83	170.12	Yes	Yes	Yes
17	Patan	7033	6744	73.84	7.74	1.42	-86.67	No	No	No
18	Porbander	0	896	0.00	0.00	0.19	9.73	Yes	Yes	Yes
19	Rajkot	17609	25229	184.90	19.37	5.30	279.73	Yes	Yes	Yes
20	Sabarkantha	14486	19093	152.11	15.94	4.01	121.12	No	Yes	Yes
21	Surat	25880	24063	271.74	28.47	5.05	782.29	Yes	Yes	Yes
22	Surendranagar	4261	7263	44.74	4.69	1.53	166.58	Yes	Yes	Yes
23	The dangs	1	468	0.01	0.00	0.10	37.07	Yes	Yes	Yes
24	Vadodara	44003	39476	462.03	48.40	8.29	279.50	No	Yes	Yes
25	Valsad	4706	5750	49.42	5.18	1.21	179.26	Yes	Yes	Yes

3.3 Narmada canal water

As discussed in the previous section of the ground water resources, the solar power plants specially CSP plants require a huge amount of water. Ground water is one of the sources while the surface water can be other source. Gujarat is developing a good network of the canal in the state. Probably some of the water from the canal can be allocated for the solar power development in the nearby districts.

The Narmada, the largest flowing Westward, rises near Amarkantak range of mountains in Madhya Pradesh. It is the fifth largest river in the country and the largest one in Gujarat. It traverses Madhya Pradesh, Maharashtra and Gujarat and meets the Gulf of Cambay. The total length of the river from source to sea is 1312 km while the length up to dam site is 1163 km.

In Sardar Sarovar Project is taking care of managing water resources for National interest - food security, energy security and upgrading the quality of life - including that of people who would be required to shift from submergence areas. It is a national project in the true sense.

Narmada Canal is the longest irrigation canal in the world. It is about 458 km long up to the Gujarat-Rajasthan border. The canal extends further into Rajasthan to irrigate areas in Barmer and Jhalore districts. In all, there are 593 structures on the Narmada Canal. The total project will irrigate 1.8 million hectares of land, thus bringing a green revolution inthe state of Gujarat. This would be more than the existing total irrigation potential of all major, medium and small irrigation projects of Gujarat. The project would also meet the drinking water requirement of millions of drought affected people.

The Sardar Sarovar Project commences at Rajpipla, from where water flows towards Saurashtra by a natural gradient. The main obstacle faced by this project was to continue theflow of the canal on the ascending Saurashtra region. The pump house at this sitepumps the entire volume of water up the ascending Saurashtra region. The Saurashtra branchcanal is the largest branch canal of Narmada Project canal system which offtakes from Narmada Canal near village Karannagar, TalukaKadi. It is 104 km long and tails into Bhogavo II reservoir (Dholi Dhaja Dam) near Surendranagar. The total system will lift 630000 litres of water per second to provide irrigation and drinking water to the drought affected areas of Saurashtra region of Gujarat.

The main features of the canal are as under

Main canal

- Full supply level at H.R: 91.44 m
- Length up to Gujarat Rajasthan border: 458 km
- Base width in head reach: 73.01 m
- Full supply depth (F.S.D.) in head reach: 7.60 m
- Design discharge capacity

  (a) In head reach: 1133 m /s

  (b) At Gujarat Rajasthan border: 71 m /s

Distribution system

- Numbers of branches (Gujarat): 42
- Length of distribution system network: 66000 km
- Annual irrigation: 18 lakh hectares

The Narmada canal network is shown in the figure 3.6 below

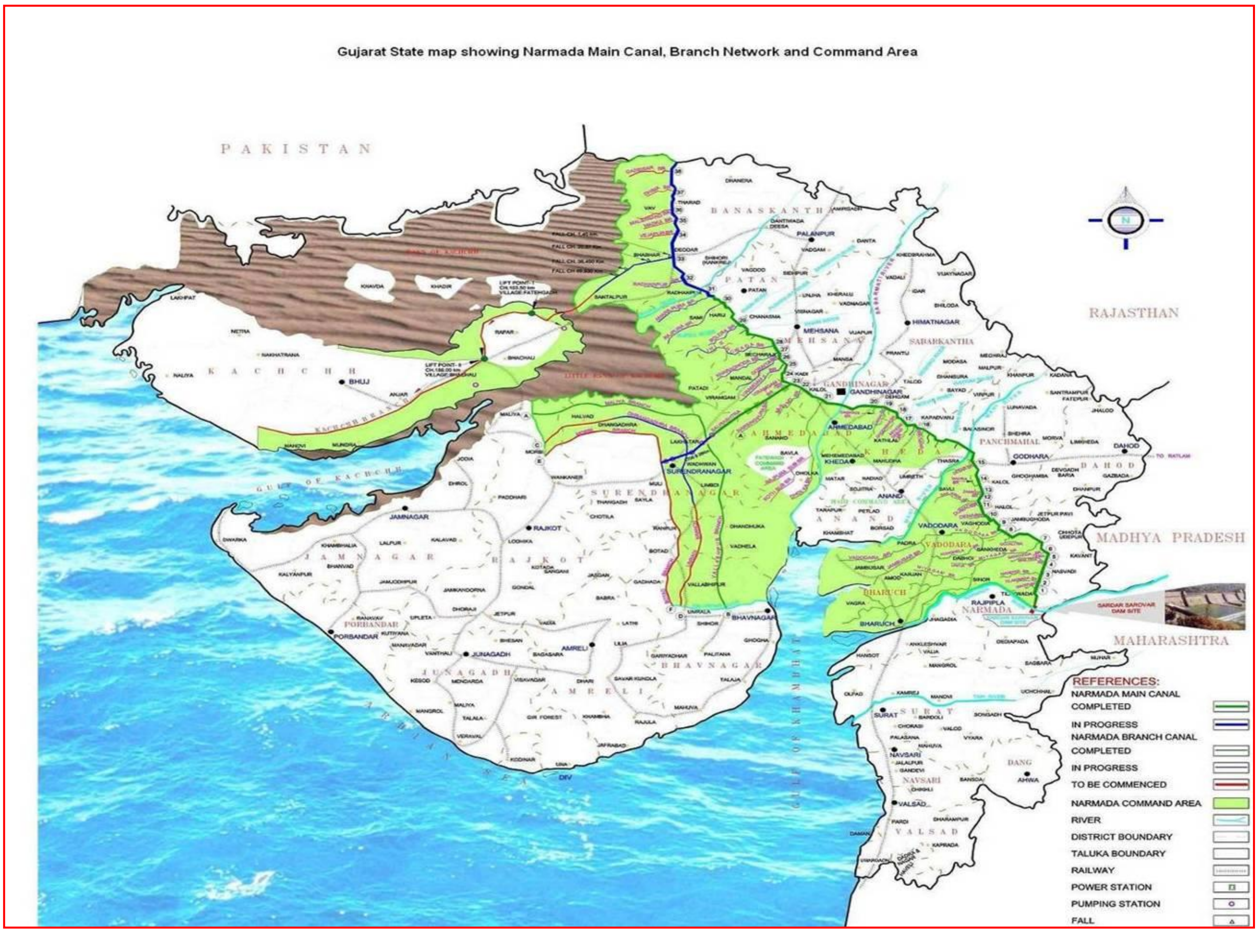

Figure 3.6 Gujarat map with the Narmada canal network

It is expected that the Narmada canal water can be used for the districts located around the canal for the solar power plants to some extent.

3.4 Existing grid Sub Stations

Government of India has an ambitious plan of 20000 MW of Grid connected solar power by the year 2022 under the Jawahar Lal Nehru National Solar Mission (JNNSM). These power plants are envisaged to be connected to the grid at 33 kV and above through substations of distribution utilities or state transmission utilities. In Gujarat, Gujarat Energy Transmission Company (GETCO) is the agency which is 66 kV substations are there instead of 33 kVwith (GETCO) and the 66/11 sub-stations are with GETCO only. The availability of such sub-stations was more than 99%. GETCO has made detailed investment plan for building the transmission lines to evacuate power generated by solar power developers, most of which are located in Kutch area. There was no possibility of local consumption of such electricity due to lack of demand in Kutch area.

The following figure 3.7 represents the power map of the state of Gujarat with the transmission lines and Grid sub stations

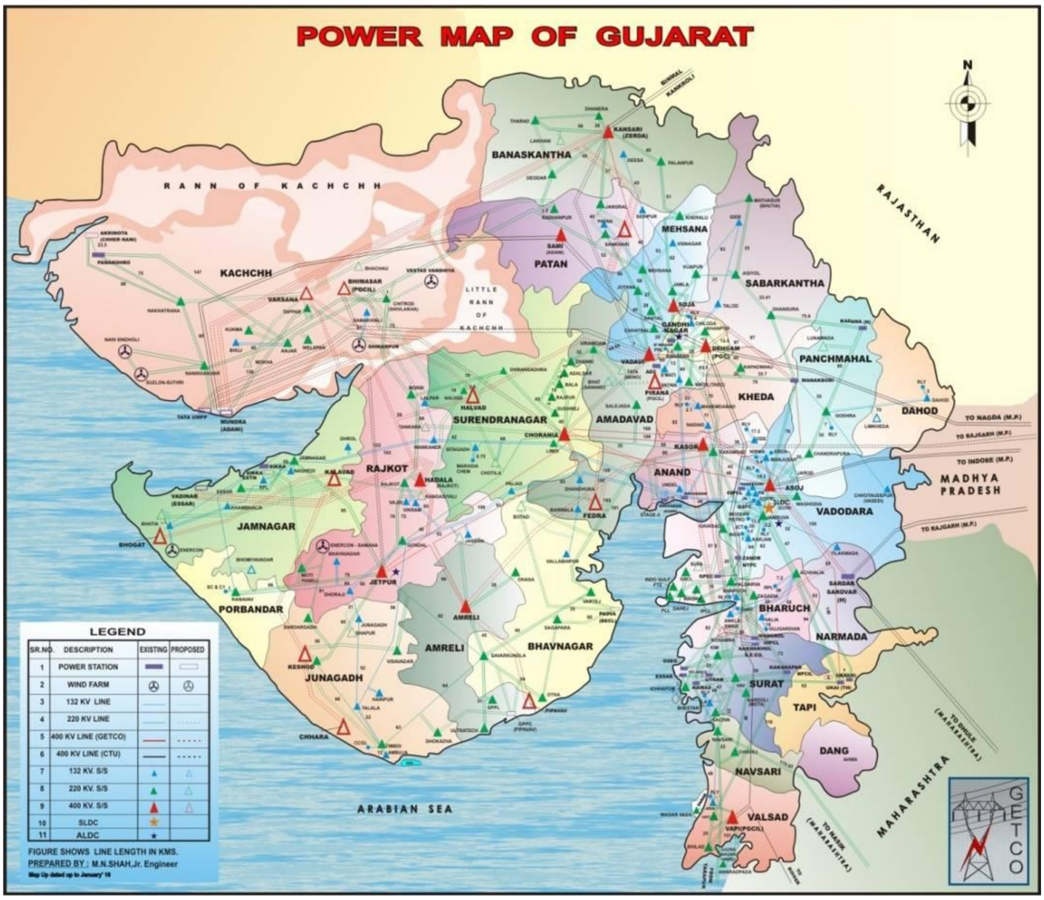

Figure 3.7 Power map of Gujarat

3.5 Gas grid infrastructure

As Gujarat gradually phases to a Gas based economy, the demand for natural gas is going to increase manifold. This gas grid infrastructure is really important in regard to solar thermal power plant so as to increase the utilization factor of these types of plants. Hybridization of solar thermal electric systems is a topic that has recently generated significant interest. The solar thermal power plants can be hybridized with natural gas power plant so as to increase the availability of solar plants year round. A rational for this is explained in the following section.

Hybridization can bring many benefits to the value of solar thermal power for current markets. One of these benefits is providing a low-risk pathway to substitute for technology that has not been developed commercially. Another benefit of hybridization is that it can reduce the financial risk of commercial deployment of new technology. If the plant is designed as a solar-only plant, the financial risk exposure is the total cost of the plant. If a parallel source of fossil heat is added to the plant, the plant costs would increase somewhat, but the financial risk from the new technology would now be limited to the capital cost of the original plant less that of the electric power generating system. Reduction in the delivered cost of energy can also be achieved through proper hybrid design. In today's environment of low-cost fossil fuels, hybridization decreases the delivered energy cost of the system as fossil energy displaces solar. A less obvious design option is the use of the fossil energy source to increase the temperature of the solar heat, allowing a more efficient conversion of the solar energy into electricity by allowing the use of higher temperature, more-efficient thermodynamic cycles. The hybrid solar thermal system will inject solar-generated steam into the steam cycle of the fossil plants, and the approach solves the intermittency challenge of integrating solar power onto the grid without compromising the reliability of supply.

Solar Energy Generation Systems in Mojave Desert of US have CSP plants that also use the solar natural gas hybrid system. 90% of the electricity is produced by the sunlight. Natural gas is only used when the solar power is insufficient to meet the demand. This also favours for the success of hybrid plants.

A simple schematic of the hybrid solar power plant is shown in the figure 3.8

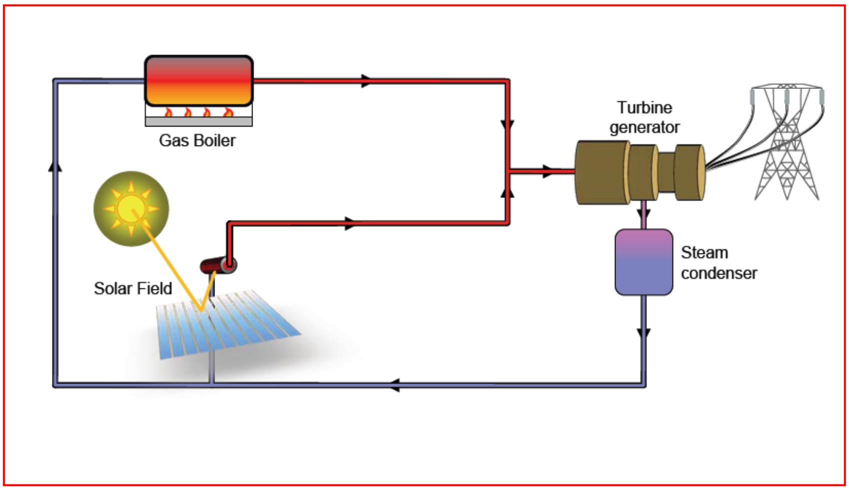

Figure 3.8 Schematic of hybrid solar power plant[1]

In the sunny locations of desert, CSP plants will be able to have a capacity utilization factor of roughly 25-30%.Most natural gas power plants in the world are under-utilized, operated at an average of only 42% Capacity Factor. This is because they typically serve a "load-following" function, turned on only when needed, during the higher-demand parts of the day and year. When demand for power drops to minimum levels, they are turned off because "Base Load" power plants designed to run all the time, are already running all the time to provide this base load demand. Most "Base Load" power plants are coal or nuclear plants. If a "hybrid" solar/natural gas plant were also operated as a "Load Following Plant", it might also be needed only 42% of year-round time. However, if 30% of year-round time its energy came from sunshine, the percentage of energy supplied by sunshine could be very high -- 30% over 42% -- or about 70% or more of the energy supplied. This is good to cut fossil fuel emissions from power plants. Solar power could cut fossil fuel use (and hence CO^2 emissions) by load-following power plants by roughly 2/3 compared to current patterns of operation for these plants.

This has become an important for the state of Gujarat to consider such type of hybridization being having a very good gas grid infrastructure throughout the state. Gujarat has the

[1] http://www.energybulletin.net/49878

largest natural gas pipeline network among all the Indian states. The pipeline network in Gujarat comprises of the North Gujarat and South Gujarat network of GAIL, a part of the HBJ pipeline network, the ex-Hazira network of GAIL, a part of the DVPL pipeline network, the pipeline network of GGCL and pipeline network of GSPL. Gujarat has the only two operational LNG terminals in India. Supplies to Gujarat are expected to increase manifold, with Petronet and Shell expanding their LNG re-gasification capacity. Industrialization, proximity to supply sources and developed natural gas transportation infrastructure have resulted in Gujarat emerging as the largest natural gas consuming state in the country, with more than 35% of India's total natural gas consumed in Gujarat.The organization intends to expand its grid to 2200kms with an outreach to all the 25 districts of Gujarat.

Gujarat State Petronet Limited transport natural gas on open access basis and is a Pure Natural Gas Transmission Company. GSPL, a GSPC subsidiary, has taken a lead in developing energy transportation infrastructure in Gujarat and connecting major natural gas supply sources and demand markets. The transmission network of the company envisages development of systematic and seamless pipeline network across Gujarat connecting various suppliers and users. The suppliers of natural gas include traders, producers and LNG terminals. The users comprise industries such as power, fertilizer, steel, chemical plants and local distribution companies.

Gujarat gas grid network is shown in the figure 3.9

Figure 3.9 Gas grid of Gujarat[1]

Based on the previous analysis of solar potential in different districts, districts of Surendra Nagar, Kutch, Bhavnagar which has good solar thermal potential and are close to the existing/ planned gas grid network can be developed further with the view of solar hybrid power plants. Figure 3.10 represents the proposed gas grid for the entire India part from the existing grid.

[1] http://www.gujpetronet.com/

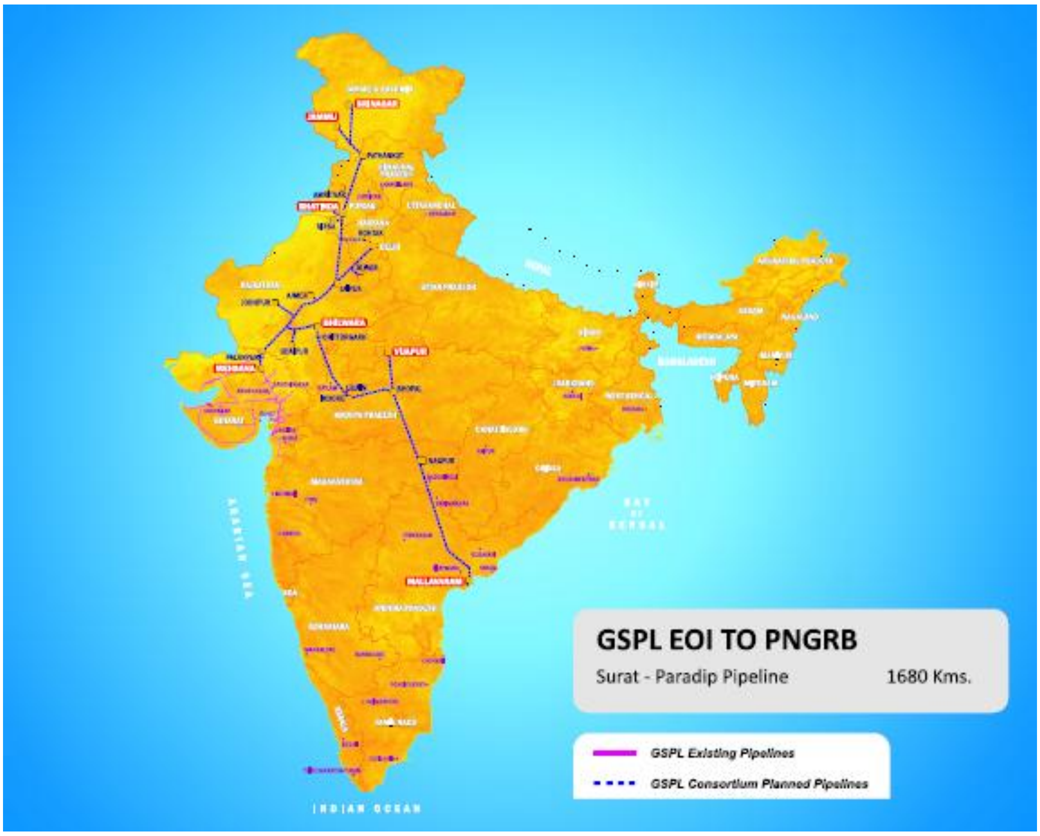

Figure 3.10 Gas grid network in India[1]

[1] http://www.gujpetronet.com/

4. Limitations of the study

4.1 Limitation of solar power potential assessment study

- In this study, satellite data have been used for both Solar PV and Concentrating solar power potential estimation. These data sources have been selected due to availability for all the districts, but it has the disadvantage of being at low resolution (30 by 30 km).
- The present study is based on the total waste land present in the district. Neither any check on the continuity of the land parcel done nor is topography checked for the slope. Hence, it is further suggested to go for ground truthing exercise.
- For CSP suitability study Bravo et al. (2007)[1] included all areas which have a suitable slope (gradient below 7% for slopes facing SE to SW or below 2% for all other orientations), a suitable land use profile and average direct normal solar irradiation values above 4.1 $kWh/m^2/d$ (1500kWh/m2/a) whereas Pletka et al. (2007)[2] include all areas with a suitable slope gradient below 1%,asuitable land use profile and average direct normal solar irradiation values higher than 6.75kWh/m2/d. But in the present study, neither slope study nor the slope directions were studied. It is suggested to look in to these in more details by studying the land topography.
- The solar irradiance over a district has been assumed constant; however it may be different for different locations in the same district so the actual potential at any particular location might be slightly different from what has been estimated in the study.

4.2 Limitation of wind power potential assessment study

Though attempt has been made to collect all the available data with best resolutions to maximise the accuracy of the assessment there are some limitations which could not be overcome at this stage of study

1. The wind power density map is taken from Indian Wind Atlas and has been digitised using GIS. As the map had contiguous contouring the finally digitised map may not contain the minor level of the wind power density distribution and there would be a chance that the areas actually with little less WPD than 200 W/m2 may come under the area of 200 W/m2 considered in our study this may result in somewhat higher potential estimation than the actual potential. On the other way the areas actually with WPD more than 200 W/m2 might have been digitised under low WPD area which may result in somewhat lower wind power potential estimation than the actual one.
2. The data about the existing utilisation of the areas where wind power potential exists is not available. If there already are some establishments on the lands considered suitable for wind power then it would be difficult to setup the wind power in those areas. This fact could not be considered in the study as there is no data available for the same.
3. No ground trothing for wind power suitable sites have been made while developing the atlas. So there is a scope for further refinement of the potential assessment by ground trothing of the identified land for its availability and other factors.

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[1] Bravo, J., Casals, X., Pascua, I., 2007. GIS approach to the definition of capacity and generation ceilings of renewable energy technologies. Energy Policy 35, 4879–4892.

[2] Pletka, R., Block, S., Cummer, K., Gilton, K., R., O., Roush, B., Stoddard, L., Tilley, S., Woodward, D., Hunsaker, M., 2007.Arizona Renewable Energy Assessment.Black & Veatch Corporation, Overland Park, Kansas.

4.3 Limitation of biomass power potential assessment study

Huge amount of agro-residue is used in captive power generation and in boilers. The related industrial biomass consumption data is not available for reference. Therefore, actual biomass consumption in the state may be more than what is estimated in the study and hence the actual surplus biomass availability may differ than the amount mentioned in the report. For any biomass power project development it is recommended to carry out the detailed survey for actual biomass availability in the project area.

4.4 Other limitations

1. Though the study focussed to estimate the renewable energy potential with highest accuracy, the actual estimated potential may vary as the renewable energy resource data used for the study are the mesoscale data representing the average resource data at district level (the long term measured data for all the locations are not available) and not at the micro level so the actual renewable power potential at a given land polygon may be different from the estimated one depending upon the actual solar radiation or wind speed being received over that land area.
2. Ground water data is considered from the database witch is few year old, i.e. of 2004 because of non-availability of recent year data.

5. Conclusion

Based on the above study it has been analyzed that there the overall renewable energy potential in Gujarat is very high, considering if all the identified suitable lands for RE projects can be made available. The GIS based land use land cover study gives an idea about the quantity of the lands which are suitable for the renewable energy projects installations, though it is very much important to carry out the depth ground level survey and analysis for finding out the actual/realizable renewable power potential. This study helps in identifying the districts where the great potential exists for the standalone CSP, SPV, Wind power, Biomass power and other renewable power, and also the probable SPV-WIND hybrid plant development for the optimized utilization of the lands.

The above analyzed district wise renewable energy resource potential that is put in the form of an atlas in the GIS platform, incorporating the layers of electricity grid network, gas grid network, ground water and surface water (Narmada canal route) etc., is a very useful tool in the planning of the renewable energy sector development in the state. The integrated approach that gives logic for the selection of the renewable energy technology (wind, solar, biomass and others) as per the strength of the resource availability in that particular area has been successful in developing this renewable energy atlas of Gujarat with spatial distribution of all renewable energy resource availability with the other infrastructure data.

There is a need to focus on developing guidelines and policy for prioritisation of the land utilisation which enables easy and early clearance of lands for the renewable energy projects development. The Integrated renewable energy resource atlas developed is an interactive tool that will help the planners and policy makers for promotion and development of RE projects at large scale. Based on the adaptability of this atlas, the same type of atlases can be developed for all the states having good renewable energy resources.

Annexure 1: Land use land cover pattern in Gujarat

Description of land classes

Sl No.	Land Class	Description
1	Built-up	These are human habitation areas covering residential, commercial and industrial areas. These all include all routes of transportation and communication.
2	Deciduous forest	These are the forest area comprising of green cover in a particular season and shed the leaves in dry seasons.
3	Scrub/Degraded forest	These are the forestland where crown density is less than 10%. These are mostly at the fringes of forestlands.
4	Current fallow	These are the land parcels left out of cultivation for a short period.
5	Gullied/Ravine	These are the excessive land dissection with very sparse vegetative growth.
6	*Kharif* crop only	These are the cropped areas sown in June-July and harvested in September-October. These are also called rain-fed crop s under dry land farming and with no irrigation facility.
7	Littoral swamp	These are very specific kind of forest types (including mangrove) found in the coastal areas.
8	Plantation/Orchard	These are the areas under tree cropping and plantation.
9	*Rabi* crop only	These are the cropped areas sown in November/December and harvested in February/March. These are in the areas having relatively good irrigation facility.
10	Rann area	
11	Scrub land	These are as defined in the scrub forest category but more outside the forest and in and around agriculture areas.
12	Double/Triple crop	These refer to the areas having a combination of Kharif, Rabi and summer crops. These are more associated with irrigated areas.
13	Zaid Crop/Summer crop only	Zaid crop/Summer crop are the third season which are mostly in the irrigated areas or along with river. These are very short period crops in which vegetable and fruits are grown.
14	Evergreen forest	These are the forest areas comprising of green cover predominantly throughout the year.
15	Other wastelands	It includes all categories of wasteland otherwise defined.
16	Water bodies	These are surface water bodies includes part of estuary.

District wise land area covered under all land classes

DISTRICT	Built up	Kharif crop only	Rabi crop only	Summer crop only	Double/ Tripple crop	Current fallow	Plantation / Orchard	Deciduous forest	Scrub / Deg. forest	Littoral swamp	Other wastelands	Gullied / Ravine	Scrub land	Water bodies	Rann area	TA (Sqkm)
Ahmedabad	222.72	930.11	674.91	3.51	2964.53	1191.01	0.00	1.43	0.62	0.31	1118.30	78.96	476.47	1044.11	0.00	8707
Amreli	8.06	1190.74	248.42	5.61	3283.68	497.94	0.00	152.49	214.53	9.86	195.05	93.30	709.27	151.06	0.00	6760
Anand	32.52	113.67	59.03	3.42	2594.05	36.60	0.00	3.24	2.14	0.10	180.04	0.00	32.41	156.79	0.00	3214
Banaskantha	24.80	1546.94	499.25	16.16	4880.78	498.14	16.56	670.89	190.12	0.00	435.59	0.00	921.39	55.97	101.42	9858
Bharuch	77.92	466.96	648.05	29.59	2143.41	1092.79	3.88	17.39	143.09	36.94	155.12	0.00	1254.82	388.02	0.00	6458
Bhavnagar	3.66	1530.81	191.14	12.51	5370.26	701.01	0.00	168.92	505.97	1.39	786.58	168.10	1269.09	445.55	0.00	11155
Dahod	7.21	569.03	145.20	0.44	1426.18	154.39	0.00	580.11	425.46	0.00	11.99	0.00	914.05	170.95	0.00	4405
Gandhinagar	58.30	45.53	6.94	0.65	419.52	14.84	0.00	0.42	0.32	0.00	2.04	0.00	91.70	8.75	0.00	649
Jamnagar	103.04	2817.17	205.82	3.26	4797.09	848.54	0.00	235.95	145.12	164.72	1802.45	157.49	2340.89	503.46	0.00	14125
Junagadh	12.56	335.73	1499.05	8.56	3937.71	376.15	0.00	1104.56	261.82	0.00	91.22	26.17	432.09	195.37	0.00	8281
Kutch	92.60	1918.05	338.89	21.66	1342.58	4188.97	0.03	0.88	1775.60	480.88	1632.56	2.50	9564.87	3035.90	21256.02	45652
Kheda	29.42	228.94	97.01	3.35	3012.00	28.03	0.00	0.00	0.00	0.00	42.31	0.00	455.67	83.27	0.00	3980
Mehsana	139.74	785.91	212.99	6.92	6351.77	153.32	4.06	199.95	50.12	0.00	56.03	0.00	501.57	77.62	0.00	8540
Narmada	2.39	185.30	24.32	0.54	490.01	26.08	0.00	562.24	463.99	0.00	3.46	0.00	625.04	196.63	0.00	2580
Navsari	19.09	129.79	6.13	10.46	1312.74	58.41	82.32	262.25	89.90	12.60	9.03	0.00	142.42	79.86	0.00	2215
Panchmahal	30.53	663.31	33.00	0.95	2447.69	23.00	0.00	278.88	190.04	0.00	16.86	0.00	612.74	164.00	0.00	4461
Patan	15.57	490.74	359.71	1.28	1046.31	554.54	0.19	0.00	0.00	0.00	399.02	0.00	273.90	65.70	125.05	3332
Porbandar	10.81	235.22	394.68	2.28	623.64	261.53	0.00	113.33	137.55	0.00	220.39	5.42	116.28	204.88	0.00	2326
Rajkot	79.35	1426.40	340.10	2.34	6285.14	462.59	0.00	20.03	237.85	0.57	394.02	128.72	1398.29	418.46	9.15	11203
Sabarkantha	26.30	841.16	35.71	3.32	4084.87	55.47	0.00	833.16	287.61	0.00	63.11	0.00	999.95	159.35	0.00	7390
Surat	131.51	608.65	61.54	69.05	3544.05	150.91	39.32	632.62	639.46	1.55	26.49	0.00	1124.94	626.91	0.00	7657
Surendranagar	5.79	965.83	975.31	6.17	3101.89	1710.01	0.00	0.41	428.25	0.01	1364.17	311.99	819.71	673.91	125.56	10489
The dangs	1.19	143.79	0.49	0.04	107.53	1.22	0.00	1129.37	271.90	0.00	3.21	0.00	67.20	36.05	0.00	1762
Vadodara	167.29	485.21	219.39	9.57	4394.87	134.58	3.85	159.41	235.11	0.00	39.28	0.00	1695.14	250.30	0.00	7794
Valsad	20.62	174.56	23.48	5.00	1102.63	79.12	0.00	730.87	499.39	27.78	12.60	0.00	243.56	109.40	0.00	3029
Total	1323.00	18829.55	7300.57	226.61	71064.94	13299.19	150.22	7858.80	7195.95	736.71	9060.90	972.65	27083.47	9302.26	21617.19	196022

Annexure 2: Solar energy conversion technologies

Solar thermal technology

Non - concentrating: These technologies harness heat from the sun to provide hot water or hot air, e.g. flat plate collector, evacuated tube collector, heat pipe technologies fall under this category.

Concentrating Solar Power: These technologies harness heat from the sun through the concentration of solar rays to provide electricity for large power stations. Parabolic trough, Fresnel linear reflector, Power tower, Stirling dish etc. are main solar concentrator technologies for power generation.

Solar photovoltaic technology

These technologies convert sunlight directly into electricity. They work on the principal of photoelectric effect. All materials used are semiconductors. In many cells, this is just one material, in most instances, silicon. However, in order to improve performance, there could be multiple layers of different materials. This technology can be broadly divided into following categories

Crystalline silicon: There are two type of crystalline silicon cell available, namely Mono-crystalline, where the atoms form a regular lattice and due to this, it has a better response rate with the purity of > 99.99999% (7N) and Poly-crystalline, where this is in effect a series of crystals rather than one crystal with purity of 99.999% (5N) to 99.9999% (6N)

Thin-film: Thin film modules use compounds with very strong light absorption characteristics, requiring only a thin layer. The absorption materials are deposited on glass or foil. They include Amorphous Silicon (a-Si),the response rate is much lower than in mono-crystalline structure. However, it captures more of the highly-intensive light than crystalline silicon and can be changed by alloying it with, among others, Germanium or ***Carbon, CdTe:*** Cadmium-Telluroid: Inexpensive technology with medium efficiency and CIS/CIGS (cadmium-indium-gallium-selenide and copper indium gallium diselenide), these have efficiencies as high as crystalline silicon.

Multi-junction: Differences in spectral sensitivities between materials can be exploited by adding multiple absorption layers on top of each other, resulting in multiple p-n junctions; the material with the largest band gap is positioned closest to the incoming light, absorbing all the high- energy photons. For low- energy (long wavelength) photons, this first layer will be transparent until they hit the second layer with a lower band gap. This way, overall efficiency can be increased to 40%, compared to 20% for mono-crystalline silicon

The Concentrated Solar Thermal (CST) power plants produce electricity by converting the solar radiation into high-temperature heat using various mirror/reflector and receiver configurations. In CST plants solar radiation is converted to high-temperature heat source which, in turn, is used to produce steam or hot gas for power production through turbine generator combination.

The overall generic arrangement in a typical CST power plant is shown in Figure A2.1.

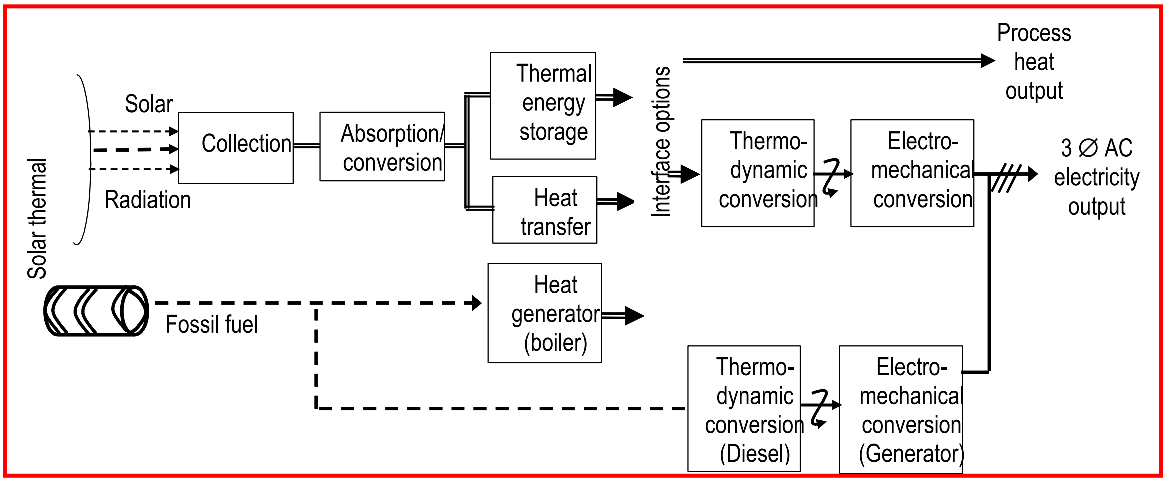


Figure A2.1 Generic arrangement of CSP plant

Grid connected solar PV systems offer a unique opportunity to silently and cleanly generate significant amounts of energy, which are designed to operate in parallel with, and interconnected, with the electric utility grid. A grid-connected solar electricity system links several solar panels together through an inverter to the power grid. No electrical storage batteries are required. The overall generic arrangement in a typical SPV power plant is shown in Figure A2.2.

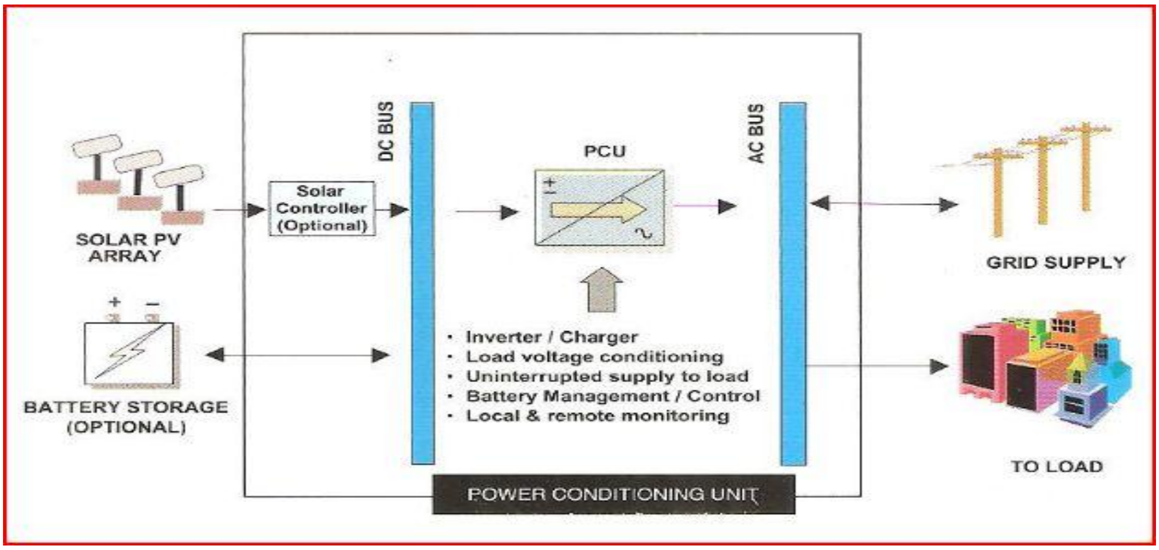


Figure A2.2 Generic arrangement of SPV plant

Annexure 3: Solar radiation data source and accuracy

The data for solar radiation has been taken from Surface meteorology and Solar Energy website which is sponsored by NASA's Applied Sciences Program in the Science Mission Directorate. The meteorological data is on a 1 degree longitude by 1 degree latitude equal-angle grid covering the entire globe (64,800 regions). The data is generated using the NASA Goddard Earth Observing System - Version 4 (GEOS 4) Multiyear Assimilation Time series Data. The GEOS 4 data set has a spacing of 1.25 degrees of longitude by 1 degree of latitude. Bilinear interpolation is used to produce 1 by 1 degree regions.

The solar energy data is generated using the Pinker/Laszlo shortwave algorithm. Cloud data is taken from the International Satellite Cloud Climatology Project DX dataset (ISCCP). ISCCP DX data is on an equal area grid with an effective 30x30 km pixel size. The output data is generated on a nested grid containing 44,016 regions. The nested grid has a resolution of one degree latitude globally, and longitudinal resolution ranging from one degree in the tropics and subtropics to 120 degrees at the poles. This, in turn, is re-gridded to a one degree equal-angle grid (360 longitudes by 180 latitudes). The re-gridding method is by replication, wherein any grid region that is larger than 1x1 degree is subdivided into 1x1 degree regions, each with the same value as the original.

This section provides estimates of the levels of uncertainty for insolation (solar radiation), temperature, surface pressure, relative humidity, and wind speed through comparisons with ground measurement data. It is generally considered that quality measured data are more accurate than satellite-derived values. However, measurement uncertainties from calibration drift, operational uncertainties, or data gaps are unknown for ground site data sets. In 1989, the World Climate Research Program estimated that most routine-operation ground sites had "end-to-end" uncertainties from 6 to 12%. Specialized high quality research sites are hopefully more accurate by a factor of two.

SSE estimates were compared with ground site data on a global basis. Radiation parameters were compared with data from the Baseline Surface Radiation Network (BSRN).

Table A3.1 Regression analysis of SSE versus BSRN monthly averaged values for the time period July 1983 through June 2006

Parameter	Region	Bias (%)	RMS (%)
Horizontal Insolation	Global	-.01	10.25
	60° Pole ward	-1.18	34.37
	60° Equator ward	0.29	8.71
Horizontal Diffuse Radiation	Global	7.49	29.34
	60° Pole ward	11.29	54.14
	60° Equator ward	6.86	22.78
Direct Normal Radiation	Global	-4.06	22.73
	60° Pole ward	-15.66	33.12
	60° Equator ward	2.40	20.93

The state under the study Gujarat lies between latitude of 20° 6' N to ° 24° 42' N, hence from the table A3.1, it can be found out that regression analysis of this data source when compared with BSRN network, have an bias error of 0.29% and RMS error of 8.71% in horizontal insolation. The same errors are respectively 6.86% and 22.78% in the case of horizontal diffuse radiation. When the errors are compared with DNI, although the bias error is 2.4% only but the RMS value is as high as 20.93%.

In India, India Meteorological Department (I.M.D.) is maintaining a network of radiation measuring stations. The network which initially had 4 stations in 1957 has gradually expanded to the present 45[1] odd stations. The most basic parameter, the incident solar radiant energy is measured at 43 stations, where as the diffuse solar irradiation is measured at 24 locations in India. The data obtained at different sites spread over the country are collected by the Climatology Division of the Department at Pune and scrutinized thoroughly before being archived at the National (Climatological) Data Centre at Pune.Few of the stations are also located in the state of Gujarat. Data collected by IMD for periods ranging from 2 years to 21 years has been compiled by A. Mani (1980) and A. Mani and S. Rangarajan (1982) in two volumes of books. The first one[2] contains the results of measured values whereas the second one[3] gives the derived values – derived based on various meteorological parameters. The main purpose of these books is to provide a database for the designers of systems for harnessing the solar energy received at a place.

In the present study, an effort has been made to compare the satellite data for such location for which IMD data are present. Satellite data is considered as the basis and presented in the following graphs.

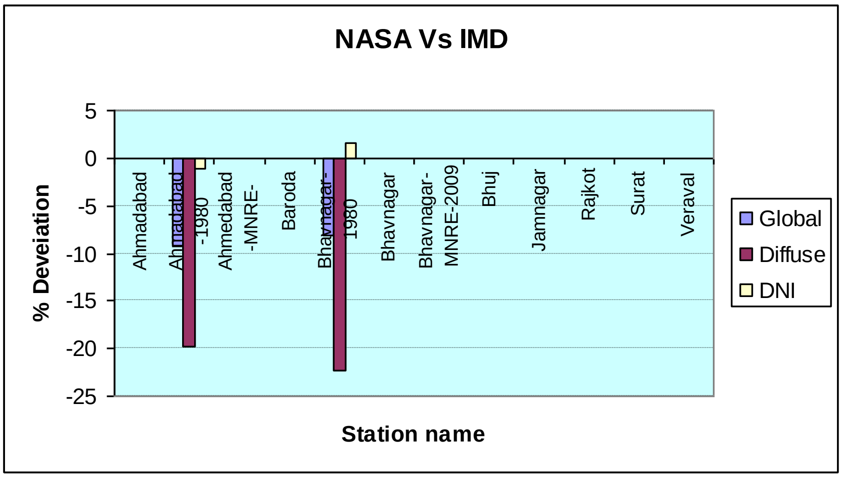


Figure A3.1 Comparison of Satellite data with IMD - Measured data

It can be observed from the above graph that when annual values of Global , diffuse and direct normal irradiation is comapred with the same values of IMD Measured data base for Ahemdabad, a variation of respectively 9.2, 19.7, and 1.2 % was there whereas in the case of other available station Bhavnagar these values are 8.0, 22.3 and 1.5%. Clearly, this analysis varifies the satellite data compariosn with BSRN netwrok study. A huge varioation is found in the diffuse radition measurement w r t measured values.

The other possible comparison can be made for the other available data source i.e. the derived values for solar radiation from other parameters measured by IMD, which extends the list of stations (8) in Gujarat. The comparison graph is shown in the following figure A3.2

[1] "Solar Radiation Resource Assessment"Presentation made by Mr. M K Gupta, , Director –Instrument Division, IMD, Pune, at MNRE in Expert group committee meeting on 4th Dec 2009
[2] "Handbook of Solar Radiation Data for India", by A. Mani (1980)
[3] "Solar Radiation Over India" by A. Mani and S. Rangarajan (1982)

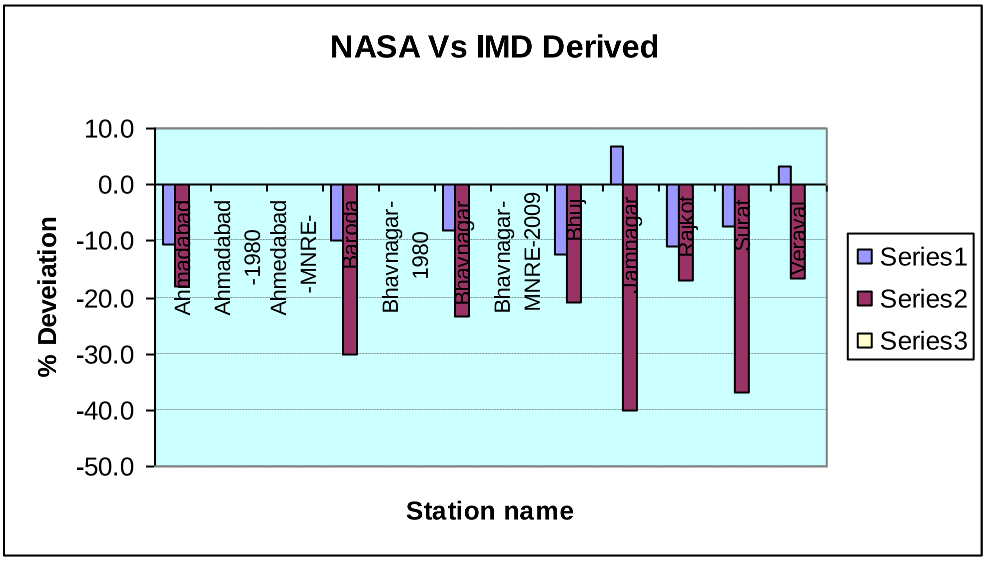


Figure A3.2 Comparison of Satellite data with IMD – Derived data

It can be observed from the graph, that similar trend as the previous one is there in all the parameters for all the available locations with the diffuse radiation variation as high as 40%. This can be possible due to modelling error in the derived data.

Again Ministry of Non-Conventional Energy Source formed a core group committee to revise the Handbook based on the data from 1986 to 2000. As all stations do not use the same type of instruments and also do not have the same parameters to be monitored. 23 stations were identified which have a common database - those of global solar irradiation and of diffuse solar irradiation. Direct solar irradiances are measured at 21 locations - 13 making instantaneous observations at selected timings during the daytime and 10 others record it continuously with the sensors on solar trackers. The report came in the form of book[1]. It is one of another source of IMD data base with the latest data of the network stations. Hence, it is worthwhile to compare this also with the satellite data source so as to find out the variation in the different radiation data. A comparison of the measured current data of IMD, compiled in the new version of the book is shown for the available stations Ahmedabad and Bhavnagar.

[1] "Solar Radiant Energy Over India", Editor in chief Dr A P Tyagi, (2009)

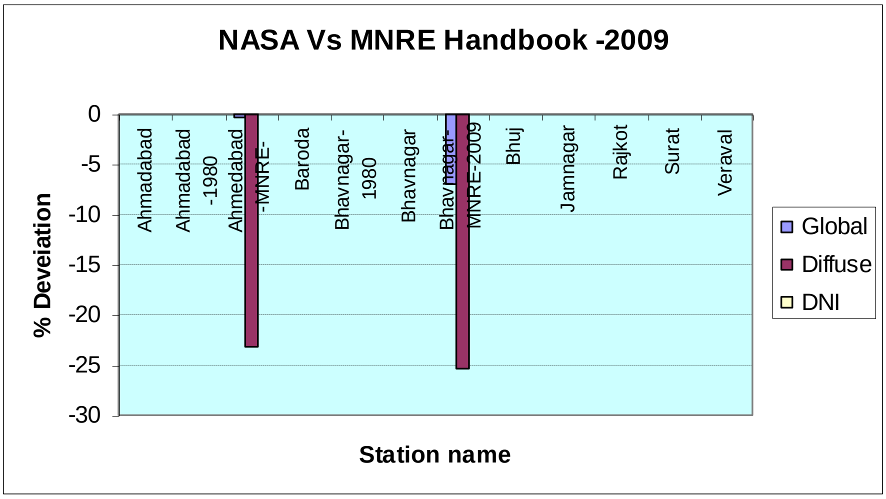


Figure A3.3 Comparison of Satellite data with MNRE Handbook (2009) data set

Variation in the global radiation for the station is below 10% but for diffuse radiation it is as high as 25%.

The other set of comparison which is possible, is with the Meteonorm[1] data set. Several databases from different parts of the world have been combined and checked for their reliability. In the present version, most of the data is taken from the GEBA (Global Energy Balance Archive), from the World Meteorological Organization (WMO/OMM) Climatological Normals 1961–1990 and from the Swiss database compiled by Meteo Swiss. Meteonorm data set contains few stations (4) that are located in Gujarat. So a comparison graph for the same is shown in the figure A3.4

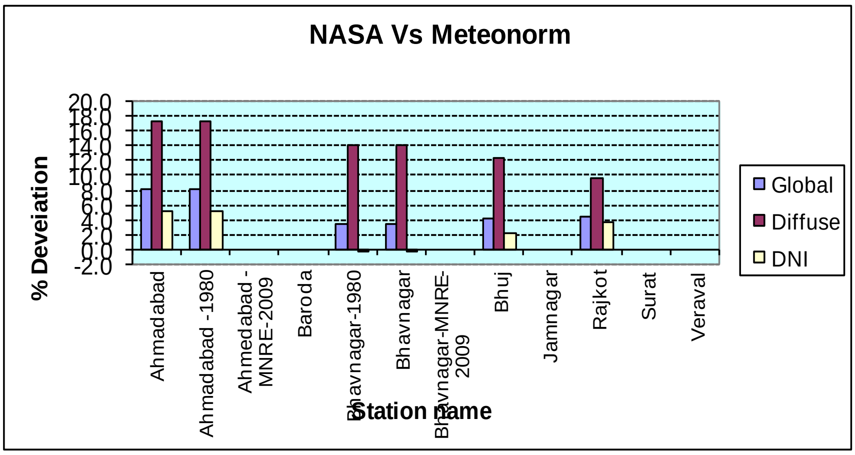


Figure A3.4 Comparison of Satellite data with Meteonorm data base

It can be seen from the graph that variation of Meteonorm and Satellite data set is below 8% in case of global radiation, 17.2% in diffuse radiation and 5% in case of DNI.

[1] METEONORM is a comprehensive meteorological reference, incorporating a catalogue of meteorological data and calculation procedures for solar applications and system design. More information about the software can be found at http://www.meteonorm.com/

Annexure 4: Details of district wise land area and MW potential estimates for solar power at different percentage of land availability

Table A4.1 Total SPV potential in different scenarios

District	Total SPV land area (km²)	Total SPV Potential (MW) 10% Land availability	25% Land availability	50% Land availability	75% Land availability	100% Land availability
Ahmedabad	130	336	839	1678	2516	3355
Amreli	416	1096	2739	5478	8217	10955
Anand	0	0	0	0	0	0
Banaskantha	449	1158	2895	5789	8684	11579
Bharuch	772	1991	4977	9954	14930	19907
Bhavnagar	432	1138	2844	5689	8533	11378
Dahod	939	2455	6137	12273	18410	24547
Gandhinagar	47	122	306	611	917	1223
Jamnagar	1284	3851	9627	19255	28882	38509
Junagadh	264	790	1974	3948	5921	7895
Kachchh	8378	21447	53617	107234	160852	214469
Kheda	262	680	1699	3399	5098	6797
Mahsana	48	123	307	614	921	1228
Narmada	613	1580	3951	7902	11852	15803
Navsari	37	105	262	524	786	1048
Panchmahal	334	872	2180	4359	6539	8718
Patan	265	674	1686	3372	5058	6744
Porbander	30	90	224	448	672	896
Rajkot	969	2523	6307	12614	18921	25229
Sabarkantha	736	1909	4773	9546	14320	19093
Surat	921	2406	6016	12032	18048	24063
Surendranagar	276	726	1816	3631	5447	7263
The dangs	18	47	117	234	351	468
Vadodara	1510	3948	9869	19738	29607	39476
Valsad	201	575	1438	2875	4313	5750
Total	**19329**	**50639**	**126598**	**253197**	**379795**	**506393**

Table A4.2 Total CSP potential in different scenarios

		Total CSP Potential (MW)				
District	**Total CSP land area (km²)**	**10% Land availability**	**25% Land availability**	**50% Land availability**	**75% Land availability**	**100% Land availability**
Ahmedabad	50	161	403	806	1208	1611
Amreli	175	587	1468	2936	4404	5872
Anand	0	0	0	0	0	0
Banaskantha	288	948	2371	4742	7113	9484
Bharuch	707	2274	5685	11369	17054	22739
Bhavnagar	117	393	983	1966	2948	3931
Dahod	752	2496	6239	12479	18718	24957
Gandhinagar	24	80	200	401	601	802
Jamnagar	871	3711	9279	18557	27836	37115
Junagadh	94	394	985	1970	2955	3940
Kachchh	8068	25625	64062	128124	192185	256247
Kheda	166	548	1371	2741	4112	5482
Mahsana	10	33	83	166	249	332
Narmada	553	1776	4440	8880	13320	17760
Navsari	13	48	120	240	359	479
Panchmahal	215	721	1802	3604	5406	7208
Patan	222	703	1758	3516	5275	7033
Porbander	3	13	33	65	98	131
Rajkot	536	1761	4402	8805	13207	17609
Sabarkantha	435	1449	3622	7243	10865	14486
Surat	785	2588	6470	12940	19410	25880
Surendranagar	126	426	1065	2131	3196	4261
The dangs	0	0	0	0	0	1
Vadodara	1323	4400	11001	22002	33002	44003
Valsad	123	471	1177	2353	3530	4706
Total	**15655**	**51607**	**129017**	**258035**	**387052**	**516070**

Table A4.3 CSP potential based on the water availability in different scenarios

		Total CSP Potential (MW), based on water availability				
District	**Total land area for CSP based on water availability (km²)**	**10% Land availability**	**25% Land availability**	**50% Land availability**	**75% Land availability**	**100% Land availability**
Ahmedabad	50	161	403	806	1208	1611
Amreli	175	587	1468	2936	4404	5872
Anand	0	0	0	0	0	0
Banaskantha	235	774	1934	3868	5801	7735
Bharuch	707	2274	5685	11369	17054	22739
Bhavnagar	117	393	983	1966	2948	3931
Dahod	752	2496	6239	12479	18718	24957
Gandhinagar	24	80	200	401	601	802
Jamnagar	871	3711	9279	18557	27836	37115
Junagadh	94	394	985	1970	2955	3940

		Total CSP Potential (MW), based on water availability				
District	**Total land area for CSP based on water availability (km²)**	**10% Land availability**	**25% Land availability**	**50% Land availability**	**75% Land availability**	**100% Land availability**
Kachchh	2763	8776	21941	43882	65823	87764
Kheda	166	548	1371	2741	4112	5482
Mahsana	10	33	83	166	249	332
Narmada	553	1776	4440	8880	13320	17760
Navsari	13	48	120	240	359	479
Panchmahal	215	721	1802	3604	5406	7208
Patan	222	703	1758	3516	5275	7033
Porbander	0	0	0	0	0	0
Rajkot	536	1761	4402	8805	13207	17609
Sabarkantha	435	1449	3622	7243	10865	14486
Surat	785	2588	6470	12940	19410	25880
Surendranagar	126	426	1065	2131	3196	4261
The dangs	0	0	0	0	0	1
Vadodara	1323	4400	11001	22002	33002	44003
Valsad	123	471	1177	2353	3530	4706
Total	**10294**	**34571**	**86427**	**172853**	**259280**	**345706**

Table A4.4 SPV potential remaining after CSP land utilisation in different scenarios

		Total SPV Potential excluding CSP (MW)				
District	**Total SPV land area after excluding CSP land (km2)**	**10% Land availability**	**25% Land availability**	**50% Land availability**	**75% Land availability**	**100% Land availability**
Ahmedabad	80	206	516	1032	1548	2064
Amreli	241	635	1587	3173	4760	6347
Anand	0	0	0	0	0	0
Banaskantha	214	552	1380	2759	4139	5518
Bharuch	65	168	420	840	1260	1680
Bhavnagar	315	830	2075	4149	6224	8298
Dahod	187	490	1224	2448	3671	4895
Gandhinagar	23	60	150	300	449	599
Jamnagar	412	1237	3093	6185	9278	12370
Junagadh	170	509	1272	2544	3816	5088
Kachchh	5615	14373	35933	71866	107799	143732
Kheda	96	249	623	1245	1868	2491
Mahsana	37	97	242	484	725	967
Narmada	60	154	385	769	1154	1539
Navsari	24	69	173	345	518	691
Panchmahal	119	311	776	1553	2329	3105
Patan	43	109	273	546	818	1091
Porbander	30	90	224	448	672	896
Rajkot	433	1127	2818	5637	8455	11274
Sabarkantha	301	782	1954	3909	5863	7818
Surat	136	355	887	1774	2661	3548

		Total SPV Potential excluding CSP (MW)				
District	Total SPV land area after excluding CSP land (km2)	10% Land availability	25% Land availability	50% Land availability	75% Land availability	100% Land availability
Surendranagar	149	394	984	1968	2951	3935
The dangs	18	47	117	234	350	467
Vadodara	187	489	1223	2447	3670	4893
Valsad	79	224	561	1121	1682	2243
Total	**9035**	**23555**	**58887**	**117774**	**176661**	**235548**

Further depending upon the different level of efficiencies for SPV and CSP there could be multiple scenarios of the estimated power potential. Some possible scenarios are given in the table below

Table A4.5 Parameters of different scenarios

Scenarios	Parameters		
	Land Availability (%)	ηSol-elec, CSP(%)	ηSol-elec, SPV (%)
Scenario1	25	12	10
Scenario2	50	12	10
Scenario3	75	12	10
Scenario4	25	14	10
Scenario5	50	14	10
Scenario6	75	14	10
Scenario7	25	14	12
Scenario8	50	14	12
Scenario9	75	14	12

An estimate of solar power potential has also been carried out considering only the land without scrub data obtained from wasteland atlas of Gujarat. The estimated potential with above mentioned scenarios is given below. However these could not be mapped in the atlas because of non-possibility of classifying the lands up to this level in land use land cover analysis.

Table A4.6a Solar power potential considering total Land without Scrubs

	Solar Potential, GWe, CSP or SPV		Solar Potential, GWe		
Scenarios	**CSP alone**	**SPV alone**	**CSP**	**SPV**	**Total**
Scenario1	36.98	27.72	36.44	0.41	36.85
Scenario2	73.97	55.44	73.57	0.30	73.87
Scenario3	110.95	83.16	110.72	0.17	110.89
Scenario4	43.15	27.72	42.52	0.41	42.93
Scenario5	86.30	55.44	85.84	0.30	86.14
Scenario6	129.44	83.16	129.18	0.17	129.35
Scenario7	43.15	33.26	42.52	0.49	43.01
Scenario8	86.30	66.53	85.84	0.36	86.20
Scenario9	129.44	99.79	129.18	0.21	129.38

Table A4.6b Solar power potential considering land without scrubs with slope less than 3%

Scenarios	Solar Potential, GWe, CSP or SPV		Solar Potential, GWe		
	CSP alone	**SPV alone**	**CSP**	**SPV**	**Total**
Scenario1	29.59	22.18	29.16	0.33	29.48
Scenario2	59.17	44.35	58.73	0.34	59.07
Scenario3	88.76	66.53	88.45	0.24	88.68
Scenario4	34.52	22.18	34.01	0.33	34.34
Scenario5	69.04	44.35	68.52	0.34	68.86
Scenario6	103.56	66.53	103.19	0.24	103.43
Scenario7	34.52	26.61	34.01	0.39	34.41
Scenario8	69.04	53.22	68.52	0.40	68.93
Scenario9	103.56	79.83	103.19	0.28	103.47

Annexure 5: Wind power technology and its improvement

Wind power plant components

The wind power generation is simple conversion of kinetic energy of wind into the electrical energy. However the mechanism to capture the energy, transmit and convert in electrical energy involves several stages, components and controls. The important components / controls of horizontal axis wind turbine are

- Rotor blades
- Tower
- Generator
- Gear Box
- Main Shaft
- Nacelle at hub height which accommodates generator and gearbox
- Aerodynamic power regulation and brakes

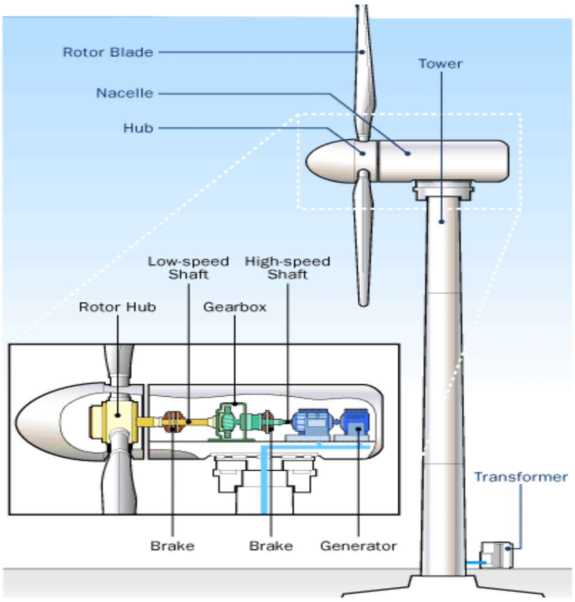


Figure A5.1 Components of a horizontal axis wind turbine

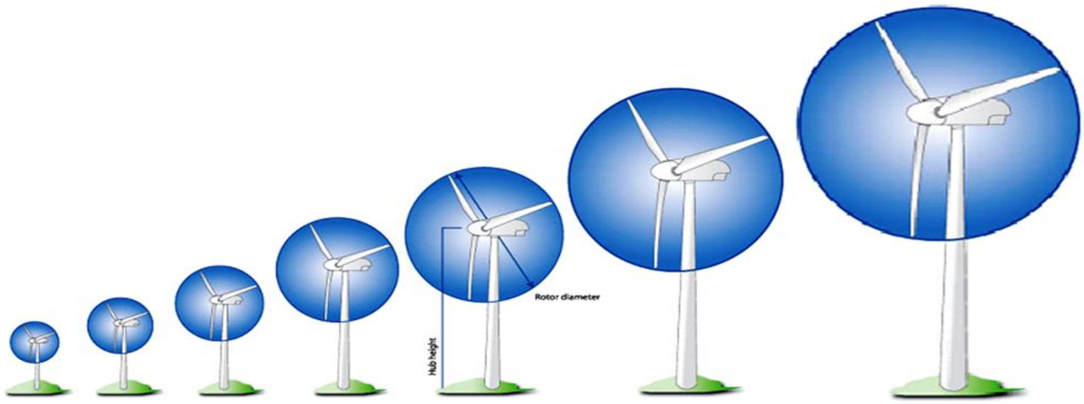
Source: How stuff works (http://science.howstuffworks.com/wind-power2.htm: Last accessed on 10 January 2011

Based on the axis of rotation of the rotor, wind turbines are classified into horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). Because of their higher energy conversion efficiency compared to VAWT, the HAWT has been preferred by the wind turbine manufacturers, especially in the large size wind turbine sector[1]. All the grid connected wind power projects in India are with HAWT. Figure A5.1 shows various components of the wind power system

[1] Source: Kishore VVN, Renewable Energy Engineering and Technology- A knowledge Compendium, The Energy and Resources Institute-2008

Though there has been no major change in the overall architecture of the modern wind turbines there have been many technological improvements in the design of the wind turbines worldwide resulting in improved performances, optimal land use and better grid integration. The areas in which development work is being targeted are large size wind turbines with higher rated generating capacity, development of powerful and larger blades, improved power electronics and taller towers. The developments in these fields are as following.

Lot of improvements have been taking place in the size and performance of wind turbines with the market demand and the manufacturer's initiatives. An exponentially increasing growth with time in turbine size has taken place since the start of the millennium. In the last 20 years the turbine sizes have been increased by a factor of 100 (i.e. from machines of just 25 kW twenty years ago to 2500 kW and above). Today, modern wind turbine technology is available for a greater range of sites, such as for low and high wind speeds, desert and arctic climates. In these years interest is in the larger size turbine development for offshore project sites. The land-based market is being focussed for volumetric production of the wind turbines in the range of 1.5 MW to 3.0 MW rated capacity[1]. Figure A5.2 shows the development in the rated capacity of wind turbines being installed in India.



Year	1985	1990	2000	2002	2003	2005	2006
kW	50	250	500	750	1250	1500	2100

Figure A5.2 Growth of wind turbine size in India

The exponential growth of turbine size is driven by the factors such as the fact that

- For a required capacity lower number of turbines are required which leads to low land area requirement, lower cost per unit capacity and lower operation and maintenance cost
- Integration to the grid became more effective as the utilities are used to take power in much larger capacities than the smaller capacity generators.

Currently trend is of increasing turbine sizes. Further the development of new higher capacity machines is focused mainly on the offshore / high wind regimes. In case of India, at

[1] Source: Wind Energy- The Facts 2009

present, only the onshore wind resources are being tapped and the plans for tapping offshore potential are at just the formulation stage. India is yet to install its first offshore wind turbine. The designs of specific types of wind turbines that have been installed in India, or those being offered for installation, are validated by a standardised certification process under the guidelines of Ministry of New and Renewable Energy, Government of India. The certification process is called Type Certification and the certification agency for this is the Centre for Wind Energy Technology (C-WET), Chennai. In the previous years the wind turbines ranging from 225 kW to 1.65 MW, from various manufacturers, having the type certificates from C-WET, have been installed in India. Those manufacturers include the major wind turbine manufacturers of MW scale such as Bharat Heavy Electricals Limited (BHEL) (800 kW), Enercon India Limited (600 kW), GE Wind Energy India (1500 kW), NEG Micon Pvt, Ltd. (1500 kW and 1650 kW), Pioneer Asia Wind Turbines (850 KW), Suzlon Energy Limited (1000 kW, 1250 kW,1500 kW) Vestas RRB (500 KW), etc. Currently the wind turbines being offered in India range from 250 kW to 2.5 MW capacities[1]. Since India is having low wind regimes, with highest wind power density at 50 m level of about 450 W/m2, and the offshore use of wind turbines has to begin the high capacity wind turbine were not being offered in India. Now with some innovations in the technology, the higher rating wind turbines, designed for low wind regimes too will see some potential in the Indian wind turbine market. Currently there are seventeen manufacturers in India with the type test certification of C-WET, and some are under the process of obtaining certification. The specifications of wind turbines being offered in India by the major manufacturers are given in Table A5.1 below.

Table A5.1 Details of wind turbines currently available for installation in India with Type Certification from C-WET[2]

Name of Manufacturers	Model Name	Capacity (kW)	Rotor Dia (m)	Hub Height (m)	Aerodynamic control	Generator Type
Turbines which are having type test certification from C-WET						
M/s Suzlon Energy Limited	S52	600	52	75	Pitch	Asynchronous
	S82	1500	82	78	Active pitch	Asynchronous
	S88	2100	88	80	Active pitch	Asynchronous
	S64 & S66	1250	64,66	74/65/56	Active pitch	Asynchronous
M/s Enercon India Limited	E-48	800	48	50/57/75	Active Pitch	Synchronous
	E-53	800	53	73/75	Active Pitch	Synchronous
M/s Global Wind Power Limited	Norwin 750 kW	750	47	65	Active Pitch	Asynchronous
	FL-2500-100/W2E-W100 2.5 MW	2500	100.2	98.2	Pitch	Asynchronous (DFIG)
M/s Leitner Shriram Manufacturing Limited	Leitner LT77-1.35 MW	1350	76.6	65	Active Pitch	Synchronous direct drive
	Leitwind LTW77-1.5 MW	1500	76.6	65	Active Pitch	Synchronous direct drive
	Leitwind	1500	80.3	80	Active Pitch	PM

[1] www.cwet.tn.nic.in, last accessed on 20-01-2011.

[2] Source: Revised list of models and manufacturers of wind electric generators, issued by C-WET. Main list dated 18-05-2010, Addendum-I list dated 27-09-2010 and Addendum-II list dated 19-01-2011

Name of Manufacturers	Model Name	Capacity (kW)	Rotor Dia (m)	Hub Height (m)	Aerodynamic control	Generator Type
	LTW80-1.5 MW					Synchronous direct drive
M/s Pioneer Wincon Private Limited	Pioneer P250/29	250	29.6	50	Stall	Asynchronous
M/s RegenPowertech Pvt Ltd	VENSYS 77	1500	76.84	75/85	Active Pitch	Synchronous direct drive
M/s RRB Energy Limited	V-39/500	500	47	59	Pitch	Asynchronous
	Pawan Shakti-600 kW	600	47	50-lattice 65 tubular	Pitch	Asynchronous
M/s Siva Windturbine India Pvt Ltd	SIVA 250/50	250	30	50	Pitch	Asynchronous
M/s Southern Wind farms Limited	GWL 225	225	29.8	45	Pitch	Asynchronous
M/s Vestas Wind Technology India Private Limited	NM-48/750	750	48.2	45/50/55	Stall	Asynchronous
	V82-1.65 MW	1650	82	70/78/80	Active Stall	Asynchronous
M/s Winwind power energy private limited	WinWind 1 MW	1000	60	70	Pitch	PM Synchronous
M/s Chiranjivi Wind Energy Limited	CWEL C30/250 kW	250	29.8	50	Stall	Asynchronous
M/s Essar Wind Power Pvt Limited	REpower MD77	1500	76.5	85	Pitch	DFIG
M/s Gamesha Wind Turbines Pvt Ltd	G52/58-850 kW	850	52/58	44/55/65	Active Pitch	DFIG
	G90-2.0 MW	2000	90	67/78/100	Active Pitch	DFIG
	G80-2.0 MW	2000	80	60/67/78	Active Pitch	DFIG
	G87-2.0 MW	2000	87	67/78/100	Active Pitch	DFIG
M/s GE India Industrial Pvt Ltd	GE 1.5sle	1500	77	80	Pitch	PMG
	GE 1.6-82.5	1600	82.5	80	Pitch	PMG
M/s Kenersys India Pvt Ltd	K82	2000	82	80	Active Pitch	Synchronous
M/s ShriramEPC limited	SEPC 250T	250	28.5	41.2	Stall	Asynchronous
Turbines which are under type test certification from C-WET						
M/s Inox Wind Limited	WT 2000DF	2000	93	80	Active Pitch	Asynchronous
M/s Pioneer Wincon Private Limited	P750/49	750	49	61.1	Stall	Asynchronous
M/s Regen Powertech Pvt Ltd	VENSYS 82	1500	82.34	70/75/85/ 100	Active Pitch	Synchronous direct drive
M/s ShriramEPC limited	SEPC 250T	250	28.5	51.5	Stall	Asynchronous
	SEPC 250T	250	29.6	51.5	Stall	Asynchronous

Name of Manufacturers	Model Name	Capacity (kW)	Rotor Dia (m)	Hub Height (m)	Aerodynamic control	Generator Type
	with Rotor blade extender					
M/s Suzlon Energy Limited	S95	2100	95	80	Active pitch	Asynchronous
	S97	2100	97	90	Active pitch	Asynchronous
	S88 Mk II DFIG	2250	88	80	Active pitch	DFIG
M/s Vestas Wind Technology India Pvt Ltd	V100-1.5 MW	1800	100	95	Active Stall	Asynchronous

Internationally numbers of manufacturers are involved in development of higher size wind turbines in the category of 2 to 3MW and above. Table A5.2 gives details of different high capacity turbines being developed/ under development by top ten manufacturers as measured by global market share in 2007

Table A5.2 Details of some of the higher capacity wind turbines by top 10 manufacturers in the world

Sl No	Manufacturer	Model	Power rating (kW)	Rotor Diameter (m)	Regulation	Generator type
1	Vestas	V90	3000	90	Stall	Asynchronous
2	GE Energy	2.5XL	2500	100	Pitch	PMG converter
3	Gamesa	G90	2000	90	Pitch	DFIG
4	Enercon	E82	2000	82	Pitch	Synchronous
5	Suzlon	S88	2100	88	Active Pitch	Asynchronous
6	Siemens	3.6 SWT	3600	107	Active Pitch	Asynchronous
7	Acciona	AW-119/3000	3000	116	Active Pitch	DFIG
8	Goldwind	REpower750	750	48	Pitch	Induction
9	Nordex	N100	2500	99.8	Pitch	DFIG
10	Sinovel	1500 (Windtec)	1500	70	Pitch	DFIG

Source: Wind Energy – The Facts-2009

From above tables it can be observed that multi MW capacity wind turbine (2 MW to 2.5 MW) are now entering into the Indian wind market, though very few turbines of these ratings have been installed till now. The challenges involved for these turbines are the availability of high windy sites, roads and infrastructure/other facilities for the transportation and installation of large towers and blades etc. But once these challenges overcome, the wind energy in India can achieve the potential installation more than what has been estimated now based on the available resources.

The important thing is to carry out the wind resource study in detail for the planning and decision making of the wind power project implementation. Without proper wind resource analysis of an area it is unwise to invest in any wind power project. The subsequent sections describe the approach and considerations made for the previous estimates of the wind power potential and then the approach used based on the latest technology wind turbines and the wind resource data. The study is carried out for the district wise wind power potential in the state of Gujarat.

Annexure 6: Wind Power Densities at 50m and 80m level at the C-WET wind monitoring stations

Sl No.	Station	District	Mast Height (m)	MAWPD at 20/25/30 m (W/m2)	WPD Extrapol./Measured at 50 m (W/m²) C-WET-Data	WPD Extrapol./Measured at 80 m (W/m²)
1	ADESAR	Kutch	20	93	201	229
2	Amrapar (GIR)	Junagadh	20	147	241	264
3	Amrapar (SETH)	Rajkot	20	151	221	234
4	Bamanbore 1	Surender Nagar	20	108	175	192
5	Bamanbore 2	Surender Nagar	20	171	243	260
6	Bayath	Kutch	20	118	204	224
7	Bhandariya	Jamnagar	20	162	208	218
8	Butavadar	Jamnagar	20	98	200	226
9	Dahod	Dahod	20	108	199	223
10	Dandi	Navsari	20	72	106	113
11	Dhandhalpur	Surender Nagar	25	144	193	211
12	Dhank 1 1)	Rajkot	20	312	414	436
13	Dhank 2	Rajkot	20	327	367	374
14	Dhrobana	Kutch	25	124	178	194
15	Dumdha		25	94	100	108
16	Gala	Jamnagar	20	175	254	274
17	Godladhar	Rajkot	20	144	212	226
18	Haripar	Jamnagar	20	160	210	223
19	Harshad	Jamnagar	20	164	239	255
20	Jafrabad	Amreli	20	137	242	267
21	Jamanvada	Kutch	20	149	299	338
22	Jasapar	Amreli	20	104	201	225
23	Kagavad	Rajkot	20	141	212	232
24	Kalyanpur	Jamnagar	20	208	327	356
25	Kera	Kutch	20	135	172	181
26	Khambada	Amreli	20	126	204	224
27	Kukma	Kutch	20	150	239	260
28	Lamba	Jamnagar	20	164	232	247
29	Limbara	Rajkot	20	166	227	240
30	Mahidad	Surender Nagar	25	178	231	247
31	Mesaria	Rajkot	20	124	180	193
32	MotaDadawa	Rajkot	20	113	166	177
33	MotiSindholi	Kutch	20	118	204	224
34	Mundra	Kutch	20	168	303	336
35	NaniKundal	Amreli	20	163	278	304

Sl No.	Station	District	Mast Height (m)	MAWPD at 20/25/30 m (W/m2)	WPD Extrapol./Measured at 50 m (W/m²) C-WET-Data	WPD Extrapol./Measured at 80 m (W/m²)
36	Navadra	Jamnagar	20	183	297	323
37	NaviBander	Porbandar	20	153	213	226
38	Okha	Jamnagar	20	150	260	287
39	Okhamadhi	Jamnagar	20	129	209	229
40	Parewada	Rajkot	25	122	159	173
41	Poladiya	Kutch	20	177	278	303
42	Ratabhe	Surender Nagar	20	123	212	236
43	Rojmal 1	Bhavnagar	20	81	117	126
44	Rojmal 2	Bhavnagar	20	129	200	216
45	Sadodar	Jamnagar	20	126	179	191
46	Sanodar	Bhavnagar	20	197	373	404
47	Saputara	The Dangs	20	40	59	63
48	Sinai	Kutch	20	183	244	256
49	Sinugra	Kutch	20	103	161	174
50	Sivalakha		25	91	122	134
51	Surajbari	Kutch	20	184	270	288
52	Suvarda	Jamnagar	20	166	243	261
53	Taga	Kutch	20	99	177	197
54	Vandhya	Kutch	45	196	203	217
55	Velan	Amreli	20	100	197	223
56	Veraval	Junagadh	20	129	168	175
57	Warshamedi	Rajkot	20	192	282	301
58	Vadgam	Anand	50	188	188	215
59	Sangasar	Dahod	50	207	207	221
60	Nava	Surender Nagar	50	139	139	150
61	Chapriyali	Bhavnagar	50	151	151	165
62	Vekariya	Junagadh	50	130	130	143
63	Nana Asota	Jamnagar	50	151	151	165
64	Lodhrani	Kutch	50	166	166	183

Annexure 7: The sample of wind speed frequency distribution data for one location in Gujarat

STATION : AMRAPAR (GIR)						TABLE 3.3							
			FREQUENCY DISTRIBUTION OF WIND SPEED (Hrs)										
CLASS INTERVAL (MPH)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
0 - 6	5.6	9.2	8.8	6.4	3.9	11.0	4.8	8.4	23.3	18.5	14.4	3.6	9.8
6 - 8	8.8	10.7	11.8	13.3	8.1	8.8	9.3	12.6	21.7	15.5	13.3	6.9	11.7
8 - 10	12.6	15.4	13.6	16.7	14.5	10.6	10.8	14.9	18.8	16.9	16.0	10.0	14.2
10 - 12	16.1	18.5	14.5	16.4	15.9	11.7	8.7	14.8	10.8	16.6	18.1	14.2	14.7
12 - 14	19.4	16.7	17.1	14.4	14.9	11.2	11.0	12.4	11.4	12.9	16.2	19.6	14.8
14 - 16	15.9	14.6	14.9	11.5	13.6	12.6	16.1	12.4	8.4	8.5	12.4	21.7	13.6
16 - 18	11.2	8.2	10.6	11.3	11.2	11.3	13.0	9.7	4.3	4.8	6.4	14.4	9.7
18 - 20	6.7	3.3	4.8	6.4	7.1	8.3	9.9	7.5	1.3	1.7	2.7	6.2	5.5
20 - 22	2.2	2.1	2.4	2.3	6.3	4.8	8.3	4.0	0.1	1.3	0.5	2.8	3.1
22 - 24	0.9	0.9	1.1	1.2	3.4	3.6	4.0	2.2	0.0	0.7	0.0	0.5	1.5
24 - 26	0.5	0.3	0.5	0.1	0.9	2.8	2.4	1.1	0.0	0.8	0.0	0.1	0.8
26 - 28	0.1	0.1	0.0	0.0	0.1	1.7	1.0	0.0	0.0	0.5	0.0	0.0	0.3
28 - 30	0.0	0.0	0.0	0.0	0.0	0.6	0.5	0.0	0.0	0.3	0.0	0.0	0.1
30 - 32	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.0	0.0	0.0
32 - 34	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.2	0.0	0.0	0.0
34 - 36	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0
36 - 38	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0
>>38	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Total Hrs	744.0	672.0	744.0	720.0	744.0	720.0	744.0	744.0	720.0	744.0	720.0	744.0	8760.0
SENSOR HEIGHT : 20 M													
RANGE 0 - 6 EXTENDS FROM 0.0 TO 5.9 MPH									BASED ON DATA SEP 1996 - AUG 1998				
6 - 8 EXTENDS FROM 6.0 TO 7.9 MPH													
AND SO ON													

Annexure 8: District wise land area and MW potential estimates for wind power considering different percentage of land availability

Table A8.1 Wind power potential in non-crop land only

District	Total suitable area (non crop land)for Wind (km2)	Total potential for wind power in non-crop land (MW) 10% Land availability	25% Land availability	50% Land availability	75% Land availability	100% Land availability
Ahmedabad	91	81	203	406	609	812
Amreli	428	382	955	1910	2865	3821
Anand	0	0	0	0	0	0
Banaskantha	545	487	1217	2435	3652	4869
Bharuch	799	714	1784	3568	5351	7135
Bhavnagar	433	387	966	1933	2899	3866
Dahod	939	838	2096	4192	6288	8384
Gandhinagar	9	8	20	39	59	78
Jamnagar	1386	1238	3095	6190	9284	12379
Junagadh	251	224	560	1120	1680	2240
Kachchh	22955	20495	51238	102476	153713	204951
Kheda	262	233	584	1167	1751	2335
Mahsana	18	16	40	81	121	162
Narmada	613	547	1368	2736	4103	5471
Navsari	43	38	96	192	289	385
Panchmahal	334	298	746	1492	2238	2984
Patan	474	424	1059	2118	3177	4236
Porbander	30	27	67	133	200	267
Rajkot	883	788	1971	3942	5913	7883
Sabarkantha	533	476	1190	2379	3569	4758
Surat	899	803	2007	4013	6020	8027
Surendranagar	400	357	892	1784	2676	3568
The dangs	18	16	41	82	122	163
Vadodara	1510	1348	3371	6742	10113	13483
Valsad	244	218	545	1091	1636	2182
Total	**34097**	**30444**	**76110**	**152220**	**228330**	**304440**

Table A8.2 Wind power potential in crop land only

District	Total suitable area (only crop land)for Wind (km2)	Total potential for wind power in only crop land (MW) 10% Land availability	25% Land availability	50% Land availability	75% Land availability	100% Land availability
Ahmedabad	4968	4436	11089	22178	33267	44356
Amreli	5801	5179	12948	25897	38845	51793

		Total potential for wind power in only crop land (MW)				
District	Total suitable area (only crop land)for Wind (km2)	10% Land availability	25% Land availability	50% Land availability	75% Land availability	100% Land availability
Anand	2349	2097	5243	10486	15729	20972
Banaskantha	8128	7257	18144	36287	54431	72574
Bharuch	3210	2866	7164	14328	21493	28657
Bhavnagar	5533	4940	12351	24702	37054	49405
Dahod	2631	2349	5872	11744	17615	23487
Gandhinagar	62	55	138	276	415	553
Jamnagar	5968	5329	13322	26644	39966	53288
Junagadh	6320	5643	14107	28215	42322	56430
Kachchh	6489	5794	14484	28969	43453	57938
Kheda	3066	2737	6843	13686	20529	27372
Mahsana	2608	2329	5822	11644	17466	23288
Narmada	592	529	1321	2643	3964	5286
Navsari	1043	932	2329	4658	6987	9316
Panchmahal	2815	2513	6284	12567	18851	25134
Patan	4889	4365	10912	21824	32736	43647
Porbander	1401	1251	3126	6253	9379	12506
Rajkot	8072	7207	18018	36037	54055	72074
Sabarkantha	2886	2577	6442	12883	19325	25766
Surat	4104	3664	9160	18319	27479	36639
Surendranagar	6703	5985	14961	29923	44884	59845
The dangs	151	135	338	676	1013	1351
Vadodara	5087	4542	11355	22709	34064	45419
Valsad	1254	1119	2799	5597	8396	11195
Total	**96128**	**85829**	**214573**	**429145**	**643718**	**858290**

Table A8.3 Wind power potential in both crop and non-crop land

		Total potential for wind power in both crop and non crop land (MW)				
District	Total suitable area (both crop and non crop land)for Wind (km2)	10% Land availability	25% Land availability	50% Land availability	75% Land availability	100% Land availability
Ahmedabad	5059	4517	11292	22584	33876	45168
Amreli	6229	5561	13903	27807	41710	55614
Anand	2349	2097	5243	10486	15729	20972
Banaskantha	8674	7744	19361	38722	58083	77444
Bharuch	4009	3579	8948	17896	26844	35792
Bhavnagar	5966	5327	13318	26635	39953	53270
Dahod	3570	3187	7968	15936	23903	31871
Gandhinagar	71	63	158	316	473	631
Jamnagar	7355	6567	16417	32834	49250	65667
Junagadh	6571	5867	14668	29335	44003	58670
Kachchh	29444	26289	65722	131444	197167	262889

Annexure 8: District wise land area and MW potential estimates for wind power considering different percentage of land availability

		Total potential for wind power in both crop and non crop land (MW)				
District	**Total suitable area (both crop and non crop land)for Wind (km2)**	**10% Land availability**	**25% Land availability**	**50% Land availability**	**75% Land availability**	**100% Land availability**
Kheda	3327	2971	7427	14853	22280	29707
Mahsana	2626	2345	5862	11725	17587	23449
Narmada	1205	1076	2689	5378	8068	10757
Navsari	1087	970	2425	4851	7276	9701
Panchmahal	3149	2812	7030	14059	21089	28118
Patan	5363	4788	11971	23942	35912	47883
Porbander	1431	1277	3193	6386	9579	12773
Rajkot	8955	7996	19989	39979	59968	79957
Sabarkantha	3419	3052	7631	15262	22893	30524
Surat	5003	4467	11166	22333	33499	44666
Surendranagar	7102	6341	15853	31707	47560	63413
The dangs	170	151	379	757	1136	1514
Vadodara	6597	5890	14726	29451	44177	58902
Valsad	1498	1338	3344	6688	10033	13377
Total	**130226**	**116273**	**290682**	**581365**	**872047**	**1162730**

Annexure 9: District wise wind power potential for different wind power density areas

Table A9.1 Wind power potential for different wind power density areas for Non Crop lands only

District	Wind Power Potential (MW)			
	WPD between 200-300 W/m²	WPD between 300-400 W/m²	WPD >400	Total potential (MW)
Ahmedabad	812	0	0	812
Amreli	1876	1482	463	3821
Banaskantha	4869	0	0	4869
Bharuch	7135	0	0	7135
Bhavnagar	2793	826	246	3866
Dahod	8384	0	0	8384
Gandhinagar	78	0	0	78
Jamnagar	12379	0	0	12379
Junagadh	2140	90	10	2240
Kachchh	204951	0	0	204951
Kheda	2335	0	0	2335
Mahsana	162	0	0	162
Narmada	5471	0	0	5471
Navsari	385	0	0	385
Panchmahal	1291	1330	362	2984
Patan	4236	0	0	4236
Porbander	267	0	0	267
Rajkot	7883	0	0	7883
Sabarkantha	4758	0	0	4758
Surat	8027	0	0	8027
Surendranagar	3568	0	0	3568
The dangs	163	0	0	163
Vadodara	13368	113	2	13483
Valsad	2182	0	0	2182
Total	**299515**	**3842**	**1083**	**304440**

Table A9.2 Wind power potential for different wind power density areas for crop lands only

District	Wind power Potential (MW)			
	WPD between 200-300 W/m²	WPD between 300-400 W/m²	WPD >400	Total potential (MW)
Ahmedabad	44356	0	0	44356
Amreli	36433	10624	4737	51793
Anand	20972	0	0	20972
Banaskantha	72574	0	0	72574
Bharuch	28657	0	0	28657
Bhavnagar	34481	10812	4112	49405
Dahod	23487	0	0	23487
Gandhinagar	553	0	0	553

District	Wind power Potential (MW) WPD between 200-300 W/m²	WPD between 300-400 W/m²	WPD >400	Total potential (MW)
Jamnagar	53288	0	0	53288
Junagadh	52365	3088	977	56430
Kachchh	57938	0	0	57938
Kheda	27372	0	0	27372
Mahsana	23288	0	0	23288
Narmada	5286	0	0	5286
Navsari	9316	0	0	9316
Panchmahal	18116	5816	1203	25134
Patan	43647	0	0	43647
Porbander	12506	0	0	12506
Rajkot	72074	0	0	72074
Sabarkantha	25766	0	0	25766
Surat	36639	0	0	36639
Surendranagar	59845	0	0	59845
The dangs	1351	0	0	1351
Vadodara	44395	1016	8	45419
Valsad	11195	0	0	11195
Total	**815898**	**31355**	**11037**	**858290**

Table A9.3 Wind power potential for different wind power density areas for both crop land and non crop land

District	Wind power Potential (MW) WPD between 200-300 W/m²	WPD between 300-400 W/m²	WPD >400	Total potential (MW)
Ahmedabad	45168	0	0	45168
Amreli	38309	12106	5200	55614
Anand	20972	0	0	20972
Banaskantha	77444	0	0	77444
Bharuch	35792	0	0	35792
Bhavnagar	37275	11638	4358	53270
Dahod	31871	0	0	31871
Gandhinagar	631	0	0	631
Jamnagar	65667	0	0	65667
Junagadh	54505	3178	987	58670
Kachchh	262889	0	0	262889
Kheda	29707	0	0	29707
Mahsana	23449	0	0	23449
Narmada	10757	0	0	10757
Navsari	9701	0	0	9701
Panchmahal	19407	7146	1566	28118
Patan	47883	0	0	47883
Porbander	12773	0	0	12773
Rajkot	79957	0	0	79957
Sabarkantha	30524	0	0	30524
Surat	44666	0	0	44666
Surendranagar	63413	0	0	63413

District	Wind power Potential (MW) WPD between 200-300 W/m²	WPD between 300-400 W/m²	WPD >400	Total potential (MW)
The dangs	1514	0	0	1514
Vadodara	57763	1129	10	58902
Valsad	13377	0	0	13377
Total	**1115413**	**35196**	**12120**	**1162730**

Annexure 10: Tidal Power

Gravitational interaction between the Moon, the Sun and the Earth attributes to the rhythmic generation of tides that shows harmonic motion. Due to less distance between moon and earth, the moon exerts 2.17 times greater force on the tides as compared to the sun (Hammons, 1997), thus they are primary cause of tides. As a result, the tide closely follows the moon during its rotation around the earth, bulging on the axis pointing directly towards at the moon. This interaction occurs in to cause mainly two forms of tides (Khaligh & Onar, 2010):

- Spring tide: It is a high tide that occurs when moon and sun are aligned in the same line and exerting pulls either on the same side or opposite. The cumulative gravitational pull results in the development of high tide.
- Neap tide: It occurs when moon and sun are aligned at 90° angle to each other; their gravitation force pulls the water in different directions, causing the bulge to eliminate the other effects resulting in the tide higher than low tide but lesser than high tide.

The period between two spring or neap tides is 14 days, that is half of the lunar cycle. Figure A10.1 illustrates the formation of spring and neap tide. The range of the spring tide is commonly about twice as that of a neap tide, whereas the longer period cycles impose small perturbations. Most tides occur twice a day (two highs, two lows), called semidiurnal tides but in some geographical areas there is only one tide a day, with one high and one low, called diurnal tides. The time period of diurnal tides is double than that of semidiurnal tides. The periodicity of other types of tides may be far less, for instance that of equinoctial and spring tides, or even exceptional such as those occurring less than once a century (Charlier, 2003).

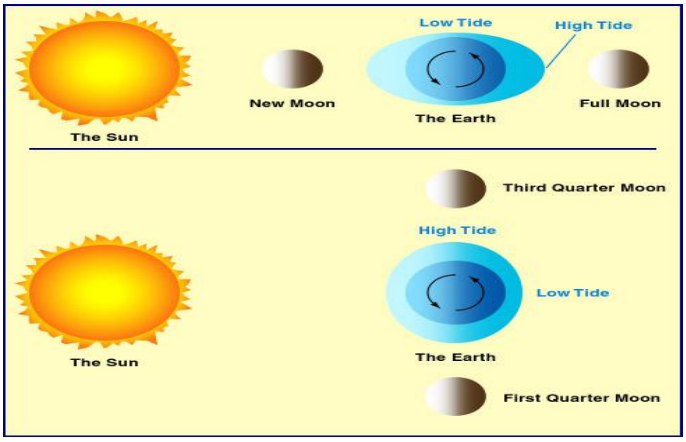


Figure A10.1 Formation of tides through moon-earth-sun interaction[1]

Tidal power resource

The major advantage of tidal energy is that tides are regular and predictable. Also, they are not affected by the lack of rain or climate change.

Tidal energy harnessing is aimed at semidiurnal and diurnal tides. Energy can be extracted from tides by creating a reservoir or basin behind a barrage and then passing tidal waters

[1](Source:http://www.lcsd.gov.hk/CE/Museum/Space/EducationResource/Universe/framed_e/lecture/ch06/ch06.html [Accessed 17 January 2011]

through turbines in the barrage to generate electricity, as illustrated in Figure A10.2. Given a basin, the theoretical potential energy can be calculated as (Gorlov, 2001; Charlier, 2003; Khalig&Onar, 2010)

$E = 0.5g\,\rho A h^2$………………… (1)

Where,

E = Energy (J)

g = Acceleration due to gravity (m/s^2)

ρ = seawater density (approx. 1022kg/m^3 of sea water)

A = surface area of the basin (m^2)

h = water head or the tidal range (m)

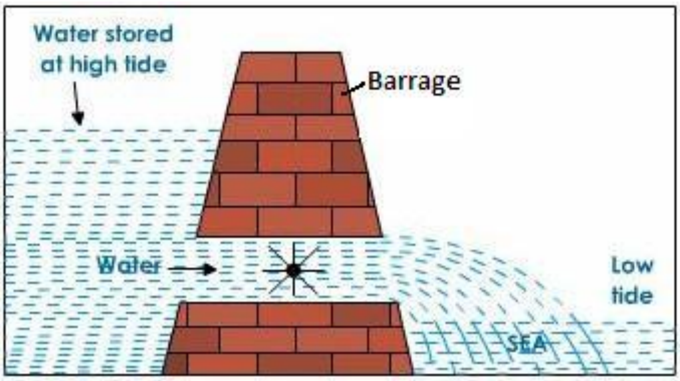


Figure A10.2 Barrage construction to harness tidal energy[1]

It is important to understand that tides and tidal currents must be differentiated, and their relation is not the same at all sites. The geometrical shape of the basin and its surface will of course determine the complexity of barrage building , the ratio of the aperture section to the basin's surface is important, to wit, its dimension in absolute value, basin minimum depth, basin opening and more or less widening shape. In short there are oceanographic, geographic, geologic, technologic and economic factors at play (Charlier, 2003). Potential energy of tidal power sites can be calculated by (Bernshtein, 1961&Mosonyi, 1963):

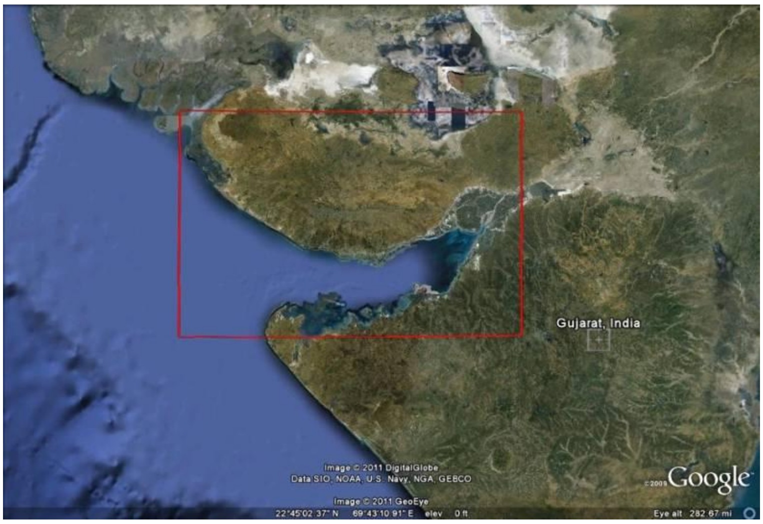
$Ep = K . 106AR^2$

in which the coefficient K is the only to vary (1.92 and 1.97). R is either the average, range (in meters) or the average range of the equinoctial tide, A is the basin area (in km^2), and Ep the potential energy (in kW/h/year). A type of utilization factor is introduced which is based on the system selected: for a single or double basin plant and a single tide it is 0.224, double tide 0.34 but 0.21 for a double basin; for a double basin, single tide with reverse pumping it is 0.277 and with pumps 0.234.

[1] (Source: http://www.tutorvista.com/topic/low-tide [Accessed 17 January 2011]

Gulf of Kachchh[1]

The Gulf is an east-west oriented indentation north of Saurashtra Peninsula. It is about 170



km long and 75 km wide at the mouth, narrowing down abruptly with a distinct constriction at 70°20′E (Figure A10.3) at Satsaida Bet, and dividing into a creek system often called the Little Gulf of Kachchh. Depth varies from 20 m at the head (Kandla-Navlakhi) to 60 m in the outer region.

Figure A10.3 Area of Gulf of Kachchh enclosed

Basin and the coastal regions

Within the Gulf, though water depths of 25 m exists in broad central portion up to a longitude 70°E, the actual fairway in the outer Gulf is obstructed by the presence of several shoals. The high tidal influx covers the low-lying areas of about 1500 km2 comprising a network of creeks and alluvial marshy tidal flats in the interior region. All along the coast, very few rivers drain into the Gulf and they carry only a small quantity of freshwater, except during monsoon. They are broad-valleyed and the riverbeds are mostly composed of coarse sand and gravel.

The coastal configuration is very irregular with numerous Islands, creeks and bays. Due to high tidal ranges in the inner regions, the vast mudflats and coastal low lands, which get submerged during high tide, are fully exposed during low tide. The inter-tidal region is sandy and muddy or rocky.

Tidal properties

Tides in the Gulf are of mixed, predominantly semidiurnal type with a large diurnal inequality. The tidal front enters the Gulf from the west and due to shallow inner regions and narrowing cross-section, the tidal amplitude increases considerably, upstream of Vadinar. The surfaces currents are moderate (0.7-1.2 m/s) but increase considerably (2.0-2.5 m/s) in the central portion of the Gulf. The spring currents are 60 to 65% stronger than the neap currents. The bottom currents are also periodic with a velocity normally 70% of the

[1] http://drs.nio.org/drs/bitstream/2264/87/2/Gulf%20of%20Kachchh.pdf [Accessed 10 January 2010]

surface currents. The mean high and low water spring and neap tide values for various ports in the gulf are given in the table A10.1.

Table A10.1 Tidal elevations along the gulf (in metres)[1]

Ports	MHWS	MHWN	MLWN	MLWS	MSL	Depth[2]
Okha	3.47	2.96	1.2	0.41	2	20
Vadinar	5.3	4.3	1.7	0.7	3	5
Mundra	5.5	5	2	1.2	3.4	5
Rozi	5.87	5.4	1.89	1	3.6	10
Kandla	6.66	5.17	1.81	0.78	3.9	5
Navlakhi	7.21	6.16	2.14	0.78	4.2	5

Gulf of Khambat (CAMBAY)[3]

The Gulf of Khambat bounded by latitudes between 210 and 220 20' N and longitudes between 720 and 730 E is a funnel shaped indentation on the western shelf of India, lying between the Saurashtra peninsula and the mainland of Gujarat (Figure A10.4). It is about 70 km – 80 km wide that funnels down to 25 km and 130 km – 140 km long (Vora et al., 1980). Middle part of the Gulf is deeper with depth ranging up to 30 m.

Figure A10.4 Location of tidal sites

[1] http://drs.nio.org/drs/bitstream/2264/87/2/Gulf%20of%20Kachchh.pdf [Accessed 10 January 2010]
[2] Kunte, P.D., Wagle, B. G. &Sugimori, Y. 2003.Sediment transport and depth variation study of the Gulf of Kutch using remote sensing, International Journal of Remote Sensing. 24(11), pp. 2253-226
[3] Kunte, P.D., Sediment concentration and bed form structures of Gulf of Cambay from remote sensing, International Journal of Remote Sensing, 29(8), pp. 2169-2182.

Tidal properties

Both semidiurnal and diurnal tides occur here. The semi-diurnal tides in the Gulf of Khambhat amplify about threefold from mouth to head, whereas the amplification of diurnal tides is much smaller.[1] The Gulf comprises an area of high tides (up to 11 meters) and is characterized by domination of strong tidal currents, the largest amplitude on the west coast (Unnikrishnanet al.1999). The measured current speed is found to vary from about 1.4 m/s in the open ocean to about 3.2 m/s in the Gulf of Khambhat.[2] The tides in the Gulf remain the largest of the Indian coast with spring tidal ranges of around 9 m and resulting in strong currents. Figure A10.5 shows the major ports and the depth on their region.

Basin area

The main rivers that drain into the Gulf are the Sabarmati, the Mahi, the Narmada, the Tapti and the Shetrunji. Entire banks surrounding the Gulf area bordered with large tidal flats nested into numerous tidal creeks.[3]

Seabed in most part of the Gulf remains in quasi steady state and it moves as sand bars with tides.[4]

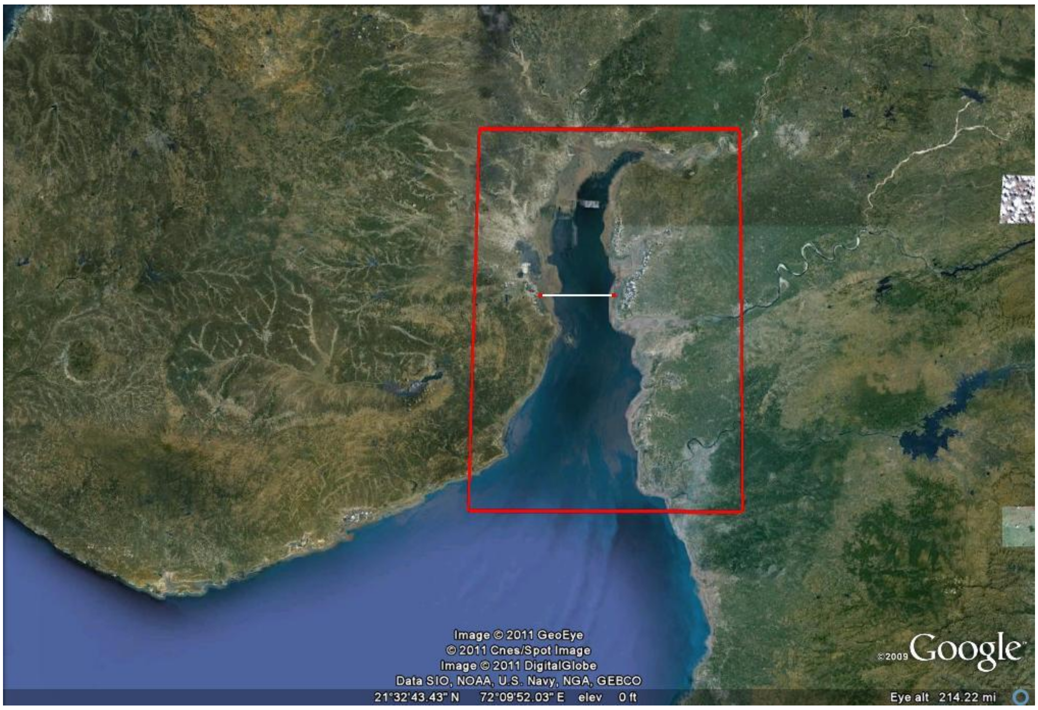


Figure A10.5 Gulf of Khambat (Image from Google Earth)

[1] Nayak, K.R. &Shetye, S. R.2003.Tides in the Gulf of Khambhat, west coast of India.Estuarine, Coastal and Shelf Science, 57 (2003), pp. 249–254

[2] Kumar, V.S., Pathak, K.C., Pednekar, P., Raju, N.S.N. &Gowthaman, R. 2006. Coastal processes along the Indian coastline. Current Science, 91(4), pp. 530-536.

[3] Kumar, V.S. & Kumar K.A.,2010. Waves and currents in tide dominated location off Dahej,Gulf of Khambhat, India, 33(2), pp. 218-231.

[4] Kumar, V.S. & Kumar K.A.,2010. Waves and currents in tide dominated location off Dahej,Gulf of Khambhat, India, 33(2), pp. 218-231.

Annexure 11: Geothermal Energy

Existing geochemical data

It is important to determine how hot a resource might be at depth without drilling during the exploration. Minerals and springs on the surface act like trail-markers by indicating the temperatures underneath that were necessary to create those mineral properties on the surface. This is where geochemical analysis plays a very important role. The underlying assumption of geochemical analysis in geothermal exploration is that the surface manifestations of geothermal fluids can provide information on temperature and physiological conditions in the subsurface geothermal reservoir. Obtaining this information is accomplished by using geo-thermometers that are based on the relative amounts and ratios of various elements or isotopes in the water. The levels of these elements within the geothermal fluid and with respect to each other provide insights into the geothermal reservoir temperature. Geochemists gather such data for analysis from multiple geo-thermometers in order to make the most reliable subsurface temperature estimates.

Some other technologies and techniques that are used for geochemical exploration are soil and gas geochemistry and rare earth element (REE) geochemistry. Soil and gas geochemistry involves the placement of detectors in/on the ground to detect gases (such as mercury or carbon dioxide) associated with geothermal reservoirs at a depth. Background calibrations for local conditions need to be taken, and sometimes the detectors need to remain in the ground for months to obtain useful data. The advantage of soil and gas geochemistry is that it can be used to locate information on hidden geothermal systems. Modern ultra low-level measurement techniques enable geochemical explorers to measure elements associated with geothermal activity that were previously undetectable. The development and implementation of new types of geothermometers such as the use of nitrogen isotopes, would add another data point for the estimation of geothermal energy potential thereby increasing the accuracy of the results, even if marginally.

Surface manifestations of geothermal fluid are not necessarily required to perform geochemical analysis. Occasionally, upwellings of geothermal fluid that have since dried out will leave traces of evaporites such as boron-bearing salts. These evaporites can sometimes be located with exploration technologies such as remote sensing.

Existing geophysical data

Geophysical analytical techniques can also provide clues as to what is happening in the subsurface. Geophysical techniques can provide indications of the structure of subsurface geology and how those structures can be drilled to bring hot water from the geothermal aquifer to the surface. Combined with geochemical studies, geophysical analysis seeks to identify temperatures, permeability, and the orientation of fractures at depth. While the oil industry has found 3D Seismic Tomography to be extremely effective in locating subsurface oil and gas plays, no such geophysical tool currently exists for the geothermal industry. Rather, geothermal developers will employ various studies from a suite of geophysical exploration methods to better understand a geothermal reservoir prior to drilling. The combination of geophysical survey methods employed in an exploration program are dependent on intrinsic (i.e. local geology, hydrogeochemistry) and extrinsic (local weather, economic, and land issues) factors. As such, some methods will be more effective in certain resource areas than others, guaranteeing their widespread use. Still, certain geophysical technologies are more widely used than others and incremental improvements in their technology or use could yield improved exploration success rates.

Methodology for mapping geothermal potential

The methodology chosen for producing map-able data for Gujarat state is that followed by Chopra & Holgate [9]. For this methodology, the data that is needed has been tabulated in table A11.1. Unfortunately, the time available in this project has not allowed for such an extensive data collection from the listed sources, since such data is either confidential or not available in the public domain. However, the methodology that is to be used for mapping the geothermal resources of the state has be described in this section for future reference and further work when such data becomes available.

Table A11.1 Data needed for geothermal mapping of Gujarat state

Sl. No.	Data	Source
1	Mean Annual Surface Temperature (MAST)	Indian Meteorological Department (IMD)
2	Borehole data • Rock thermal conductivity • Rock geochemistry • Thermal gradient • Rock geology	Geological Survey of India (GSI); National Geophysical Survey of India (NGRI); Oil & gas exploration companies
3	Geology of crust (surface & subsurface)	GSI, NGRI
4	Sedimentary isopachs (first basement thickness)	GSI, NGRI
5	Tectonic blocks on India	GSI, NGRI

Once the MAST data is available, this would be distributed over the entire geographic region of the state by dividing the state into a uniform grid pattern (5 km x 5 km) with MAST values at each grid point. For those grid points that do not have measured MAST values, the same would be interpolated using a method called Ordinary Kriging. This method is based on the estimation of regionalised variables over a finite geographic distribution, i.e. within the neighbourhood of the variable. Points contained within a neighbourhood are assumed to be spatially correlated and can be used to interpolate other values within that same space. With increasing distance the degree of spatial correlation declines until it approaches that of the entire population. Thus as the distance between an interpolated point and any known reference point increases, the ability of that datum to predict the interpolated value falls [Chopra & Holgate].

To find the MAST values for those locations other than the ones provided by the meteorological agencies, an interpolation technique would have to be used. In the analysis published by Chopra & Holgate, the spatial spread of the dataset was considerably large as compared to the state of Gujarat. As a result, the interpolation results would be influenced by factors such as latitude, topography, surface geology and so on. Hence the method adopted by Chopra & Holgate was Universal Kriging - a method that takes into account the spatial gradient of the parameter being interpolated.

Then with the help of line data of sedimentary isopachs, the depth to the basement of the first geological layer is determined. This will have to be determined in a grid-form for the entire state of Gujarat using minimum curvature spline method (not kriging, as kriging was found to produce large spikes and other "interpolation noise". After dividing the state into a uniform grid, the existing borehole locations can be overlaid with surface temperatures and borehole bottom temperatures. This is the most critical aspect of geothermal resource estimation, i.e. predicting the temperature at a particular depth in the crust based on the information available.

After obtaining the MAST values for the grid points, the temperature at a depth of 5km is estimated using a uniform geothermal gradient of 25°C/km for whatever basement rock that exists at that location. It is important to have fairly contiguous and homogenous basement rock for the entire depth so that thermal conductivity levels do not differ largely. For this, the methodology adopted by Chopra & Holgate initially involved a one-dimensional extrapolation along the depth of all those drilled holes for which drill data was available[1]. The Geothermal gradient is calculated between the earth's surface and the bottom of the drill hole. The temperature at the surface is taken as the MAST value for that location, and the bottom hole temperature is taken from the drill hole data. This geothermal gradient is then extended further below till it reaches the basement interface / sedimentary basin. In this process, if the 5 km depth mark is not yet encountered, then the rest of the depth is assumed to have an average geothermal gradient of 25°C/km. In this way, the 5 km depth temperatures are generated for each of the drill-hole locations. With such a liner extrapolation exercise, we can establish a database of underground temperatures for several hundred locations whose borehole data was used. These point estimates can then be used to spatially interpolate estimates of the temperature at 5km on a regular 5km x 5 km grid map, using the Ordinary Kriging method.

Something the method of Chopra & Holgate does not take in account is the presence of surface manifestation of geothermal energy, like hot springs or fumaroles, etc. A reason for this could be that such locations are possibly well-known and investigated with boreholes such that they are already included in the database. However, in case there are any non-investigated sites that have such surface manifestations of geothermal energy, then the neighbourhood grid points will have their MAST or their thermal gradient adjusted to be horizontally related to the temperature of the fluid at these sites.

This method is also limited to the data that goes into the modelling process. The more the number of boreholes whose data is available, the geographic distribution of these borehole locations would impact the final kriged map that is produced. As a result of data unavailability for certain large geographic regions, the method has generated maps that show some geothermal potential in a location and then no potential in the immediate neighbourhood of the location in the direction of the region for which data is not available. This is illustrated in the figure A11.1 in the analyses done by Chopra and Holgate.

[1] These numbered to some 5306 locations. In India, the number of drilled locations is not known as this data is with National laboratories engaged in geophysical characterization, or with Oil and Gas companies

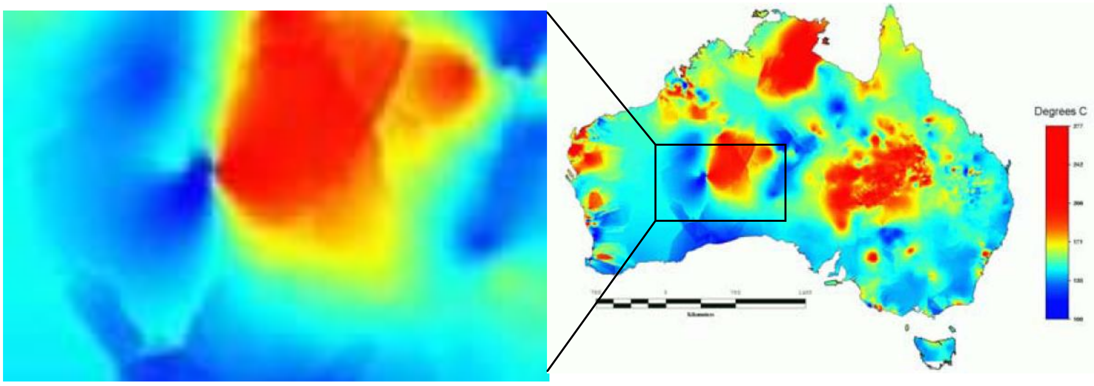


Figure A11.1 The kriged map of temperature at 5km depth for the Australian landmass [9]. The kriged anomaly is exploded and shown on the right side

In areas with high densities of temperature observations the kriging process has been well constrained and smooth variations in interpolated temperature and rounded anomalies are typical. However in areas where there is little or no data, structures that may appear spurious will appear in thekriged results (as seen in above picture).

Another way of augmenting the quality of kriged results in region with little or no borehole data, is using tectonic information for the crust in those areas. This can be used to restrict the region of influence of results from kriging to the respective geological blocks of common tectonic provenance. This means that the spatial kriging of borehole data will be largely confined to the respective geological block where the borehole is located. The tectonic blocks map[1] divides the basement of the Australian continent into 335 tectonic elements each of which has a similar magnetic and gravity character that is assumed to relate to crustal-scale domains of like composition and/or structural configuration. The data of tectonic elements are displayed in Figure A11.2 where it has been superimposed with the kriged map.

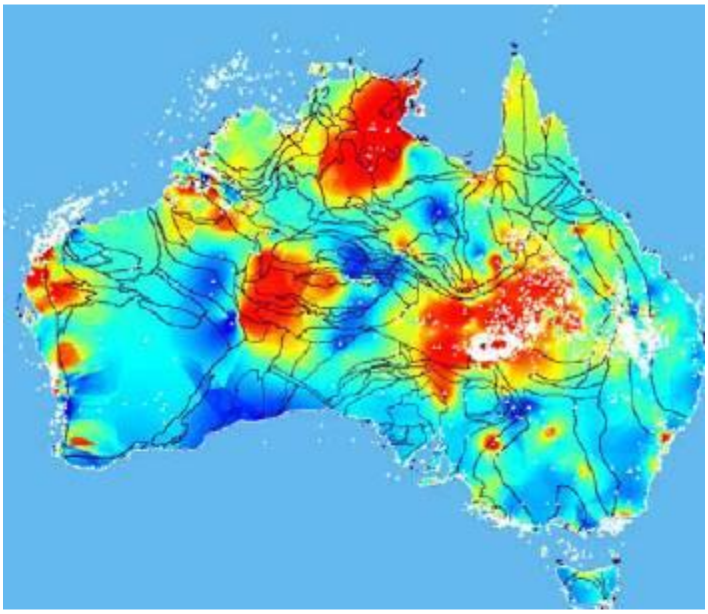


Figure A11.2 Map of Australia showing the kriging results along with boreholes marked by white crosses and the tectonic elements shown by black lines.

[1] Tectonic blocks -

Alternate analysis of geothermal resource in Gujarat

After the Indian plate separated from the Gondwana landmass, it began moving towards the Asian and Burmese plates at differential rates resulting in large compressive stresses at the interplate boundaries. The accumulation of compressive stresses eventually led to the creation of basins associated with interplate rifts – one such basin is the Cambay graben. The outpouring of Deccan basalt probably coincides with the culmination of these events. The continental collisional phase of the on-going geodynamic processes resulted in episodic uplift of the Himalayas. This has given rise to the present-day geomorphic configuration of the Indian sub-continent and resulted in intense fragmentation of the Indian Shield. This in turn controls all neotectonic features, contemporary tectonism, the present phase of geothermal activity and distribution of heat flow values[1].

The Cambay graben is the only known geothermal province[2] in the state of Gujarat. Temperatures between 100-150°C have already been recorded up to 3.5 km depth in this zone in the Cambay graben [Ravi Shankar et al]. The Cambay Basin, the southern continuation of the Barmer-Sanchor Graben is a narrow elongated (NNW-SSE trending) intra-cratonic rift basin (area 59,000 sq.km), situated between Saurashtra craton to the west, Aravalli swell on the northeast and Deccan craton to the southeast (see figure A11.3). In the south, it extends into Cambay Gulf and ultimately into the Arabian Sea. The extensional architecture of the basin is defined by three major Precambrian trends viz., NNW-SSE trend related to Dharwarian orogeny, NE-SW trend related to Aravalli orogeny, and ENE-WSW trend related to Satpura orogeny. The basin is sub-divided into four major tectonic blocks - Sanchor-Patan, Ahmedabad-Mehsana, Tarapur-Cambay and Jambusar-Broach, by cross-trending NE-SW. Extensive exploration in this basin has resulted in numerous oil and gas discoveries, notably Ankleswar, Gandhar, Nawagam, Dholka, Kalol, Sanand, Jhalora, Viraj, Kadi and S. Kadi, N. Kadi, Jotana, Sobhasan, Balol, and Santhal.

[1] Heat flow map of India – update, presented at 21stNew Zealand Geothermal Workshop; Ravi Shanker, A. Absar, I. P. Bajpai; Geological Survey of India, Lucknow, India

[2] There are totally around nine identified geothermal provinces in India. These include Himalaya, SO-NA-TA, Cambay graben, Godavari, West coast, Mahanadi, Naga-Lushai, Andaman-Nicobar (BarrenIsland) and Aravalli

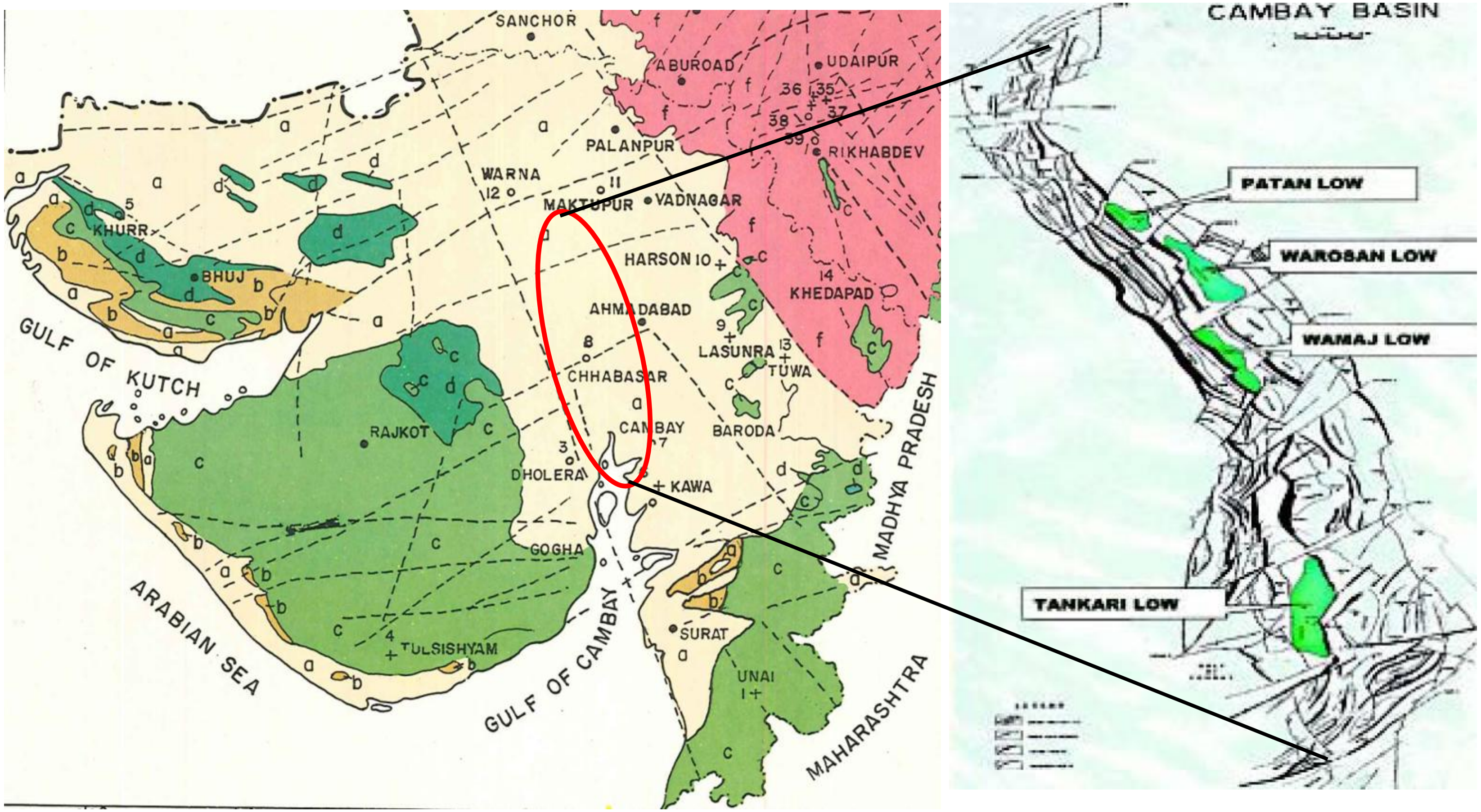


Figure A11.3 Location of Cambay graben in Gujarat with the geology juxtaposed for reference[1]

[1] Source: Geology of Gujarat by GSI, Cambay graben map by P.K. Bhowmick, PhanerozoicPetroliferousBasins of India, Oil and Natural Gas Commission; Glimpses of Geoscience Research in India; Weblink - http://khup.com/download/21_keyword-cambay-graben/phanerozoic-petroliferous-basins-of-india.pdf, accessed on 15.01.2011

Some studies by GSI have shown that several sites in the cambaygraben have active geothermal sites. While drilling for oil, hot water and steam under pressure was encountered in two bore holes (Cambay-15 and Kathana-4)In Cambay-15, steam was struck at the depth of 1750 m, while in Kathana-4 it was at 1958 m. Steam discharge was estimated at 3000 m3/day with high thermal gradients and bottom hole temperatures of about 160 °C. The GSI reports that large areas in Gujarat adjacent to the Cambay graben contain groundwater at elevated temperatures.

Gujarat has around 14 documented thermal springs. Figure A11.4 shows these spring locations marked with circles and a number corresponding to their local names. The names of the locations are as follows: 1-Unai, 2-Goha, 3-Dholera, 4, 5 & 6-Tulsi Shyam, 7-Cambay, 8-chhabasar, 9-Lasunra, 10-Harsan, 11-Maktupur, 12-Warna, 13-Tuwa, and 14-Khedapad

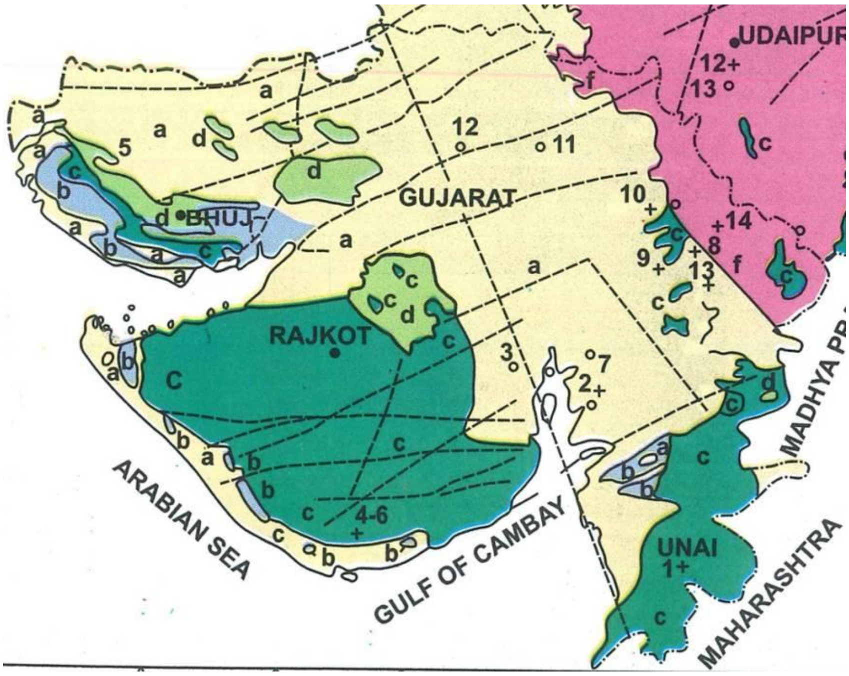


Figure A11.4 Thermal springs in Gujarat[1]

Figure A11.5 (a) shows the Gujarat region with markings of different surface temperature ranges. The squares stand for a surface temperature less than 35 °C, triangles for 35 to 55 °C and circles for 55 to 75 °C. The Cambay graben region in particular has a consistent marking indicating that the elevated surface temperatures are indeed signs of geothermal activity. Figure A11.5 (b) on the other hand is a map of the geothermal resource. This map, by virtue of colour codes, delineates the regions with different subsurface temperatures (up to a depth of 3 km). The pink colour region has a subsurface temperature of 120 – 159 °C, followed by the dark blue region at 90 – 120 °C and the light blue region with less than 90 °C. This map was constructed on the basis of surveys carried out by the GSI towards the last 3 decades of the 20th century. The black lines delineating the zones can be considered to be isopachs of the temperature enclosing the area that is at the same temperature. In light of recent surveys and tests carried out in the region, there will be significant scope to modify this map to account for more resources, or simply the accuracy of the extents of different temperature regions.

[1] Source: Geothermal Energy Resources of India, GSI, 2002 (ISSN 0254-0436); pp 156-158

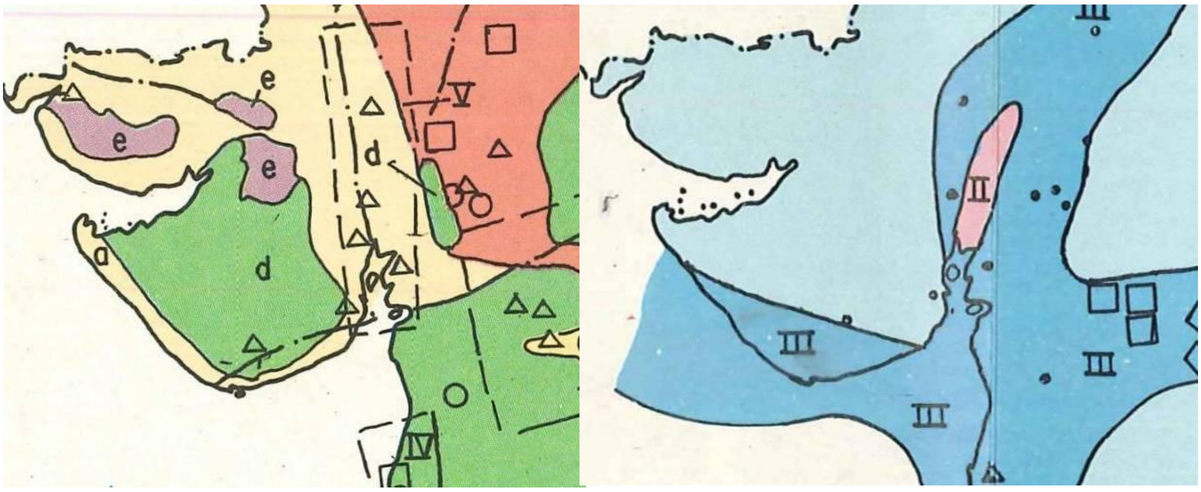


Figure A11.5 (a)[1] Geothermal province in Gujarat – the Cambay graben; **(b)** [2]High temperature isopachs in Gujarat

The heat flow map is a useful tool to examine the viability of geothermal resources. With the location of the major geothermal region in Gujarat (i.e. Cambay graben), the information on the amount of heat that can be economically extracted from this region for useful applications will depend on the depth that needs to be drilled and the temperature of the geothermal fluid. Presence of high heat flow zones above the crust suggest that the geothermal resource is either located close to the crust or has a high reservoir temperature. In both cases, considerably high geothermal gradient is most likely to be encountered while drilling, thus obviating the need for going too deep.

Figure 11.6 shows the heat flow map of Gujarat. The stars are color-coded against the respective oil fields in table A11.2. Since well-data for other wells around Gujarat are not available at the moment, our analysis is restricted to the Cambay area and those listed in table A11.2. From figure A11.6, we can see that surface temperatures in this region are in the range of 35 – 55 °C. This range has been used as the starting temperature for subsurface temperature estimation in the last two columns of table A11.2 All five oil wells are located within the Zone – III having a heat flow of 70-100 mW/m2. However, region south of Ankleshwar are indicated to have higher heat flow values. But absence of any well data for that region inhibits the inclusion of such areas in the discussion at the moment.

[1] Source: Geothermal Atlas of India, GSI, Special Publication 19, 1991; pp 7

[2] Source: Geothermal Atlas of India, GSI, Special Publication 19, 1991; pp 8

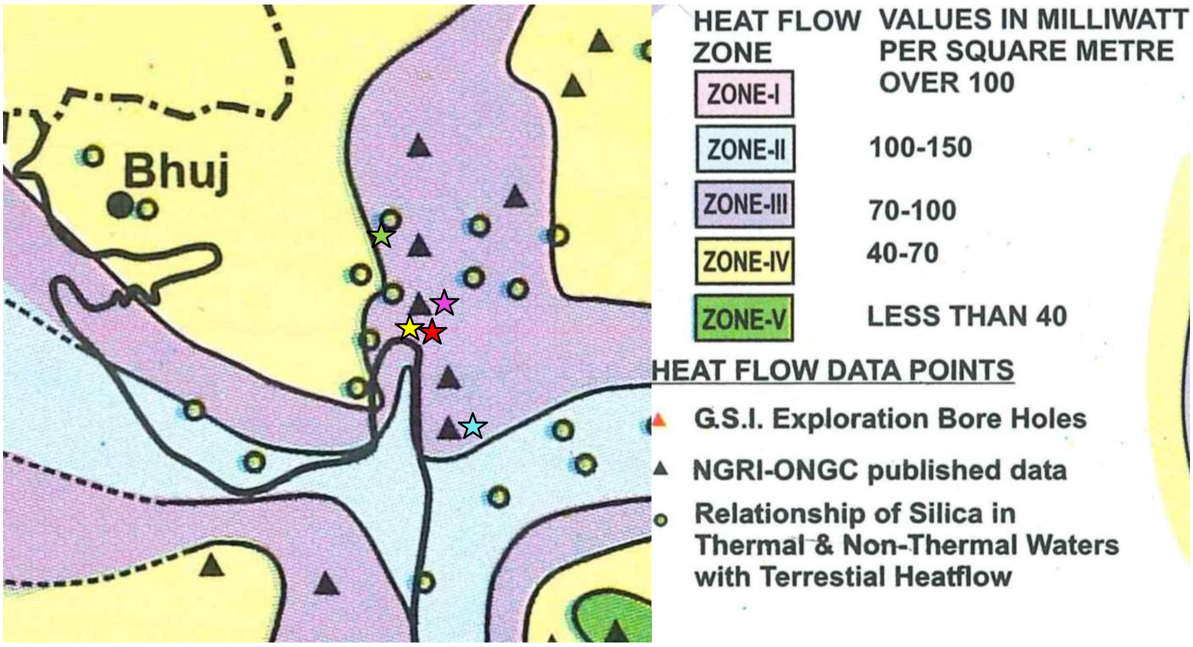


Figure A11.6 Heat flow map of Gujarat region[1]

Table A11.2 Oil-well data for five different oil fields in Gujarat state located within the Cambay graben; all wells are out of production and filled with water[2]

Sl. No.	Location name	District	Min. Temperature gradient (°C/km)	Max. Temperature gradient (C/km)	Heat flow (μcal/cm^2.s. °C)	Min. estimated temperature (°C) at 5 km depth	Max. estimated temperature (°C) at 5 km depth[3]
1	Kathana oilfield	Anand	48.4±0.7	70.7±2	2.2	277.0	408.5
2	Nawagam oilfield	Anand	43.3±2.1	61.8±1	1.9	251.5	364.0
3	Kalol oilfield	Gandhinagar	31.1±3.4	59±5.7	1.8, 1.9	190.5	352.5
4	Cambay gas field	Anand	42.5±0.9	74.9±8	2.4, 2.3, 2	247.5	429.5
5	Ankleshwar oilfield	Baruch	32.3±1.1	47.3±0.3	1.5, 1.65, 1.7	196.5	291.5

As discussed in the previous section on the analysis of Chopra & Holgate using tectonic information and location of fault lines, the same can be used here for preliminary analysis sans kriging of borewell points. The Chopra and Holgate tectonic analysis presupposes that

[1] Source: Geothermal Energy Resources of India, GSI, 2002 (ISSN 0254-0436); pp 182

[2] Source: Terrestrial heat flow and tectonics of the Cambay basin, GujaratState (India); M. L. Gupta et al, NGRI; Journal of Tectonophysics 10 (1970) 157 - 163

[3] Uniform linear extrapolation carried out using minimum and maximum thermal gradients for minimum and maximum temperature estimation respectively. Surface temperatures assumed are 35 °C and 55 °C for minimum and maximum temperatures respectively.

the hypothesis of Shaw et al[1] for a fragmented tectonic structure for the Australian plate is correct. This hypothesis advocates that the Australian plate was not a single plate (like the Indian plate), but an assemblage of several smaller plates. Since such a verified hypothesis does not exist for India in, we shall use the widely accepted tectonic structure for India. Chopra & Holgate's tectonic analysis may however be used with fault lines in the Indian context. Here fault lines can be treated as breaks in the geologic continuum thereby limiting influence of neighbouring geothermal activity from the other side of a fault line.

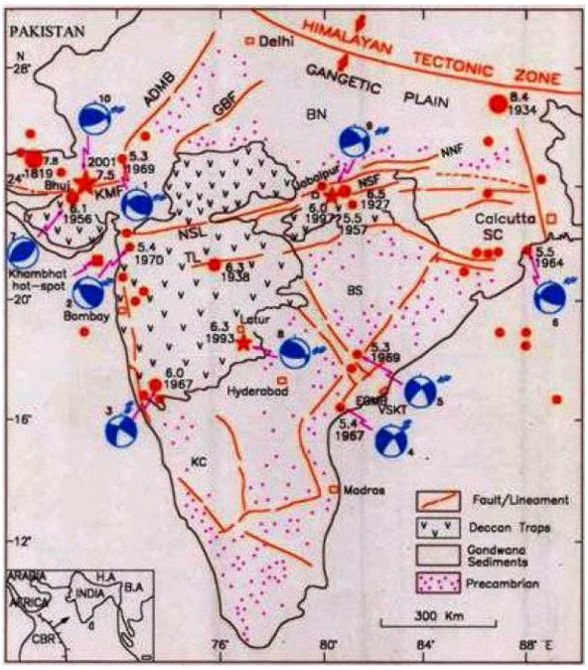


Figure A11.7 Seismo-tectonic map of India[2]

A simplified tectonic map for Gujarat state is given in figure A11.8. From the figure, we see that the three regions that are between faults lines are Cambay graben[3], Kutch graben and the Narmada graben. The Cambay graben is clearly a very narrow rifting zone that is likely to have heat generation due to friction, if not subsurface magmatic activity.

[1] Shaw et al published their tectonic element map of Australia based on the hypothesis that Australia was not a single plate, (like India) but a collection of several tectonic elements. This was referred in the work of Chopra and Holgate.

[2] Source: India – seismic images, IGCP Project 559, Crustal Architecture and Images; Jnana R. Kayal; GSI; Weblink – http://www.earthscrust.org/earthscrust/science/transects/india.html, accessed on 05.09.2010

[3] The Cambay graben is not as linear as shown in figure 8 but curves north-westwards

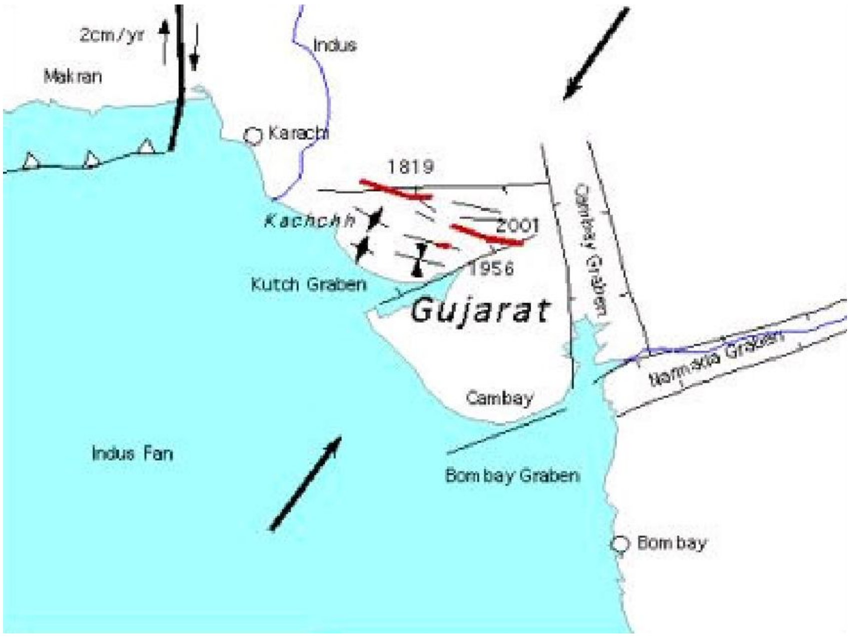


Figure A11.8 Simplified tectonic map for Gujarat showing fault lines[1]

A combined map of heat flow values, tectonic blocks, thermal springs and existing bore wells needs to be prepared to be able to make better inferences on the extent of the Cambay graben's geothermal activity. The closest geothermal provinces to Gujarat state with some publicly available information are the West Coast province (Konkan coast) and the western tip of the Son-Narmada-Tapi (So-Na-Ta) province. The Konkan province spreads nearly a few hundred kilometers in Deccan basalt along the west coast of India. In this region, hot springs are known to be located at 23 locations, 9 located north of Bombay and 14 in the southern part. It is believed that water from the springs is of meteoric origin. Originated from the steep hills of Western ghats situated at a few kilometers away from the springs towards the east, the water must have seeped into the subsurface through deep fractures and got heated up down below due to anomalous geothermal gradient and emerge to the surface through suitable conduits to appear a hot springs[2]. The high geothermal gradient at Ankleshwar (located in south of Gujarat; table A11.2) could be one of the verifying signs of geothermal potentials arising out of the West Coast province and the Sonata province.

Presence of lineaments indicates historical seismic activity and possibility of tectonic activity. These are usually also associated with fractures and seepage of magmatic heat to subsurface from earth's mantle. Regional gravity studies over Deccan traps indicated a major lineament along the west coast. In Koyna region, deep seismic sounding (DSS) studies provided the crustal structure. From deep electrical soundings in the south east of the present study region obtained a thickness of 500 m and a resistivity of about a few hundred ohm-m for the basalt. The traps are reported to become thicker towards the west, the thickness reaching a value of about 1.5 km.

Magneto-telluric studies are used to determine subsurface geology by way of electrical conductivity measurements of the earth's crust. The inference of rock types from these studies can provide usual information on age and process of rock formation. This can be a

[1] Source: India – seismic images, IGCP Project 559, Crustal Architecture and Images; Jnana R. Kayal; GSI; Weblink – http://www.earthscrust.org/earthscrust/science/transects/india.html, accessed on 05.09.2010
[2] Source: Reference no. 8 from reference list given at the end

crucial bit of information to geothermal assessments vis-à-vis the nature of rock. A reconnaissance telluric field study in the northern part of Konkan geothermal province has indicated a distinct subsurface conductive anomaly. Further work has apparently been taken up with additional telluric and a few experimental MT measurements in the area, but this data is not yet readily available. These studies have not only confirmed the presence of the conductive anomaly near Sativili-Koknere group of hot springs, but also helped further extending the earlier telluric field anomaly.

The analysis of the data shows that the telluric field parameter, 'μ' varies from 1.0 to 0.7 in the southern part of the study area near Ganeshpuri-Akloli group of hot springs and tends to decrease northwards to about 0.2 towards the Sativili-Koknere group of hot springs. It is observed that this decreasing trend continues even further towards north of Koknere from the telluric field contour map. The contour map also indicated that the telluric anomaly representing a subsurface conductive anomaly is not a localized feature but covers a large region. It needs to be investigated further to see if this region would include part of Gujarat state.

In its simplest form the anomaly may be explained by a near surface horizontally extending conductive zone (2-5 ohm-m) located at shallow depths (<1 km). Since it is improbable that such an electrically high conductive zone could be explained from any known geological or any hydrological considerations, it is inferred that the anomaly should be attributed to deeper source, probably magmatic in nature (which has geothermal energy implications). Accordingly, from detailed modeling studies referred to in [8], it is concluded that a deeper conductive zone with a 1 km would account for the observed telluric field anomaly in addition to the shallow conductors indicated from deep electrical resistivity soundings results.

The key geological ingredients of the Hot Rock geothermal model are high-heat-producing granites overlain by thick accumulations of low-thermal-conductivity sediments. The decay of low concentrations of radiogenic elements (mostly uranium, thorium and potassium) over millions of years produces heat in the granite. This heat may be trapped at depth within the crust by the sedimentary cover which, lying above the granite, acts like a blanket. By mapping out deeply buried granites and having knowledge of both their chemistry and the thermal conductivity of any overlying sediment, it will be possible to make predictions about crustal temperature [17]. By mapping granite outcrops it is also possible to make predictions of the composition of buried granites as they trend from outcrop areas to beneath sediments. In this way the heat production beneath sedimentary basins may be estimated. With information about the thicknesses and thermal conductivity of the overlying sedimentary strata, the heat production of the buried granites and estimation of heat flow upwards from the mantle, local temperature profiles of the crust in that location may be estimated.

Annexure 12: State wise ground water resources availability, utilization and stage of development in India

Sl. No.	States / UnionTerritories	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon Season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future Irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources									
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	States													
1	Andhra Pradesh	16.04	8.93	4.2	7.33	36.5	3.55	32.95	13.88	1.02	14.9	2.67	17.65	45
2	Arunachal Pradesh	1.57	0.00009	0.98	0.0002	2.56	0.26	2.3	0.0008	0	0	0.009	2.29	0.04
3	Assam	23.65	1.99	1.05	0.54	27.23	2.34	24.89	4.85	0.59	5.44	0.98	19.06	22
4	Bihar	19.45	3.96	3.42	2.36	29.19	1.77	27.42	9.39	1.37	10.8	2.14	15.89	39
5	Chattisgarh	12.08	0.43	1.3	1.13	14.93	1.25	13.68	2.31	0.48	2.8	0.7	10.67	20
6	Delhi	0.13	0.06	0.02	0.09	0.3	0.02	0.28	0.2	0.28	0.48	0.57	0	170
7	Goa	0.22	0.01	0.01	0.04	0.28	0.02	0.27	0.04	0.03	0.07	0.04	0.18	27
8	Gujarat	10.59	2.08	0	3.15	15.81	0.79	15.02	10.49	0.99	11.5	1.48	3.05	76
9	Haryana	3.52	2.15	0.92	2.72	9.31	0.68	8.63	9.1	0.35	9.45	0.6	-1.07	109
10	Himachal Pradesh	0.33	0.01	0.08	0.02	0.43	0.04	0.39	0.09	0.02	0.12	0.04	0.25	30
11	Jammu & Kashmir	0.61	0.77	1	0.32	2.7	0.27	2.43	0.1	0.24	0.33	0.42	1.92	14
12	Jharkhand	4.26	0.14	1	0.18	5.58	0.33	5.25	0.7	0.38	1.09	0.56	3.99	21
13	Karnataka	8.17	4.01	1.5	2.25	15.93	0.63	15.3	9.75	0.97	10.7	1.41	6.48	70
14	Kerala	3.79	0.01	1.93	1.11	6.84	0.61	6.23	1.82	1.1	2.92	1.4	3.07	47
15	Madhya Pradesh	30.59	0.96	0.05	5.59	37.19	1.86	35.33	16.08	1.04	17.1	1.74	17.51	48
16	Maharashtra	20.15	2.51	1.94	8.36	32.96	1.75	31.21	14.24	0.85	15.1	1.52	16.1	48

Sl. No.	States / UnionTerritories	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon Season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future Irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources									
17	Manipur	0.2	0.005	0.16	0.01	0.38	0.04	0.34	0.002	0.0005	0	0.02	0.31	0.65
18	Meghalaya	0.79	0.03	0.33	0.005	1.15	0.12	1.04	0	0.002	0	0.1	0.94	0.18
19	Mizoram	0.03	0	0.02	0	0.04	0.004	0.04	0	0.0004	0	0.0008	0.04	0.9
20	Nagaland	0.28	0	0.08	0	0.36	0.04	0.32	0	0.009	0.01	0.03	0.3	3
21	Orissa	12.81	3.56	3.58	3.14	23.09	2.08	21.01	3.01	0.84	3.85	1.22	16.78	18
22	Punjab	5.98	10.91	1.36	5.54	23.78	2.33	21.44	30.34	0.83	31.2	1	-9.89	145
23	Rajasthan	8.76	0.62	0.26	1.92	11.56	1.18	10.38	11.6	1.39	13	2.72	-3.94	125
24	Sikkim	-	-	-	-	0.08	0	0.08	0	0.01	0.01	0.02	0.05	16
25	Tamil Nadu	4.91	11.96	4.53	1.67	23.07	2.31	20.76	16.77	0.88	17.7	0.91	3.08	85
26	Tripura	1.1	0	0.92	0.17	2.19	0.22	1.97	0.08	0.09	0.17	0.2	1.69	9
27	Uttar Pradesh	38.63	11.95	5.64	20.14	76.35	6.17	70.18	45.36	3.42	48.8	5.3	19.52	70
28	Uttaranchal	1.37	0.27	0.12	0.51	2.27	0.17	2.1	1.34	0.05	1.39	0.08	0.68	66
29	West Bengal	17.87	2.19	5.44	4.86	30.36	2.9	27.46	10.84	0.81	11.7	1.24	15.32	42
	Total States	**247.88**	**69.51**	**41.83**	**73.15**	**432.4**	**33.73**	**398.7**	**212.383**	**18.0419**	**230**	**29.1198**	**161.92**	58
	UnionTerritories													
1	Andaman &Nicobar	-	-	-	-	0.33	0.005	0.32	0	0.01	0.01	0.008	0.303	4
2	Chandigarh	0.016	0.001	0.005	0.001	0.023	0.002	0.02	0	0	0	0	0.02	0
3	Dadara& Nagar Haveli	0.059	0.005			0.063	0.003	0.06	0.001	0.007	0.01	0.008	0.051	14
4	Daman & Diu	0.006	0.002	0	0.001	0.009	0.0004	0.008	0.007	0.002	0.01	0.003	-0.002	107
5	Lakshdweep	-	-	-	-	0.012	0.009	0.004	0	0.002	0	-	-	63
6	Pondicherry	0.057	0.067	0.007	0.029	0.16	0.016	0.144	0.121	0.03	0.15	0.031	-0.008	105
	Total Uts	**0.138**	**0.075**	**0.012**	**0.031**	**0.597**	**0.036**	**0.556**	**0.129**	**0.051**	**0.18**	**0.05**	**0.365**	**33**
	Grand Total	**248.018**	**69.585**	**41.842**	**73.181**	**433**	**33.766**	**399.256**	**212.512**	**18.0929**	**231**	**29.1698**	**162.285**	**58**

Annexure 13: District wise ground water resources availability, utilization and stage of development in Gujarat-2004

S. No.	District	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon Season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future Irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Ahmedabad	34550	6404	0	6602	47556	2378	45178	42374	6454	48828	9597	-6793	108
2	Amreli	58975	2578	0	9037	70590	3529	67060	43603	2376	45980	3532	19925	69
3	Anand	22416	22681	0	18461	63558	3178	60380	28670	4622	33293	6875	24835	55
4	Banaskantha	71839	8456	0	10177	90473	4524	85949	96663	5150	101813	7638	-18352	118
5	Bharuch	20380	1994	0	5504	27878	1394	26484	13349	1835	15184	2729	10406	57
6	Bhavnagar	63595	2467	0	10502	76564	3828	72735	41732	5084	46816	7561	23442	64
7	Dohad	20584	2700	0	3659	26943	1347	25596	11720	3998	15718	5894	7982	61
8	Gandhinagar	27096	4767	0	4329	36192	1810	34383	60388	2861	63249	4257	-30262	184
9	Jamnagar	68632	9607	0	11396	89635	4482	85153	46688	4057	50745	6033	32431	60
10	Jungagadh	93251	8838	0	17253	119342	5967	113375	75384	6197	81581	9203	28788	72
11	Kachchh	44934	13161	0	14215	72311	3616	68695	58314	3821	62135	5684	4697	90
12	Kheda	35382	15985	0	16960	68327	3416	64911	38044	5287	43331	7862	19005	67
13	Mahesana	67283	8732	0	6571	82586	4129	78457	113587	5013	118600	7455	-42585	151
14	Narmada	15228	2341	0	3883	21452	1073	20380	5100	1403	6503	2085	13195	32
15	Navsari	17883	10928	0	22129	50940	2547	48393	20731	2096	22827	3117	24545	47
16	Panchmahals	25565	10047	0	14947	50559	2528	48031	23514	5050	28564	7505	17012	59
17	Patan	19786	1800	0	1761	23347	1167	22180	28352	1678	30030	2495	-8667	135
18	Porbandar	12248	909	0	1440	14597	730	13867	11354	1035	12389	1540	973	89

S. No.	District	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon Season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future Irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources									
19	Rajkot	77417	17058	0	23575	118051	5903	112148	73741	7016	80757	10434	27973	72
20	Sabarkantha	69430	8009	0	16659	94098	4705	89393	69737	5072	74809	7544	12112	84
21	Surat	43234	29022	0	63604	135860	6793	129067	40645	6855	47500	10193	78229	37
22	Surendranagar	42538	4533	0	6975	54046	2702	51344	31081	2423	33504	3605	16658	65
23	The Dangs	4481	702	0	61	5244	262	4982	516	510	1026	758	3707	21
24	Vadodara	83030	8508	0	13764	105302	5265	100037	61521	7106	68627	10566	27950	69
25	Valsad	19224	5283	0	11137	35644	1782	33862	12358	2406	14763	3578	17926	44
	State Total (ham)	**1058981**	**207510**	**0**	**314601**	**1581095**	**79055**	**1502040**	**1049166**	**99405**	**1148572**	**147740**	**305132**	**76**
	State Total (bcm)	**10.59**	**2.08**	**0.00**	**3.15**	**15.81**	**0.79**	**15.02**	**10.49**	**0.99**	**11.49**	**1.48**	**3.05**	**76**

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