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The Necessity of the Development of Standards for Renewable Energy Technologies in Nigeria

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Abstract

Clean energy is vital for the sustainability of any economy in the world. Many industrialized nations have increased their production capacity of renewable energy while other countries lacking the technical expertise and resource have resorted to import these technologies. The imported technologies mostly have standards that are followed by the manufactures while others are manufactured cheaply and exported to developing countries that do not have adequate standards and certification bodies. Nigeria which is a fast growing country has no existing standards to check the influx of renewable energy technologies into the country. This study stresses the need for the development of standards for renewable energy technologies in order to prevent the importation of substandard renewable energy technologies in Nigeria. The study reviews the renewable energy potentials in Nigeria, introduces the concept of standardization and discusses the development of standards for renewable energy technologies.

Keywords

Standards, Standardization, Renewable Energy Technologies, Substandard

1. Introduction

Energy is an important factor for socioeconomic development and economic growth of any nation. Energy is usually stored in energy system which provides energy services. Energy services are desired and useful products, processes or services that result from the utilization of energy like lighting, powering of home-based appliances such as air-conditioner, refrigerators, and cookers for cooking. The energy chain to deliver these cited services

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begins with the collection or extraction of primary energy, which is converted to energy carriers suitable for the final consumers. These energy carries are utilized in energy end-user technologies to provide the desired energy services [1].

Energy sources are divided into conventional energy which is crude oil, natural gas and coal while non-conventional energy or renewable energy is solar, wind, hydro and biomass energy [2]. About 90% of the total energy supply in the world comes from conventional energy. Conventional energy contains mostly carbon which is the leading cause of global warming when released from crude oil products, gas and coal to the atmosphere [3]. The increase in global warming has indulged both the developed and developing countries to make a shift to renewable energy resources.

Most energy projection shows that the current and future world energy demand patterns are definitely not sustainable. However, the demand for energy will increase dramatically with developing countries consuming more and more energy. The only solution is to decouple the economic activities associated with conventional energy consumption [4]. This can be achieved by increasing the share of renewable energy in the energy consumption balance to enhance sustainability and improve the security of energy supply [5].

Renewable energy development in developing country aims at providing sustainable energy which will ensure the proper mitigation of energy scarcity and global warming. Renewable energy development has led to the increase in the manufacturing of renewable energy technologies such as solar panels, wind turbines and small hydropower (SHP). These technologies transform the energy stored in the sun, wind and hydro to energy which can be harnessed for human consumption.

Renewable energy that is being manufactured by different industries in various countries of the world has their specification and standards. When these technologies are imported into another country, standards are created by standards bodies in the importing country to ensure that the renewable energy technologies are reliable, compactable and safe for its citizens. Countries that don't have the technical expertise to manufacture renewable energy technologies have to import from other countries like China, South Korea, Japan, and the US etc. The countries that lack technical expertise are mostly in the African continent and they rely on imported technologies. These technologies are sometimes substandard and unreliable while others are even dangerous to the consumers and can cause fire outbreak which can destroy lives and property.

Nigeria, which is located in the West African region has been importing renewable energy technologies but has failed to ensure the establishment of standards for renewable energy by the Standards Organization of Nigeria (SON). This has led to the import of substandard renewable energy technologies into the country and has posed some dangers to her citizens who pay with their money hard earning but get low value for their money [6].

The question that arises now is: what should be done to ensure that this menace of the influx of substandard renewable energy technologies into the country is checked and how can a renewable energy standard be developed in Nigeria. This study seeks to answer the research questions by first reviewing the renewable energy resources in Nigeria, identifying the barriers to its development, provides strategies to enhance its development and then discusses on the development of renewable energy standards. The remainder of this paper is organized as follows. Section 2 reviews the renewable energy potentials in Nigeria including the policies, barriers and strategies to enhance its development. The concept of standardization is given in Section 3 which also includes the roles of standards and the standards regulatory agency in Nigeria. Section 4 discusses the development of renewable energy standards in Nigeria while conclusions are provided in Section 5.

2. Renewable Energy Resources in Nigeria

The global mindfulness of the phenomenon of climate change along with the anticipation of conventional energy scarcity have prompted many countries to develop a more sustainable energy system to cater for economic development and growth. Clean and environmental friendly energy can only be achieved through the proper utilization of renewable energy technology [7]. The renewable energy resources in Nigeria are as enormous as they are diverse [8]. However, the problem lies with the level of utilization which is very low. A long term commitment from the Government of Nigeria (GON) is crucial in implementing any kind of policies which will lead to renewable energy development, this can be seen in countries like Germany, Denmark, Japan and more recently, South Korea [9].

Nigeria's opportunity to improve the standard of living for its citizens, ensuring socioeconomic and political growth depends on the nation's ability to increase energy supply and proper utilization of its energy resources starting from the grassroots level [10]. Renewable energy technology has great potentials in alleviating the staggering energy situation currently being experienced in Nigeria. The potentials of renewable energy resources in Nigeria is about 1.5 times that of conventional energy resources in energy terms [11]. **Table 1** [12] shows the renewable energy resources in Nigeria and they are discussed in the following subsections. It should be noted that biomass energy was not discussed in this study because biomass energy technology includes biomass plants and therefore this study only focused on solar, wind and hydropower.

2.1. Solar Energy

Among all the renewable energy resources available, solar is the most promising of them all due to its apparent limitless potentials. The energy that is radiated from the sun is about 3.8 × 1023 KW per second and most of it is transmitted radially as electromagnetic radiation which gives about 1.5 KW/m^2 at the boundary of the atmosphere, a square meter of the earth's surface can receive solar power of about 1.5 KW which averages about 0.5 daily [13].

Nigeria is located within a high sunshine belt and solar radiation is well distributed within the country. The intensity of solar radiation exhibits remarkable variation from the northern region to the southern region but is higher in the northern region as shown in **Figure 1** [14]. With an average domestic load demand of 2324 Wh/m^2 per day [15], Nigeria has a solar radiation potential of about 6500 Wh/m^2 in the far north and 4000 Wh/m^2 in the southern part of the country. Given an average solar radiation level of about 5500 Wh/m^2, and prevailing efficiencies of commercial solar electric generators, then if solar collectors were employed to cover about 1% of Nigeria's land area of 923,773 KM, about 1850 × 103 GWh of solar electricity could be generated per year [16] [17].

The Energy Commission of Nigeria (ECN) has made some effort to harness the solar energy within Nigeria through the direct coordination of research and development activities undertaken by the Sokoto Energy Research Center (SERC) and the National Center for Energy Research and Development (NCERD) [18]. However, this effort has seen little or no significant impact in improving the energy situation in Nigeria. There is need for a strong industrial infrastructure which will be effective in the complete utilization of solar energy in Nigeria.

2.2. Wind Energy

Wind is a natural phenomenon related to the movement of air masses caused primarily by the movement of air masses caused primarily by the different solar heating of the earth's surface. Seasoned variations in the energy received from the sun affects the strength and direction of the wind. The ease with which aero turbines transform energy in the moving air to rotary mechanical energy suggest that the use of electrical devices to convert wind

Table 1. Renewable energy resource in Nigeria (source: [12]).

Resource type	Reserves		Production	Domestic utilization (natural units)
	Natural units	Energy units (Btoe)		
Small hydropower	3500 MW	0.34 (over 40 years)	30 MW	30 MW
Large hydropower	11,250 MW	0.8 (over 40 years)	1938 MW	1938 MW
Wind	2 - 4 m/s at 10 m height (mainland)	0.0003 (4 m/s@12% probability, 70 m height, 20 m rotor, 0.1% land area,40 years)	-	-
Solar radiation	3.5 - 7.0 kWh/m^2/day (4.2 million MW h/day using 0.1% land area)	5.2 (40 years and 0.1% land area)	6 MW h/day	6 MW h/day
Biomass fuel wood	11 million hectares of forest and wood land excess of 1.2 m ton/day	-	0.120 million ton/day	0.120 million t/day
Animal waste	211 million assorted animals waste	-	0.781 million ton of waste/day	None
Energy crops and agricultural residue	28.2 million hectares of arable land (=30% of total land)	-	0.256 million ton of assorted crops/day	None

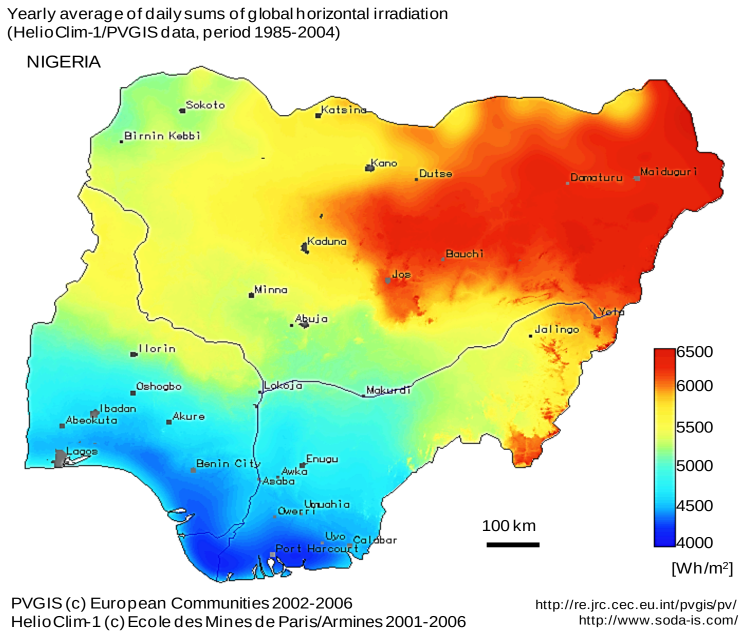

Figure 1. Yearly average of daily sun in Nigeria (source: [14]).

energy to electricity. For decades, wind has been used for water pumping and milling of grains [1].

Wind speed in Nigeria ranges from 4.0 to 6.0 m/s in the northern part of the country and 2.5 to 4.0 m/s in the southern part of the country as shown in **Figure 2** [19]. With this amount of wind energy potential, small scale wind turbine could be installed to boost electricity supply and also be integrated into the national grid [8].

Despite Nigeria's exploitable wind energy resources, the present share of wind energy in the national energy consumption has been low with no available commercial wind farms but only standalone wind power plants for pumping water which were installed in 5 northern states during the 1960s. Also, a 10 MW wind turbine is currently installed in Katsina state to tap into the wind energy potentials in northern Nigeria. More effort should be put in to adequately harness the wind energy potential in Nigeria.

2.3. Hydropower

Hydropower generation is an important option to meet the growing demand for energy worldwide. In 2004, the world hydropower capacity was 2810 TWh and is projected to increase to 4903 TWh by the year 2030, with a growth rate of 1.8% per year, but its share still remains at 2% of the world energy supply [19]. Hydropower resources in Nigeria was first harnessed in 1962 by the Niger Dams Authority. Hydropower generation in Nigeria has substantial potential like the small, mini and micro water capacity for electricity generation but its total power contribution has declined in recent years due to some technical reasons [20]. Moreover, the use of oil and gas for power generation has had a negative impact on hydropower development in Nigeria [21].

Notwithstanding, small hydropower (SHP) is fast gaining rapid consideration due to its inherent advantages like in-excessive topography problems, low environmental impact, minimal civil works and high possibility for power generation along with irrigation and flood prevention. Research has been conducted by [22] and shows that about 738 MW of SHP could be harnessed from 278 sites based on the 1980 survey. However, the SHP potential in Nigeria is estimated at 3500 MW which represent about 23% of the total hydropower potential in the county.

Hydro capacity depends mainly on annual rainfall levels, with its distribution as well as the river systems which is subject to seasonal drought. In the northern part of Nigeria, the total rainfall is about 500 mm depth with a total precipitation which last for 3 months in a year while the southern part of the country has 3400 mm with a precipitation which may be less than 8 months a year [23]. **Figure 3** shows the various water ways in Nigeria [24]. The government should do more to develop SHP to its full extent in order to improve power generation and reduce fiscal loads.

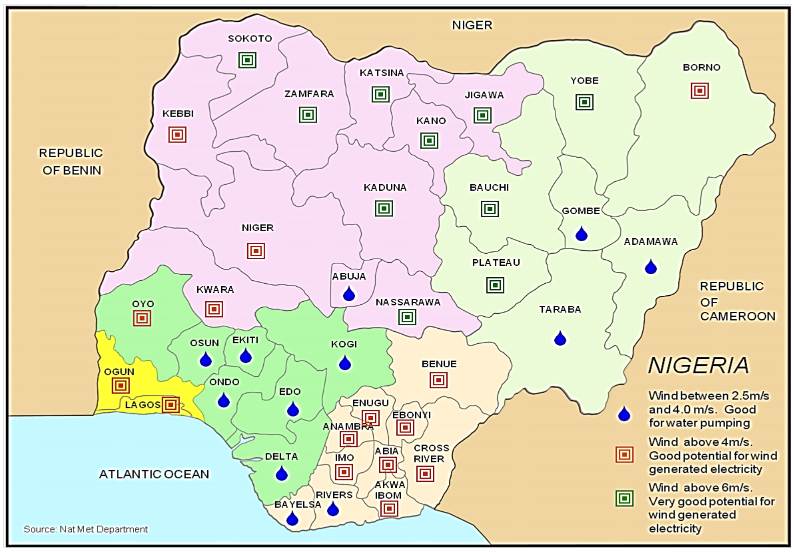

Figure 2. Wind energy locations in Nigeria (source: [19])

Figure 3. Nigerian water ways (source: [24]).

2.4. Renewable Energy Policy

The Energy Commission of Nigeria (ECN) has a mandate as an agency to develop and promote renewable energy technologies in Nigeria with strategic energy planning, policy coordination and performance monitoring for the entire energy sector. The ECN also has the responsibility of providing guidelines for the utilization of the various energy types for the different purpose and develop recommendations on new exploitable sources of energy. This includes renewable energy [25].

The Federal Government of Nigeria (FGN) in 2003 approved the National Energy Policy (NEP) which was facilitated by the ECN to articulate the sustainable exploitation and utilization of all energy sources. The key elements of the NEP on the development and utilization of renewable energy and its technologies are as follows:

- To develop, promote and harness the renewable energy resources of Nigeria and incorporate all viable ones

in the national energy mix;
- To promote decentralized energy supply, especially in rural areas, based on renewable energy resources;
- To deemphasize and discourage the use of wood as a fuel;
- To promote efficient methods in the use of biomass energy resources;
- To keep abreast of the international development in the renewable energy technologies and applications [26].

In 2006, the ECN also formulated the Renewable Energy Master Plan (REMP) as part of the strategy to reduce Greenhouse Gas (GHG) emission in Africa and address the challenges hindering the development of clean, reliable, secured and competitive energy supply [27] [28]. The REMP main objectives are given below:
- To develop and implement strategies that will achieve a clean reliable energy supply mechanism to develop the sector based on international best practices, to show case viability for private sector participation;
- To provide a comprehensive framework for developing renewable energy that will ensure:
  - Expanding access to energy services to Nigerians;
  - National agenda on emission reduction;
  - Raising the standard of living, especially in the rural areas;
  - Stimulating economic growth, employment and empowerment;
  - Increasing the scope and quality of rural services, including schools, information, health services, entertainment, and water supply and reducing rural urban migration [29].

The REMP aims at a 10% renewable energy contribution to the national energy mix by 2020 through the adoption of a renewable portfolio standard (RPS). A RPS is a requirement for electric utilities to supply a specific amount of electricity to customers. This can be achieved through the purchase of renewable energy certificates from suppliers with a larger share of renewables in their energy mix. Other measures considered are the creation of innovative fiscal and market incentives to promote renewable energy industries, as well as preferential customs duty exemptions for imported renewable energy technology components. However, the lack of implementation of the master plan has meant that the 10% target of renewable energy mix in the energy supply cannot be achieved. The REMP is presently being subjected to a review, likely resulting in the setting of new targets. It will be essential that any future targets set for the attainment of a RE energy mix should be backed by legislation to ensure compliance, which is presently lacking.

Similarly, the National Policy and Guidelines on Renewable Electricity (NPGRE) was produced in 2006 with the main aim to expand the market for renewable electricity by 5% of the total electricity generation by 2016. The strategy for achieving this target included: encouraging local manufacture and assembly of renewable energy components, provision of subsidies, and establishment of technical standards for RE components and introduction of feed-in-tariffs. The strategy is yet to be fully adopted as the reforms in the energy sector are still ongoing and decisions on tariffs and subsidies for renewable energy and other incentives have not yet been taken [8].

2.5. Barriers to Renewable Energy Development

Renewable energy in Nigeria has been inconsistent with minimal or no significant impact in the lives of Nigerians. Many barriers hinder the development and diffusion of renewable energy in Nigeria, including the following [30]:
- The lack of proper institutional framework which is due to the weak coordination between government ministries and agencies. These institutions are responsible for the promotion and development of renewable energy technologies in both the rural and urban areas;
- Low human capacity in the field of renewable energy development. Capacity building in the areas of training to install, operate, maintain and manufacturing of renewable energy is lacking in Nigeria;
- Non-existing Power Purchasing Agreements (PPA) plan for renewable energy generation to the utility grid. The PPA set the terms in which electricity is marketed and determines the delivery location, power characteristics, pricing, quality, schedule and terms of agreements including the punishment for breach of contract;
- Affordability of renewable energy technologies involves high cost of capital as compared to conventional energy. This has posed a lot of problems to investors who face the problem of high transaction costs and restricted to funds or capital. Consumers on the other side also face difficulty in purchasing these technologies because of its expensive cost of purchase;
- The lack of public awareness has negatively affected the development of renewable energy in Nigeria. Most

Nigerians view renewable energy technologies as new technologies that are only for the wealthy in the society. This has made the most of the population who are low income earners to depend on conventional energy which is cheaper;
- Uncertified/poor quality renewable energy technologies now flood the markets in Nigeria. This has led to the withdrawal of most potential consumers because most renewable technologies easily damaged due to their low quality and the replacement parts or services usually cost a lot to obtain. Nigeria presently lack the proper standards in renewable energy technologies.

2.6. Strategies to Enhance Renewable Energy Development

As Section 2.5 highlighted the barriers to renewable energy development, this section will offer some strategies which will promote renewable energy development in Nigeria:
- Placing subsides on renewable energy technologies and also improving access to micro finance loans by potential consumers;
- The government should do more in the area of public awareness campaign to promote renewable energy technologies;
- Research and development in the area of renewable energy should be encouraged. This will enable the growth of human capacity and ensure that the technologies which are mostly imported can be manufactured in the country;
- A legally binding long term Power Purchase Agreement plan should be established in order to encourage developers of renewable energy. Also, other renewable energy development mechanisms like Feed-in-Tariffs (FiTs), Renewable Obligation (RO), Renewable Energy (green) Certificate (REC) and Renewable Portfolio Standard (RPS) should be initiated to facilitate the adoption of renewable energy technologies in Nigeria;
- Development of Renewable Energy Standards by the Standards Organization of Nigeria to check the influx of substandard renewable energy technologies into the country.

3. Standardization

The process of establishing and applying standards, standardization is defined by the International Organization for Standardization as "the process of formulating and applying rules for an orderly approach to a specific activity for the benefit and with the cooperation of all concerned, and in particular for the promotion of optimum overall economy, taking due account of functional conditions and safety requirements". Standardization can be applied to specific products, as well as to, for example, norms, requirements, methods, terms, and designations commonly used in international trade and in science, engineering, industry, agriculture, construction, transportation, culture, public health, and other spheres of the national economy [31]. Standardization has a significant influence on the rate of development and level of production. Standardization provides the following advantages:
- Better product quality, reliable and durable life service;
- Components or parts mass production at a low cost;
- Availability of parts for replacement and maintenance;
- Less time and effort (productivity is high) for manufacture;
- Sizes and grades variations correction.

The concept of standardization uses numbers to limit unnecessary variations in sizes and grades of products, the general requirements indicates that such requirements are satisfied when it follows a geometric series. In international business, standards are applied to penetrate the markets in such a way that the products are made to fit into the requirements of any country. To do so, the need to follow the internationally recognized guidelines arises. Examples of products standard includes fuel economy and airbag specifications.

3.1. Definition of Standards

A "standard" can be defined as a specification (or a set of specifications) that relates to a product's attributes [32]. The International Organization for Standardization (ISO) defines standards as "a document, established by consensus and approved by a recognized body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context" [33]. In the WTO, definition for standards differentiates voluntary standards and technical regulation, where standards are voluntary and technical regulations mandatory with administrative provisions [34].

The IRENA defines standards as "a repeatable, harmonized, agreed and documented way of doing something. Standards contain technical specifications or other precise criteria designed to be used consistently as a rule, guideline, or definition. They help to make life simpler and increase the reliability and the effectiveness of many of the goods and services we use" [35]. Some economists have given various definition of standards, among them are; Alfred Marshall who defined standards as "customs" that recorded technical progress, firstly in an informal manner and then in a formal manner starting in industrial era [36]. David *et al*. (1990) defined standards as "a set of technical specifications adhered to be a producer, either tacitly or as a result of formal agreement" [37]. Richard *et al*. (1995) defined standards as "agreed external points of reference to which the physical and performance characteristics of technologies can be compared" [38].

From the above literatures we can understand that standards are published documents that establish specifications and procedures designed to maximize the reliability of the materials, products, methods, and/or services people use every day. Standards address a range of issues, including but not limited to various protocols to help maximize product functionality and compatibility, facilitate interoperability and support consumer safety and public health.

Standards form the fundamental building blocks for product development by establishing consistent protocols that can be universally understood and adopted. This helps fuel compatibility and interoperability and simplifies product development, and speeds time-to-market. Standards also make it easier to understand and compare competing products. As standards are globally adopted and applied in many markets, they also fuel international trade.

It is only through the use of standards that the requirements of interconnectivity and interoperability can be assured. It is only through the application of standards that the credibility of new products and new markets can be verified. In summary standards fuel the development and implementation of technologies that influence and transform the way we live, work and communicate.

3.2. Process of Standards Development

The process of developing a standard is typically facilitated by a Standards Development Organization (SDO), which adheres to fair and equitable processes that ensure the highest quality outputs and reinforce the market relevance of standards. SDOs, such as IEEE, IEC, ISO, and others, offer time-tested platforms, rules, governance, methodologies and even facilitation services that objectively address the standards development lifecycle, and help facilitate the development, distribution and maintenance of standards. While the goals of each SDO are essentially the same, each SDO applies its own rules, processes, and terminology to the standards development process. Typically, each SDO is comprised of boards, committees and staff who establish and maintain the policies, procedures and guidelines that help ensure the integrity of the standards development process, and the standards that are generated as an outcome of this process.

The development of a new standard is typically triggered by a formal request, submitted to an SDO by a Sponsoring Body (individual or entity, such as an industry society) for review and evaluation. The SDO mandates, oversees, and helps facilitate the process for standards development. The Sponsor for the standards project assumes responsibility for the respective area of standards development, including the organization of the standards development team and its activities. Once the SDO approves the request to develop a new standards development project, the Sponsor follows the SDOs rules and processes to recruit and assemble a collaborative team or "Working Group" to engage in active standards development (note: the term "Working Group" is an IEEE term. Working Groups may be called different names by the various SDOs, and may follow slightly different processes). Working Groups are comprised of individuals and/or entities (people, companies, organizations, non-profits, government agencies) who volunteer to support the development of standards [39].

Collectively, these volunteer participants carry a specific interest in a specific area of development as producers, sellers, buyers, users and/or regulators of a particular material, product, process or service. When a Working Group is formed the Working Group officers may either be elected by the Working Group members or appointed by the Sponsor. Consult the Sponsor's policies and procedures and the Sponsor's Working Group policies and procedures for details. Working Group officers oversee the standards development project in adherence to SDO rules and process, and remain accountable to the project Sponsor and the governance structure of the SDO itself.

Based on the rules and criteria established by the SDO, participants may contribute at varying levels to the standards development process. For example, the IEEE Standards Association (IEEE-SA) has established rules related to membership and participation, and employs a separate "Entity Standards Development Process" for standards that are sponsored by entities (such as corporations, governments, non-profits, associations or other organizations, etc.). Such rules help ensure that highly dedicated individuals lead participation and no one interest dominates the standards development process. Working Groups leverage these rules and guidelines and establish their own individual, organizational, communications and meeting structures, and govern work process, activities, consensus building, decision making, balloting and even financial reporting in accordance with SDO rules. To build consensus through democratic means, participants engage in meetings, draft and review position pieces, create and review presentations, examine data and engage in active discussion and debate to resolve outstanding issues.

These activities fuel the gradual definition of each standard, which is compiled into a draft standard that may undergo multiple revisions. Once a draft standard has been finalized, reviewed, and approved by the Working Group, it is submitted to the Sponsor for Sponsor balloting. Upon successful completion of the Sponsor ballot, the draft is submitted to the Review Committee (RevCom). The balloted draft is reviewed by RevCom and then submitted to the Standards Board for approval. After submission, review and acceptance, the approved standard is published and made available for distribution and purchasing within in a number of outlets, including through the SDO itself [39] [40].

It is important to remember that standards are "living documents", which may initially be published and iteratively modified, corrected, adjusted and/or updated based on market conditions and other factors. At any given point in time, therefore, a standard may be referred to as having a number of different "status" classifications.

These include (see **Figure 4**):

- Approved Project—An initial project request is approved, in stages of group formation.
- Active Project—An active standards development project.
- Withdrawn Project—A cancelled standards development project.
- Approved Standard—The standard is approved and published for public use.
- Withdrawn Standard—The standard is no longer market relevant or active.
- Superseded Standard—The standard has been replaced by a new standard.

In keeping with the standards development lifecycle, Working Groups may also go through periodic stages of activity or dormancy. Depending on where a standard is in its lifecycle a standard may be accompanied by supplemental documents that are produced by its respective Working Group. These may include errata (which address errors in the standard), amendments (which modify sections of the standard), corrigenda (which only correct errors or ambiguities in a standard), handbooks, tutorials and other related materials. Supplemental documents help interested parties better understand and apply the standard [39].

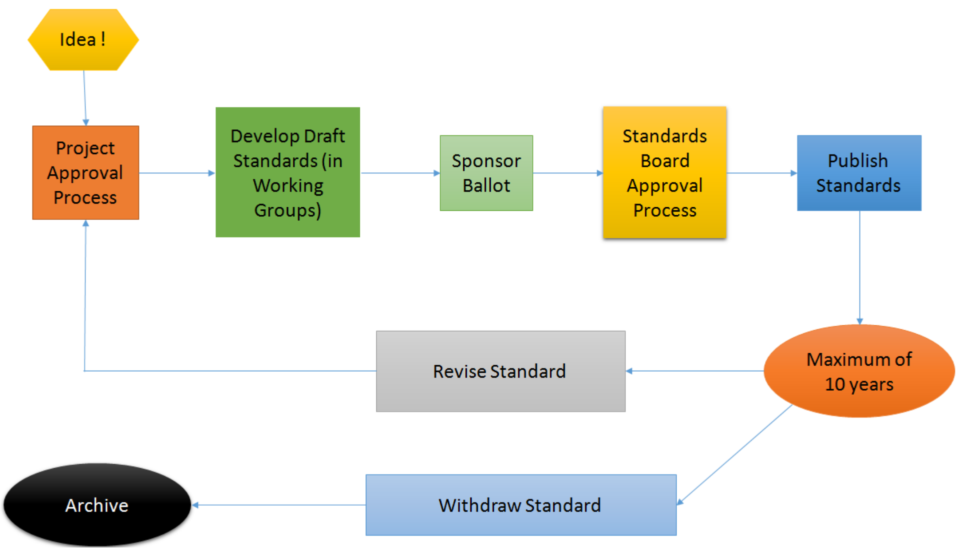

Figure 4. Process of standards development.

3.3. Roles and Functions of Standards

Standards are established through government policies or consumer protection organizations to protect the consumers of various goods and services as most consumers have little or no choice in what they are offered. In rural communities in developing countries, consumers do not generally have the luxury of comparing features and selecting their suppliers or products from the Internet. Hence, the role of standards is to ensure that whatever product or service is provided to the consumers is fit for purpose, safe and has value. An important aspect of this protection is to ensure the product or service delivers as claimed, performs as specified, and is reliable, durable and safe. In many cases renewable energy standards and conformity assessment can be the catalyst in providing alternatives to systems which are sometimes unsafe, operate with low efficiency, and use fossil fuel energy with possible detrimental effects on health. This is achieved by providing confidence and trust in renewable energy products and those who provide energy-related services. Standards also have the ability to allow those not typically trained in these energy sources to reach a level of understanding that allows them to provide, install or operate systems for themselves or under reduced supervision. This is achieved by providing guidance and best practice in designing, specifying, installing and maintaining the systems. A good example is the set of international standards for rural electrification. Standards also provide an effective framework for harmonizing information flow, understanding technical product design, manufacturing and service requirements, as well as establishing common rules and requirements. Standards should enable all these functions to take place while ensuring there is flexibility for the product, service, system provider and user [35].

3.4. The "De Facto" and "De Jure" Standards

A "de facto" standard is one created almost by default because of one dominant player in that industry. A "de facto" standard can also be described as a standard that achieved its status as a result of market competition. For example, Windows for personal computers or VHS for video cartridge recorders are typical de facto standards. A process that a product becomes a standard after it is brought to the market and exposed to competition is called the "classical model". For this instance, such case as Microsoft which maintains monopoly in the market is quite unusual. It is more common that several companies form a group, and those several groups make competition among each other and the winner is determined. A process that a winner is determined after products are brought to the market imposes a heavy burden on companies as they already have completed their capital investment. Consumers also get lost, as even if they purchased products, those styles may no longer be seen in the market some time later. A good example is that consumers felt inconvenience if they had bought video tapes of beta system for some time as they only saw those of VHS system some time later and those tapes previously bought could not be used anymore. Other de facto standards include QWERTY keyboard, Microsoft Word format for documents and Adobe Postscript languages for laser printers [41] [42].

The opposite of an informal "de facto" standard is the "de jure" standard, which means "by force of law". The de jure standards are standards that are developed after going through a certain procedure or official organization. Those standards developed by ISO or IEC are developed through a procedure that experts gather from all over the world and discuss on standardization proposals, which are finally approved through voting by national standards institutes. Japan's standards JIS are also developed going through a procedure that JISC first deliberate a proposal and competent ministers finally make decision to incorporate the proposed standards in the JIS. Korea's Standards KS are developed by Korean Standards Association which is a public organization under the Korean Ministry of Trade, Industry & Energy (MOTIE) to carry out industrial standardization, certification, and quality promotions thereby contributing to national economy of Korea. However, de jure standards are developed through a transparent and democratic procedure. As companies bring their products to the market based on de jure standards, they do not impose excessive burden on corporations or consumers. However, development of de jure standards takes a long time. They are not suitable for products with short cycle such as IT-related products. Examples of de jure standards include Internet TCP/IP protocol, Wireless 801.11n and Unicode international character encoding [41] [42].

As a result, a new type of standards "forum standards" has been introduced recently, which adopts the positive parts of both de fact standards and de jure standards. Influential companies get together to form a standard before bringing products to the market, so that neither companies nor consumers need to take risks [41].

3.5. Standards Regulatory Agency in Nigeria

The only standards regulatory agency in Nigeria is the Standards Organization of Nigeria (SON) which was established by Act. No. 56 of 1971 which vested it with the authority for: standards elaboration, specification, quality assurance system commodities, manufactured industrial and imported products and services. The Act No. 20 of 1976 which amended the previous one conferred on the Honorable Minister of Industry the power to declare Mandatory Industrial Standards in respect of products or processes recommended by the Nigerian Standards Council.

The Act No. 32 of 1984 changed the name of the Organization to Standards Organization of Nigeria (SON) from Nigeria Standards Organization (NSO) to eliminate conflicting identity with the then Nigerian Security Organization. Finally, the Act No. 18 of 1990 conferred on SON partial autonomy from the Ministry of Industry. This amendment gave far-reaching transformation to the organization succession and a common seal, and may sue or be sued in its corporate name. The statutory functions of Standards Organization of Nigeria by Section 3, subsections (1) of 1971 Act No. 56 are as follows:

- To organize test and do everything necessary to ensure compliance with standards designated and approved by the council;
- To undertake investigations as necessary into the quality of facilities, materials and products in Nigeria, and establish a quality assurance system including certification of factories, products and laboratories;
- To ensure reference standards for calibration and verification of measures and measuring instrument;
- To compile an inventory of products requiring standardization;
- To compile Nigeria Industrial Standards;
- To foster interest in the recommendation and maintenance of acceptable standards by industry and the general public;
- To develop method for testing of materials, supplies and equipment including items purchased for use of departments Government of the Federation or State and Private establishment;
- Register and regulate standard marks and specification;
- To undertake preparation and distribution of standard samples;
- To establish and maintain such number of laboratories or other institutions as may be necessary for the performance of its functions under this Act;
- To compile and publish general scientific or other data:
- Resulting from performance of its function under this Act; or
- From other sources when such data are of importance to scientific or manufacturing interest or to the general public and are not available;
- To advise departments of government of the Federation or state on specific problems relating to standards.

Nigeria represented by SON is a member of following International Standards Bodies:

- International Organization for Standardization (ISO);
- International Electrochemical Commission (IEC);
- African Organization for Standardization (ARSO).

Presently, Nigeria (SON) is a member of the International Organization for Standardization (ISO) with Participating (P-Member) and Observer Member (O-Member) in various Technical Committees (TC) and Project Development Committees (PDCs) [43]. Among all the standards available in the SON, there is none that is responsible for the standards of renewable energy technologies as at present. However, the next section describes a developmental process in which a renewable energy standard could be formulated and adapted by the SON.

4. Development of Renewable Energy Standards

Currently, the SON maintains 33 Standing Technical Committees (TC) which also have sub technical committees that deals with specific issues. The various TC usually creates a forum wherein the various experts are harnessed in the development of standards. A draft standard is usually prepared by the SON Technical Officers in the Organization depending upon the priority or work programme of the directorate and on the need or demand from the stakeholders. The officers, thereafter collect the relevant scientific data related to the draft standard under development from technical literatures including journals, laboratory tests results and factory inspections among others. The draft is then sent out to the TC members for review. The comments are received and collate the and the meeting of the relevant TC is held to review the comments and evaluated all quality parameters being prescribed are accepted by consensus to be adequate for approval by the Nigeria Standards Council or in its absence the Honorable Minister of Supervision Ministry of the Standards Organization of Nigeria, Approval of

National Standards. The responsibility of authorization of National Standards as per the Act establishing SON is vested in the Organization's Governing Council also referred to as Nigeria Standards Council. In absence of the Council, the Honorable Minister, Federal Ministry of Trade and Investments has the responsibility to approve a standard for use. Apart from development of new standards, existing standards are revised or reviewed so that the outdated matches with the current quality parameters. The procedure for review of standards is the same with that of drafting new ones. Standards are reviewed after three years, if there is technological development in the sector concerned or where inadequacies are observed. When standards reviewed and are no longer relevant for the purposes they were developed are withdrawn [43].

As earlier discussed in this study, the SON does not have any form of standards for renewable energy technologies present. However, development of renewable energy standards would be a welcomed development. The testing and proper certification of renewable energy equipment for off-grid or small scale application will still face some challenges. These challenges could come from the political class or importers who import substandard products into the country. Most renewable energy products are imported from China into the Nigerian market without proper product certification. Some of the imported technologies include solar panels, inverters, energy storage systems, small hydropower (SHP) units and wind turbines.

The deployment of renewable energy depends on some issues which are external to standards like Feed-in-Tariffs (FiTs), planning, environmental factors, building regulation and economic development. Standards will be used along with various policies, certification and regulation to open up renewable energy market.

Developing renewable energy standards involves high cost and is time consuming, this has hindered actors from participating in the process of renewable energy standards development. Development of renewable energy standards can be achieved if the SON collaborate with the ECN and other relevant bodies in engaging more external stakeholders who will make use of reports, case studies, research articles and various workshops to ensure that proper standards are developed for renewable energy technologies. These activities will improve the mix of experts that will in turn improve the quality of the standards under development. The SON will need to increase its TC to accommodate experts in the field of renewable energy. The SON should also engage specific projects related to renewable energy standards development as well as promote knowledge dissemination in renewable energy technologies.

4.1. Cost of Standards

Some challenges are faced by standard bodies in the developing countries is have the right standards in the first place and to have access to purchase the standards and also to keep them up to date. The cost implications for the standard organizations in the developing countries and emerging markets can make the difference between adopting the already existing internationally developed standards, producing local requirements or the complete rejection of the standards. The cost of standards may be seen as a barrier to the adoption of standards, but in the case of Nigeria, it should be seen as means to ensure that her citizens are protected from poor quality renewable energy technologies manufactured with the best practice of standardization. However, some recommendations for small renewable energy and hybrid systems are provided in **Table 2** for rural electrification (see [35]).

4.2. Recommended Standards for Renewable Energy Technologies

Below are some recommended standards currently available through the International Organization for Standardization (ISO). These recommended standards should be used as an immediate measure to address the issue of substandard importation of renewable energy technology.

- **ISO/TC 180 Solar Energy**

Standardization in the field of solar energy utilization in space and water heating, cooling, industrial process heating and air conditioning.

- **IEC/TC 82 Solar Photovoltaic Energy System**

Includes the entire field from light input to a photovoltaic cell to and including the interface with the electrical system(s) to which energy is supplied.

- **IEC/TC 88 Wind Turbines**

These standards address design requirements, engineering integrity, measurement techniques and test procedures. Their purpose is to provide a basis for design, quality assurance and certification. The standards are concerned with all subsystems of wind turbines, such as mechanical and internal electrical systems, support struc-

Table 2. Recommendations for small renewable energy and hybrid systems for rural electrification [35].

Standards No.	Standard Name	Cost of Standards (USD), [Cost in NGN]*
IEC/TS 62257-9-1	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 9-1: Micro-power systems	252.31 [41441.58]
IEC 60364 (all parts)	Low-voltage electrical installations Note: All parts would equate to 32 standards documents	4284.00 [703641.27]
IEC 60364-5-53:2001 included in all parts above	Electrical installations of buildings—Part 5-53: Selection and erection of electrical equipment—Isolation, switching and control	Not Available**
IEC 60529	Degrees of protection provided by enclosures (IP Code)	262.50 [43115.27]
IEC/TS 62257-2:2004	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 2: From requirements to a range of electrification systems	283.22 [46518.51]
IEC/TS 62257-4:2005	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 4: System selection and design	188.81 [31011.79]
IEC/TS 62257-5:2005	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 5: Protection against electrical hazards	188.81 [31011.79]
IEC/TS 62257-6:2005	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 6: Acceptance, operation, maintenance and replacement	94.41 [15506.72]
IEC/TS 62257-7-1:2006	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 7-1: Generators—Photovoltaic arrays	293.71 [48241.47]
IEC/TS 62257-7-3:2008	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 7-3: Generator set—Selection of generator sets for rural electrification systems	209.79 [34457.73]
IEC/TS 62257-9-2:2006	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 9-2: Micro-grids	251.75 [41349.6]
IEC/TS 62257-9-4:2006	Recommendations for small renewable energy and hybrid systems for rural electrification—Part 9-4: Integrated system—User installation	25.87 [4249.11]
	Total	**6435.18 [1056969.7]**

Note: *NGN means Nigerian naira. The currency conversation was made on 4th October, 2014; **The cost information was not available at the time of publication.

tures and control and protection systems. They are intended to be used together with appropriate IEC/ISO standards.

- **IEC/TC 4**
  Hydraulic rotating machinery and associated equipment allied with hydro-power development.
- **ISO/TC 238 Solid Biofuels**
  Standardization of terminology, specifications and classes, quality assurance, sampling and sample preparation and test methods in the field of raw and processed materials originating from arboriculture, agriculture, aquaculture, horticulture and forestry to be used as a source for solid biofuels. Excluded: areas covered by ISO/TC 28/SC 7 Liquid biofuels, ISO/TC 193 Natural gas.
- **ISO/PC 248 Sustainability Criteria for Bioenergy**
  Standardization in the field of sustainability criteria for production, supply chain and application of bioenergy. This includes terminology and aspects related to the sustainability (e.g. environmental, social and economic) of bioenergy.
- **ISO/TC 255 Biogas**
  Standardization in the field of biogas.

4.3. Recommendations to Standards Organization of Nigeria

The Standards Organization of Nigeria which is the standard body in Nigeria will need to make some adjustment to its policy in order to protect the citizens of Nigeria from the influx of poor quality renewable energy products into the country. Some recommendations are given below:

- Develop standard compliance cooperation with foreign countries where most of the renewable energy products are manufactured;
- Development of renewable energy standards with the cooperation of international standard bodies in the field of renewable energy;
- Promote the training of experts through development programmes, constructing standard databases, designating a permanent agency or commission for the promotion and implementation of renewable energy product standard;
- Implement laws for the promotion of renewable energy standardization plans, organization, budget and human resource development;
- Revise a number of laws and articles to ensure that renewable energy standardization is embedded in the political framework;
- Ensure that each renewable energy product imported into the country by an importer are given After Sales Service (ASS) for up-to 5 years from the time of purchase to the consumer.

5. Conclusions

For sustainable energy to be achieved in any country, clean energy development has to be a national priority. The issues of climate change have alerted most governments around the world to mitigate global warming by moving towards renewable energy adoption and incorporation into their energy mix. The manufacturing of renewable energy technologies like solar panels, solar thermal, inverters, energy saving systems, various kinds of wind turbines and hydropower systems has increased in recent times. Most countries like South Korea, Japan, China and the US manufacture these renewable energy technologies according to their own specification and standards and export it to other countries that do not have the technical expertise or resources to produce theirs. While this may sound good, some countries do manufacture substandard renewable energy technologies and export it to developing countries that may not have proper standards bodies to check the imported products into their market.

Nigeria has abundant renewable energy resources but do import the technology which is able to harness the renewable energy potential. These technologies are usually substandard and are dangerous to her citizens. This study has discussed the necessity of the development of standards for renewable energy technology which is imported, stressed the need to develop local content in the field of renewable energy and given some recommended standards that could be applied. Nigeria has a standard body which is the Standards Organization of Nigeria (SON) but no standards have been made available for renewable energy technologies. However, the country depends on standards set by other countries that export the technologies.

However, some immediate measures should be put in place by the SON to protect Nigerian citizens from the various substandard renewable energy technologies which include solar panels, inverters, and energy-saving systems. As an immediate measure, the SON should ensure that the technologies which are imported into the country are checked for international standards which are usually granted by International Electrochemical Commission (IEC) and also apply the given recommendation in this study. This will stop the influx of substandard renewable technologies while the SON develops its own standards.

This study strongly believes that the development of standards for renewable energy technologies is of great importance to secure the citizens of Nigeria and also to fast track the development of renewable energy in Nigeria. The study focused on the necessity for the development of standards for renewable energy technologies and recommended some standards but did not propose any standards. Thus, more studies should be undertaken to come up with a proper standard that can be submitted to the SON.

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Solar Energy Generation Potential Estimation in India and Gujarat, Andhra, Telangana States

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Abstract

It is well known that the rampant increase for the demand of electricity and rapid depletion of the fossil fuels has called for immediate response in the direction of energy sufficiency. To accomplish this, one of the important tasks is to identify the locations of high potential for renewable energy generation. It is a well-established fact that solar energy proved to be the most sought after source for energy generation. Although, solar energy potential maps of India have been prepared based on solar irradiation maps in the earlier studies, the present research study has been carried out with a focused attention directly on solar energy generation considering various parameters. In this work it is shown that solar energy generation does not depend on solar radiation alone at a location. Instead, there are various other factors that influence the energy generation. Some of them are ambient temperature, wind velocity and other parameters like weather and topographic conditions. In this study the locations with high and low solar energy generation potential in India have been identified through systematic analysis by computing the solar energy parameters at every grid point ($1^\circ \times 1^\circ$). The work has been extended with more detailed study for Gujarat, Andhra Pradesh and the newly formed Telangana states. The data points considered for the states are $0.25^\circ \times 0.25^\circ$ having resulted in adding more number of locations. Our results indicate that the total annual energy generation in India varies from 510,000 KWH to 800,000 KWH per acre of land. The least energy generation location pertains to the eastern parts of Arunachal Pradesh and eastern part of Assam and the highest annual solar energy generation has been identified in the eastern parts of Jammu & Kashmir and eastern part of Uttarakhand.

Keywords

Solar Energy, Estimation, Financial Benefits, Gujarat, Andhra Pradesh, Telangana, India

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1. Introduction

Solar energy incident on the Earth's surface also known as insolation, is dependent on many parameters such as geographic location, earth-sun movements, tilt of earth's rotational axis, atmospheric parameters, suspended particles etc. Quantification of solar energy potential in any region depends mainly on the intensity of insolation [1]. The grid-tied renewable energy from the installed PV capacity is around 6% in India [2]. The solar insolation of India is very much encouraging. The daily global radiation on an average is around 5 KWH per square meter per day and in a year the sunshine ranges from 2300 to 3200 hours [2]. Another advantage is that India lies in an ideal geographical location between the equator and tropic of cancer and has an average annual temperature ranging from 25˚C to 27.5˚C. All these advantages can be effectively and strategically used if we can identify the locations of high potential solar energy generation. This helps to achieve the target of Jawaharlal Nehru Solar Mission which is 20 GW power by the year 2022 [3].

Among all possible alternative energy options, for example, wave energy, geothermal energy, solar energy, wind energy, and hydroenergy, solar energy is becoming more popular in India. This is mainly due to 1) the availability of plenty of sunlight in all the seasons and also at all the locations of India and 2) the initiation of solar mission by the government of India with attractive incentives to the developers [4]. If we look at the total renewable energy generation of the world, which is around 5×10^{20} J per year, solar thermal contributes to 0.5%, wind 0.3%, geothermal 0.2%, bio-fuel 0.2%, and solar photovoltaic (PV) is only about 0.04% as per statistical review of world energy during 2007 [5]. In recent years, the technology upgradation has made solar photovoltaic technology as a viable technology with competitive price. It is projected that by the year 2030, the solar PV electricity will dominate compared to other sources of energy [6]. From the study growth of photovoltaic, an average about 45% annual increase is noticed during the years 2000 to 2009 [6]. From the study of cost economics of a solar photovoltaic power plant, PV modules cost about 40% - 45% and the other 55% - 60% is due to its components [7]. Additionally, cost of the power plant also depends on the land value. If the solar power plant is close to the substation near the populated area, the transmission of energy losses will be minimum, but the cost of the land will be high [8]. If the power plant is at a remote location, the cost of the land is low but the energy losses will be high. On the other hand, with less population and in a remote location, the use of energy is limited to the local community. Ideally, the solar power plant needs to be located at a place where the energy generation from the plant can be connected directly to the power grid at an optimum distance from the plant. Apart from the government of India's national solar mission program, the recent initiation by the government of Gujarat to establish the solar photovoltaic plants is commendable. During 2012, while Gujarat alone crossed 600 MW power through solar, the rest of the country was far behind with only about 200 MW. The Gandhinagar Photovoltaic Rooftop Programme for solar energy generation using PV modules has set an example by government of Gujarat to save the land cost (see http://www.gpclindia.com/gpcl_rsg/index.html). Another way to save the land cost is to adopt a new methodology to get maximum output from the solar power plant in a limited area (Ref: 2 layer panel). In India, the cost of the land has grown up five to ten times for the last 10 years. This is true in all the urban and semi-urban regions of India.

There are many places in the world still suffering to use the electricity for their needs. It is reported that many islands around the world are facing acute shortage of electricity. For instance, Papua New Guinea, Fiji islands, Ports of Andaman & Nicobar and Lakshadweep islands in India are some of the examples. Major electricity generation in these islands is based on using diesel generators, for which diesel oil needs to be transported from nearby main land to these islands [9]. For effective use of renewable energy, storage and conservation are the important factors. In fact, many nations are now looking at various renewable resources available with them and plan to utilize them optimally. In this direction nations like Nigeria have taken several steps on the use of energy utilization for equipment, lighting, machines and engines in the industry and also new designs for buildings to make them energy-efficient [10]. In the same direction we have suggested earlier to use the national highways for solar energy generation by putting the solar panels at a reasonable height of 5.7 meters above the road. This helps to save the land use [11] [12]. Realizing the importance of climate change and global warming, use of renewable energy is on the rise in many countries, especially the grid-connected PV solar installations [13] [14]. For example there is a 55% increase in solar PV with a cumulative installed capacity of around 3.1 GW during the year 2005 as compared to 2 GW during the year 2004 in the world [15]. India's solar energy scenario is also following a similar growth rate for the past few years. This is mainly due to new initiatives taken by the government, for example subsidies to the developers with tax exemption. The other necessity factors are the large gap between the energy generation and demand. It is very much an evident fact that since India has entered into a phase of rapid development, the energy and in particular the electricity demand would always be on the rise as illustrated in the **Figure 1** [16]. As seen from **Figure 1**, the present (2014) electricity generation in India is close to 248 GW. If India plans to increase its rate of growth by 7% or 8% or 9%, the target energy generation also needs to be increased. By 2034 (after 20 years) our target will be 960, 1156 and 1390 GW respectively. This means the target is close to 4 to 6 times the present value. All these challenges would require meticulous planning and start with the identification of strategic locations with high energy generation potential. The present study is aimed towards this direction. Thus the main objective of this research work is to estimate the solar energy potential at different locations of India with high and low energy regions.

2. Methodology

The methodology followed in our study is through modelling. The modelling has been carried out using PVsyst, Google Earth and Surfer software programs. A brief description of these software programs is presented in the following.

PVsyst: PVsyst simulation software is a popular tool among solar energy engineering community. It is being used extensively to analyze the detailed performance of the solar plant in field conditions. It can be used in many ways, for example, to investigate different loads on the system, to estimate the size of the system, to determine the optimal size of the system, to assess the energy production in the system etc. One of the most important features of PVsyst is that the economical evaluation of the solar photo-voltaic installation can be accomplished with reasonable accuracy. Other capabilities and options available in the PVsyst software can be seen in [17]. In the present study the 6.25 version of the PVsyst software [17] has been used.

Surfer: It is graphical software that can be used for contouring the values, 2D and 3D visualization of the data. The software runs on Windows operating system. It can also be used for bathymetric, terrain modelling studies, visualization of the landscape, watershed analysis, interpolation, extrapolation, gridding, digitization etc. [18]. In the present study, this software has been used to digitize the map boundaries, creation and plotting the contour maps. In addition to these features numerous other features mostly related to extrapolation, interpolation, and other statistical algorithm do exist.

Google Earth: It is also software that can be used to visualize the imagery for the satellite maps, 3D buildings, terrains etc. [19]. It also superimposes the various images, derived from aerial photography records, satellite imagery maps having the same coordinating system. Additionally, digital elevation map can also be prepared from the data derived from SRTM (Shuttle Radar Topography Mission) of NASA [20]. One of the key features is to obtain an altitude of a location for a given geographic parameter such as latitude and longitude. Some of these parameters are used in our study.

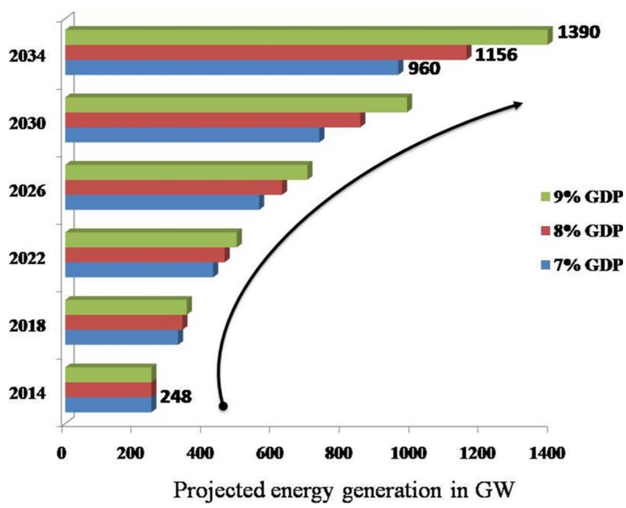


Figure 1. Projected energy generation for the next 20 years from the year 2014 until 2034. Initial energy generation is assumed as 248 GW of electricity.

3. Site Selection

Since the main objective of the study is to estimate the total solar energy potential of India, the site selection should be carried out in such a way that it effectively and uniformly covers the entire land mass of India. For this purpose, 1˚ × 1˚ grid by varying the latitude and longitude has been considered. This has rendered a total of 286 geographical locations covering the entire land mass of India. Similar method has been extended to the states of Gujarat, Andhra Pradesh and Telangana. In order to acquire high density values for individual states, the latitude and longitude has been reduced to 1/4˚ (15 arc minutes). This has been done to obtain more geographical locations that would subsequently aid in obtaining better and accurate results. Detailed computation has been carried for three states owing to the following reasons:

Rajasthan and Gujarat are the two states in India which lie in the sunny belt (>2000 KWH per Km) having bright sunlight weather for more than 250 to 300 days in a year. This way these two states receive maximum amount of annual global radiation [4] [7] [12] [21]. The newly formed states of Andhra Pradesh and Telangana are badly in need of electricity and require well directed plans aiming at energy independence.

4. The Data

In the present study grid-connected system is chosen. The basic input parameters required are PV component database, grid inverter database, geographical site information and monthly meteorological data for horizontal global irradiance and temperature. More details of the parameters are provided in **Table 1**.

The PV module chosen in the modelling is DelSolar (D6P 230 A3E). Each module has a maximum power output of 230 W. The module dimensions are 1.62 m in length and 0.99 m in width. Although the module measures 1.62 m in length an additional space of 0.05 m (5 cm approximately) has been given for easy operations, by taking mechanical aspects of the panel etc into consideration. Among the various inverters, Siemens' inverter has been chosen.

The meteorological data has been acquired from meteonorm version 6.1 (Fabrikstrasse, Bern, Switzerland) [21]. We have a choice of using meteorological data acquired from meteonorm or NASA-SSE data [22].

The meteonorm software has inbuilt database with a monthly irradiation data for 1200 stations with an average values for 20 years from 1981 to 2000. Data related to Indian region is clearly documented in meteonorm. Additionally, different European countries' data are also available. Apart from this, data for a new site can be easily derived through interpolation of values, usually carried out between three nearest stations [18]. The NASA data contains monthly average data in a region of 1˚ × 1˚ for the whole world for the years 1983 to 1993. Accordingly, the data from meteonorm data available with us is more accurate and recent as compared to NASA data. For this purpose in our study we have used meteonorm data.

Table 1. Details of the PV module and the corresponding grid inverter.

Area considered	1 acre (~=4047 Sq·m) (63 × 63 m)
Name of the manufacturer (PV module)	Del Solar
Technology (PV module)	Silicon-Polycrystalline
Pmpp	230 Wp
Impp	7.8 A
Vmpp	29.49 V
Name of the manufacturer (grid inverter)	Siemens
Nominal AC power (grid inverter)	465 kW
Total No. of PV modules in 1 acre	1944
Dimension of the PV module	L = 1.67 m (1.62 m + 0.05 m) W = 0.99 m
Active (sensitive) area of the PV modules	3129 m^2
Source of data	Meteonorm V6.1

5. Solar Panel Configuration

The area and solar panel orientation have been carried out on similar lines mentioned in the previous papers [12] [23]. The solar panels have been arranged in an area of 1 acre (4047 m^2). This can be conveniently approximated to a square with dimensions of 63 m × 63 m. The solar panels have been placed horizontally on the ground. This facilitates the accommodation of maximum number of panels. The thumb rule of solar panel placement in general states that the azimuth of the solar panel should be equal to the latitude of the place [23]. But this has been disregarded in the present work and all the panels have been placed in horizontal direction. This has been done to provide a standard and a uniform platform for energy computation throughout the present study covering the whole country. One such typical configuration is presented in **Figure 2**.

In the current study, the solar panels pertaining to the above mentioned configuration and orientation have been placed at numerous geographical locations of India considering 1 × 1 degree. For individual states, with more focused attention given to the states of Gujarat, Andhra Pradesh and Telangana considering smaller area covering 0.25 × 0.25 degree at each location. Grid locations used in our study in all the four cases, namely, India, Gujarat, Andhra and Telangana regions are shown in **Figure 3**. A total of 286 locations in India, 266 in Gujarat, 231 in Andhra Pradesh and 165 in Telangana state have been obtained. As can be seen at each location, we have computed solar energy generation for all the months and also for the annual generation. This has generated large data base of 948 locations for analysis. All these results are described in the following for each case.

6. Results

Results derived in our present study are solar energy generation at every location for each month and also the total energy for the year. All these values at each location have been considered and contouring has been carried out using gridding method. The total annual energy generation for India is presented in **Figure 4(a)** varies from 510,000 KWH to 800,000 KWH per acre of land. In **Figure 4(b)** [24], different states of India are shown. The least energy generation location pertains to the eastern parts of Arunachal Pradesh and eastern part of Assam. The highest annual solar energy generation (750,000 - 800,000 KWH/acre) potential has been identified in the eastern parts of Jammu & Kashmir and eastern part of Uttarakhand. Major part of Indian landmass has the solar energy generation potential ranging from 680,000 KWH - 730,000 KWH, among which southern parts of Saurashtra, eastern part of Rajasthan, southern part of Karnataka and western part of Tamil Nadu region have shown the average annual energy generation close to 730,000 KWH. Northern part of Rajasthan and Punjab, Haryana states and northern part of Jammu & Kashmir, West Bengal, Bihar, Nagaland, Manipur, Meghalaya and western

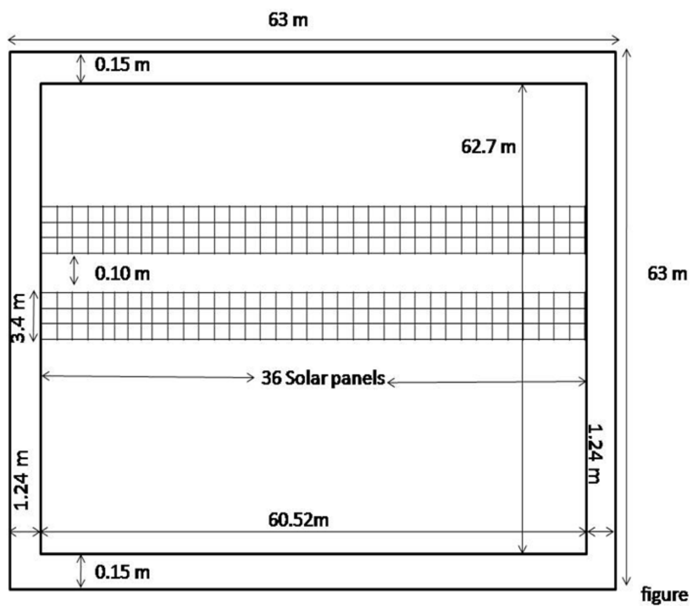


Figure 2. Typical field design of solar panels considered in one acre of land. In this design, all the panels are symmetrically arranged in a horizontal direction and giving a small area all around the land.

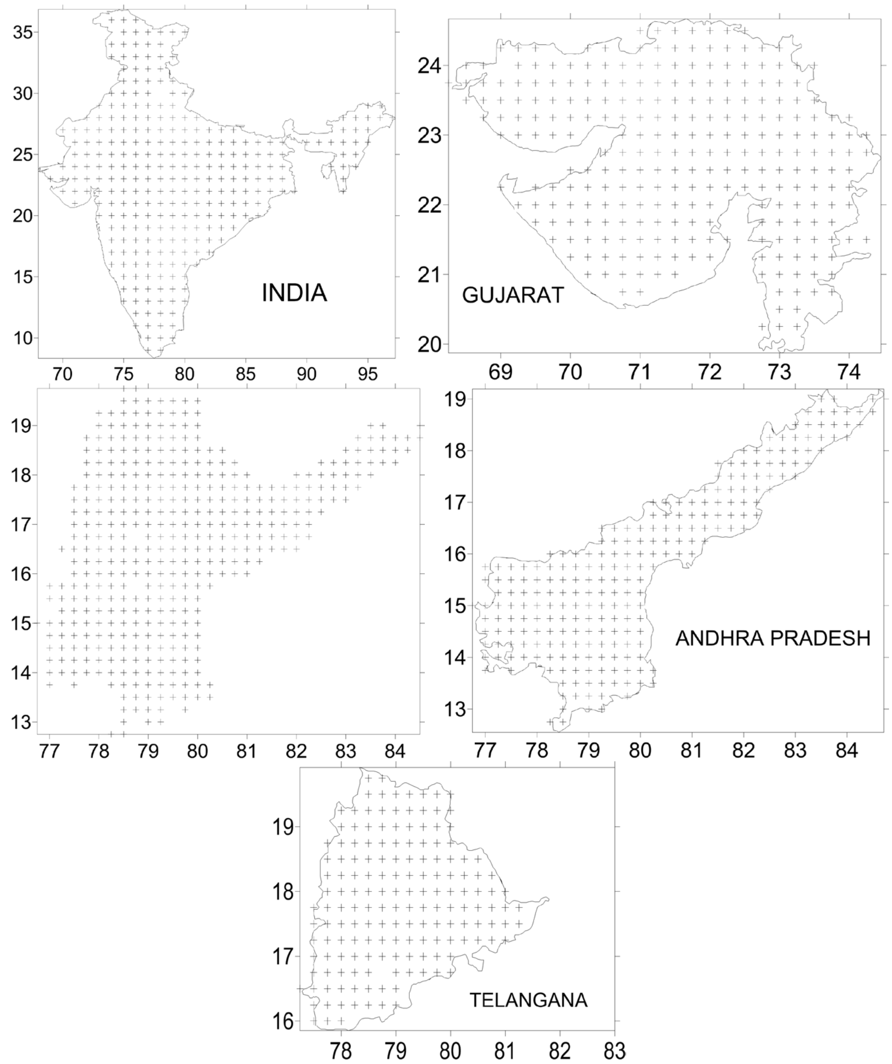
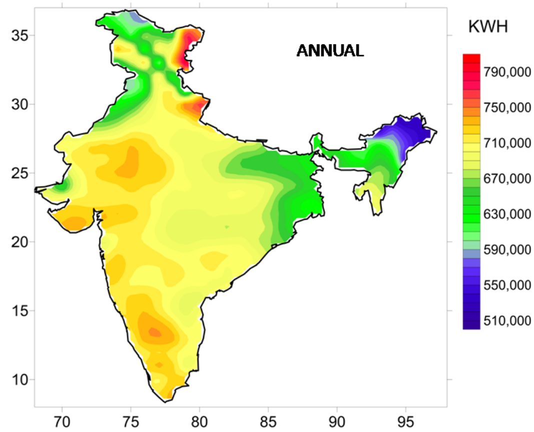


Figure 3. Data locations considered in our study. The grid locations used in our study for the entire country India (1˚ × 1˚), Gujarat, Andhra Pradesh and Telangana states (0.25˚ × 0.25˚).

part of Assam have shown average annual energy generation values ranging from 620,000 KWH - 650,000 KWH. The results derived from the present study gave a clear evidence that major portion of Indian sub-continent has substantial solar energy potential except in the area of Arunachal Pradesh & eastern part of Assam states. **Figure 5** gives the solar energy generation averaged for each month. Annual seasonal variation of weather parameters is normal in India. It is almost cyclic in each year. June to August months are considered to be monsoon months. Due to the effect of monsoon, solar radiation on the surface of the Earth decreases. This affects the solar energy generation. This can be seen clearly from **Figure 5**. The monthly energy generation picks up from the month of September. Similarly, March to May is considered as summer months. During this period, solar energy is maxima as compared to other months.

Similarly, in the state of Gujarat, solar annual energy generation ranges from 630,000 KWH to as much as 800,000 KWH (**Figure 6(a)**). Different districts of Gujarat can be seen in **Figure 6(b)** [25]. **Figure 7** shows monthly energy generation for Gujarat. The maximum solar energy generation (800,000 KWH) is limited to small area in the district of Junagarh. Interestingly, this small area has shown a near-circular shape. The reason might be attributed to the higher solar radiation received in this small area. This can be understood from the observation of the elevation map of Gujarat. This small area is located in the well-known Gir forest region where the elevation of Girnar hills is close to 1000 m. The energy generation is least in the northern part of Rann of



(a)

(b)

Figure 4. (a) Annual solar energy generation potential map for India estimated from the present study. Blue colour shows the low energy generation and Red indicates the high energy generation as shown in the Index; (b) India map showing different states.

Kutch region and northern part Kutch district. Majority of the region in Gujarat has the potential to generate energy with magnitude ranging from 700,000 KWH - 730,000 KWH. Due to low monsoon effect as compared to the rest of India, Gujarat solar energy is affected only during parts of July to August.

In the case of Andhra Pradesh state, the annual solar energy generation map, has shown a variation from 670,000 KWH - 740,000 KWH (**Figure 8(a)**). Different districts are shown in **Figure 8(b)** [26]. The least annual generation has been identified in the area of eastern part of Kurnool, northern part of Kadapa, major portion of Ongole and Guntur districts. The maximum energy potential (730,000 KWH - 740,000 KWH) is limited to the western part of Ananthapur district. The districts of Srikakulam, Vizianagarm, Vizag, east and west Godavari

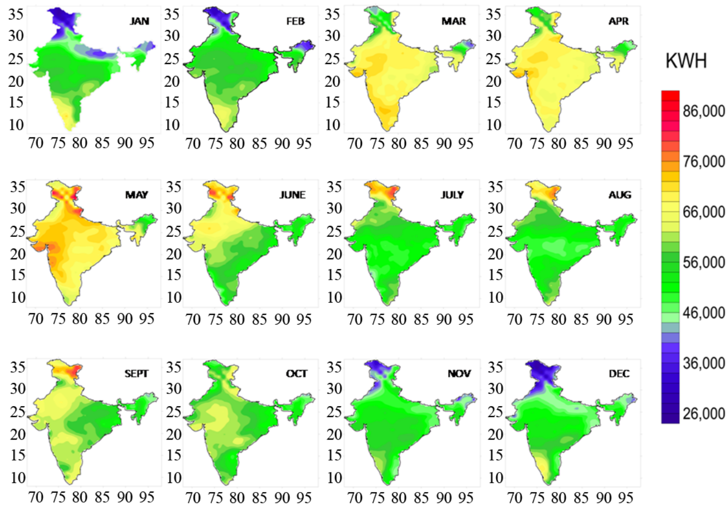
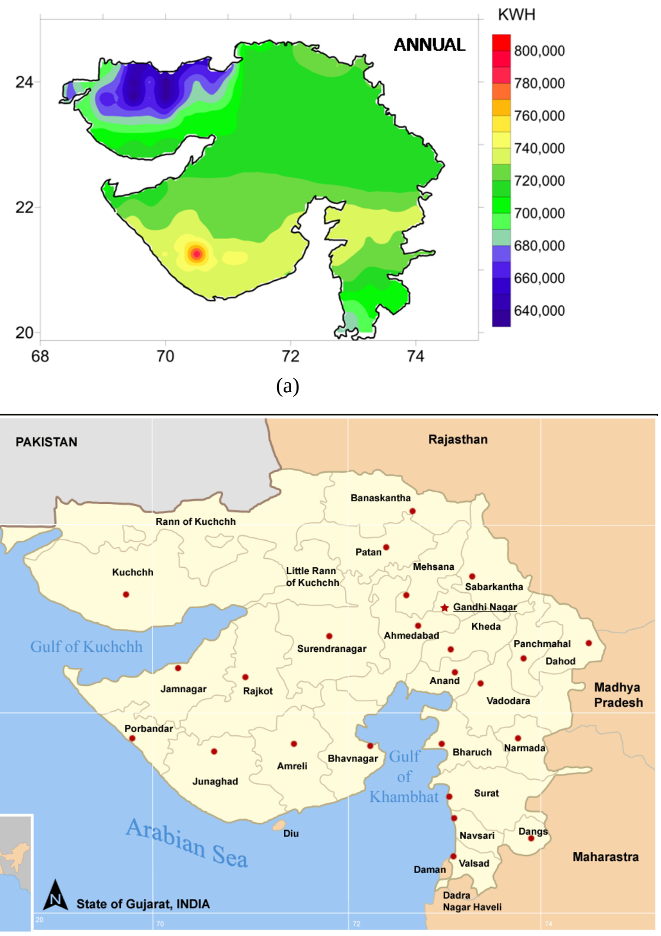


Figure 5. Solar energy generation for India, showing the variation of energy in different months. Lowest is about 26,000 KWH and the highest is close to 86,000 KWH.



(a)

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Figure 6. (a) Annual solar energy generation for the Gujarat state. Southern part of Saurashtra shows high potential compared to northern part; (b) Gujarat map showing distribution of different districts.

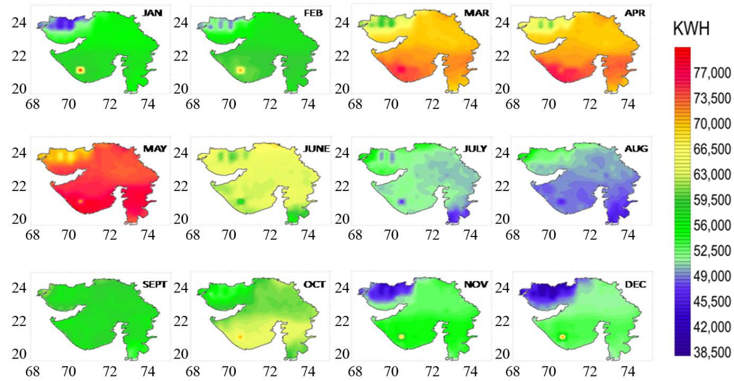
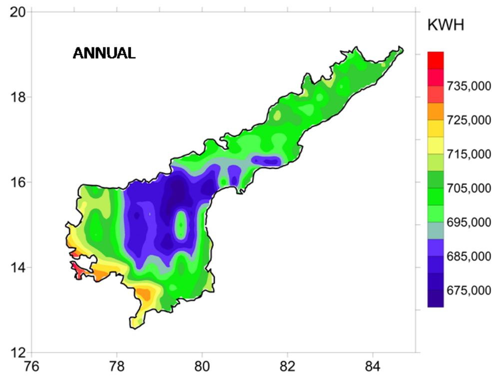


Figure 7. Monthly solar energy generation for Gujarat state, showing the variation in different months.



(a)

(b)

Figure 8. (a) Annual solar energy generation potential map for Andhra Pradesh state. Highest being about 740,000 KWH and the lowest being 670,000 KWH; (b) Andhra Pradesh map showing different districts of the two states, Andhra and Telangana.

and northern part of Krishna district have shown a variation ranging from 695,000 KWH - 715,000 KWH. Monthly variation can be seen in **Figure 9**. Due to frequent cyclonic effects, coastal districts show low energy generation during the months of October-November-December.

In the newly formed Telangana state, northern part of Adilabad district and southern part of Mahboobnagar district have the least energy generation potential ranging from 670,000 KWH - 690,000 KWH (**Figure 10(a)**). The district map of Telangana region is shown in **Figure 8(b)** [27]. The districts of Khammam and western parts of Medak seem to have the highest energy potential ranging from 715,000 KWH - 725,000 KWH. In all other districts, solar energy generation varies from 695,000 KWH - 710,000 KWH. Monthly variation can be seen in **Figure 11**. Similar to other states, Telangana region showed low energy generation during July and Aug compared to other months.

The results generated from our study are close to the results reported in earlier studies [12] [23]. For instance, in Ahmedabad district, we have shown the energy generation value close to 710,000 KWH, whereas in earlier studies, 678,574 KWH. This small variation is due to data considered in our study being meteonorm data, whereas in other studies NASA-SSE data is considered. Thus our study is close to the previous studies.

7. Discussion

An attempt has been made in our study, to estimate the solar energy generation for the whole country of India in a regional scale and more focused detailed study for three different states—Gujarat, Andhra and Telangana. It is observed that solar energy generation at a particular place does not solely depend on the solar irradiation or solar insolation. Earlier studies have made attempts in estimating the solar potential of India using solar irradiation data alone. Although the amount of solar radiation plays a significant role in energy generation, it is observed that there are other parameters which tend to influence the energy generation to a great deal [28]. Some of these parameters are ambient temperature, altitude of the place, wind velocity, weather conditions etc. The fact that weather conditions influence the energy generation can be seen from the monthly energy generation plots of India and the individual states of Gujarat, Andhra Pradesh and Telangana. It is a well-conceived fact that higher the altitude at a particular place lower is the ambient temperature. This combination of high altitude and low ambient temperature plays a crucial role in the efficient performance of the PV modules. The optimum wind velocity is also a deciding factor in the energy generation process from the view point of heat transfer.

Examination of the yearly energy generation map of India (**Figure 4(a)**) would reveal that eastern part of the states of Jammu & Kashmir and Uttarakhand which house the Himalayas have shown great potential of solar energy generation. One noteworthy remark to be made in this context is that although the radiation in these regions is low when compared to the rest of the country, the energy generation potential is high. The reason for this might be attributed to the ideal combination of solar radiation, ambient temperature and wind velocity. In **Figure 12**, the results presented in earlier sections are shown as 3D perspective diagram indicating elevated hills and valleys. Higher the elevation, greater the solar energy generation and vice versa.

From comparison of solar radiation maps of India in **Figure 13(a)** [29], and that of Germany in **Figure 13(b)**

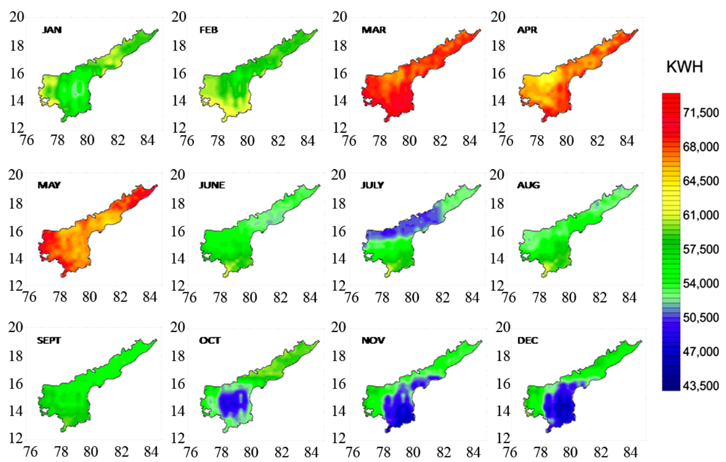
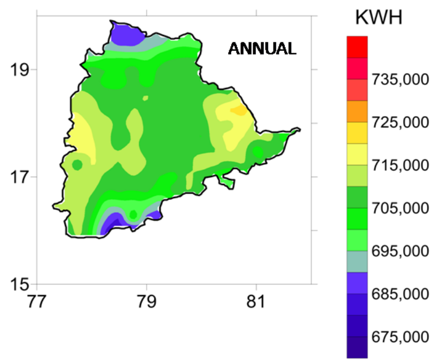
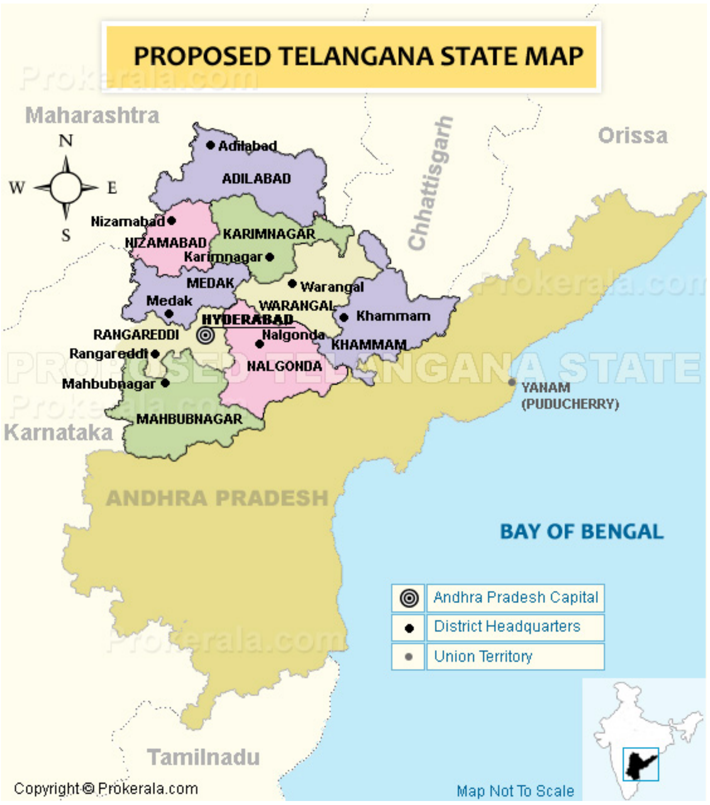


Figure 9. Monthly solar energy generation for Andhra Pradesh state, by showing the variation in different months.



(a)



(b)

Figure 10. (a) Annual Solar energy generation for Telangana state; (b) Different districts of Telangana state.

[29] offers a platform for some interesting observations. It is a well established fact that Germany is heading towards solar super power with the aid of its research and development capabilities. The solar radiation map of Germany reveals that it is making tremendous strides in solar energy generation with minimal amount of radiation it receives as compared to India. Examination of maps reveal that maximum amount of solar radiation received by Germany is approximately equal to the minimum amount of solar radiation received by India. This fact clearly lays emphasis on the abundance of resources India possesses owing to its ideal geographical location. The present day reported solar energy generation in India is close to 2.6 GW [30], whereas Germany's solar energy generation is close to 22 GW as of 25th May, 2012 [30]. From the comparison of land area between Germany and India, Indian land mass is approximately 9.2 times greater than Germany. This is another good reason to indicate that India needs to give priority in solar energy generation and formulate policies more aggressively.

Another useful result that can be drawn from our study for solar developers in India is the number of solar panels required for a fixed amount of energy generation and the cost factor involved. These results are summarized in **Table 2**. For example, in India one can generate a maximum annual energy generation ranges from

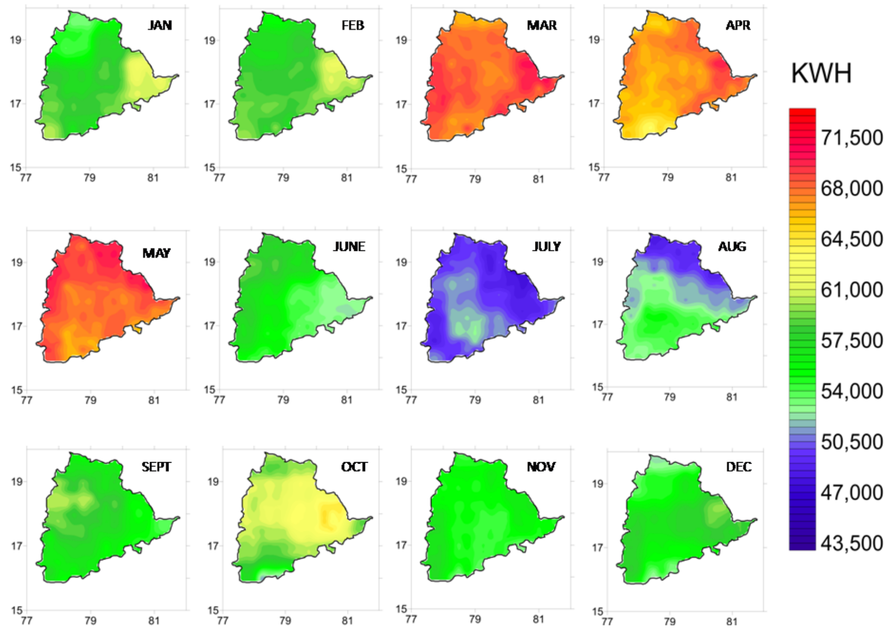


Figure 11. Monthly solar energy generation for Telangana state, showing the variation in different months.

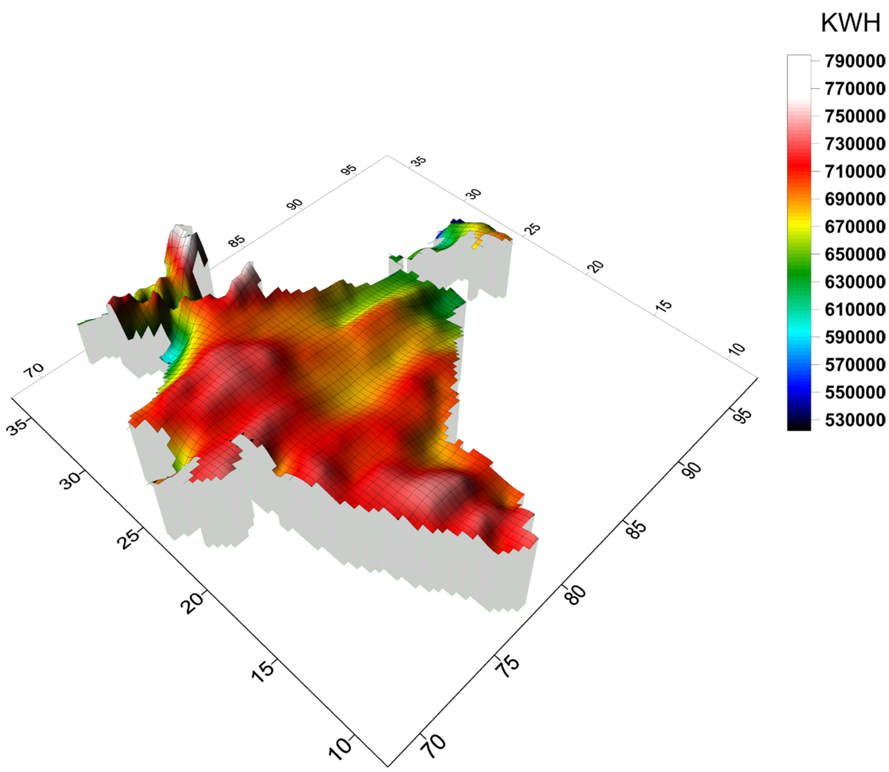
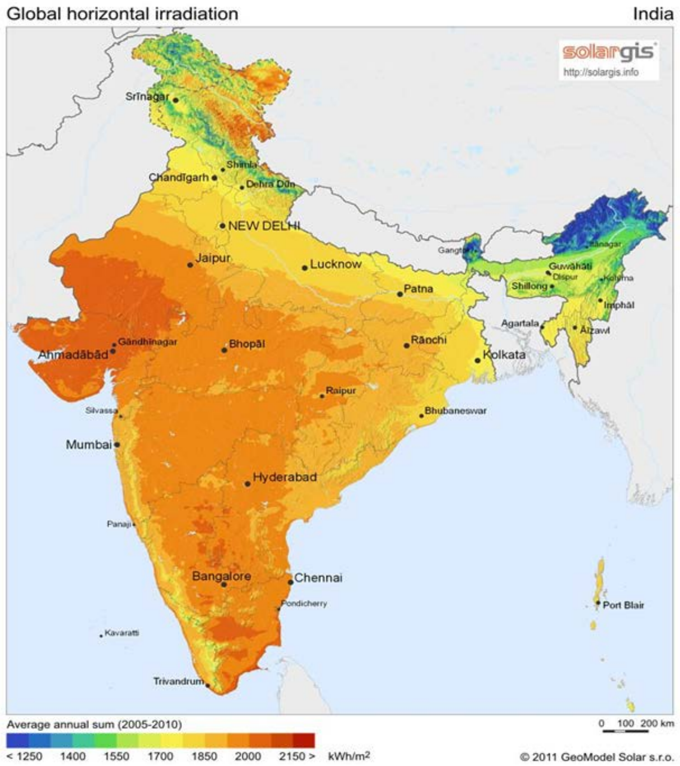
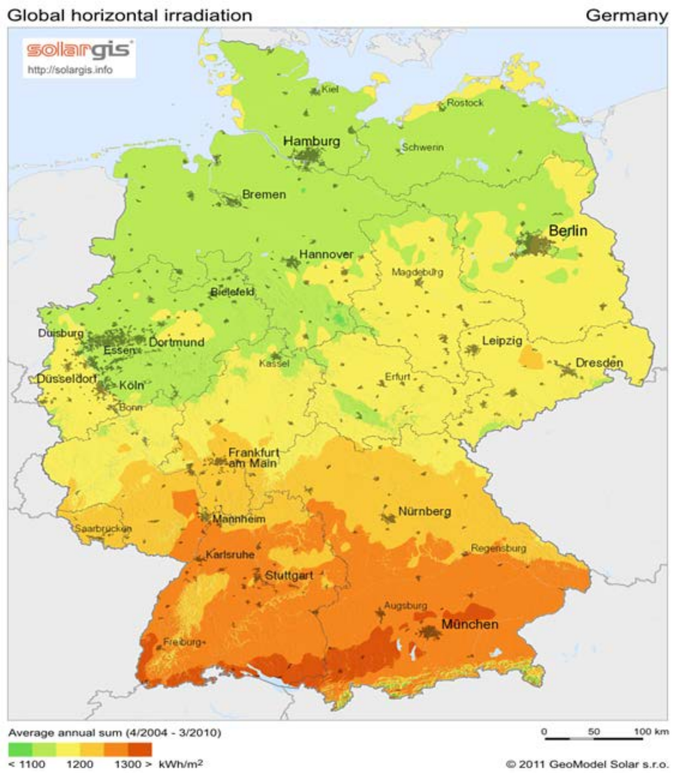


Figure 12. 3D representation of annual solar energy potential. Elevated area indicates high energy potential and the less elevated area shows low energy potential.



(a)



(b)

Figure 13. (a) Global horizontal irradiation map for India; (b) Global horizontal irradiation map for Germany (Courtesy: Geomodel Solar).

Table 2. Financial analysis keeping the target solar energy generation.

Annual energy generation in an area KWH	Annual target energy	Area of land (acres)	Number of panels	Cost of solar panels ($)	Indian rupees
800,000	800,000	1.00	1944.00	291,600	17,496,000
750,000	800,000	1.06	2060.64	309,096	18,545,760
700,000	800,000	1.43	2779.92	416,988	25,019,280
650,000	800,000	1.23	2391.12	358,668	21,520,080
600,000	800,000	1.33	2585.52	387,828	23,269,680
550,000	800,000	1.45	2818.80	422,820	25,369,200
500,000	800,000	1.60	3110.40	466,560	27,993,600

500,000 - 800,000 KWH per acre of land. In general we keep a wide gap between the rows of panels. For the sake of uniform computation throughout the country and also to estimate the maximum energy possible, we have kept the panels, as described earlier, in horizontal direction. Thus the values provided in our study are the maximum possible energy at any given location. For this type of energy generation, at a high energy (800,000 KWH) potential location, one requires 1944 panels. To achieve the same amount of energy generation in an area of 500,000 KWH potential per acre of land, one need to have 1.6 acres of land and nearly 3110 number of panels. This can be looked from the view point of financial terms as well. For example, with the assumption of 230 W solar panel cost equal to 150 $, one need 291,600 $ (nearly Rs. 1.74 crores @ 1 $ = Rs60/-) for 1944 solar panels. To achieve the same amount (800,000 KWH) of energy generation, in the low energy potential area one requires 466,460 $ (nearly 2.8 crores). This thumb rule hopefully helps the solar developers to estimate the energy generation correctly for better planning before deciding on the solar plant development in an area.

8. Conclusion

Thus, the present research study has been carried out with a focused attention directly on solar energy generation considering various parameters, such as ambient temperature, wind velocity and also other parameters like weather and topographic conditions. In future, we plan to carry out a detailed analysis on the affecting factors and determine their priority.

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