Open innovation using satellite imagery for initial site assessment of solar photovoltaic projects

Narayan Prasad Nagendra
Friedrich Alexander University Erlangen-Nuremberg
Lange Gasse 20, Sekretariat Zi. 4.428, D-90403, Nürnberg, Germany,
Email: narayan.nagendra@fau.de

Gopalakrishnan Narayanamurthy *
University of Liverpool Management School,
Chatham Street, Liverpool, L69 7ZH, UK
E-mail: g.narayanamurthy@liverpool.ac.uk

Roger Moser
Graduate School of Management, Macquarie University
99 Talavera Rd, Macquarie Park NSW 2113, Australia
Email: roger.moser@mq.edu.au

Akshit Singh
University of Liverpool Management School,
Chatham Street, Liverpool, L69 7ZH, UK
E-mail: Akshit.Singh@liverpool.ac.uk

* *Corresponding author*

Abstract

One of the responses to the fight against climate change by the developing world has been the large-scale adoption of solar energy. The adoption of solar energy in countries like India is propagating mainly through the development of energy producing photovoltaic farms. The realization of solar energy producing sites involves complex decisions and processes in the selection of sites whose knowhow may not rest with all the stakeholders supporting (e.g.

banks financing the project) the industry value chain. In this paper, we use the region of Bangalore in India as the case study to present how open innovation using satellite imagery can provide the necessary granularity to specifically aid in an independent initial assessment of the solar photovoltaic sites. We utilize the established analytical hierarchy process over the information extracted from open satellite data to calculate an overall site suitability index. The index takes into account the topographical, climatic and environmental factors. Our results explain how the intervention of satellite imagery based big data analytics can help in buying the confidence of investors in the solar industry value chain. Our study also demonstrates that open innovation using satellites can act as a platform for social product development.

Managerial Relevance Statement

The present work explores a data-driven structured process to perform photovoltaic site assessment. Our study demonstrates how open innovation using satellite data can be relied on for the initial site selection stage in the value chain and thereby highlight the possibility of capacity building for institutional investors to assess the potential sites for photovoltaic projects. By utilizing the recently made available open satellite data on Bangalore region of India, we showcase the extraction of relevant information on different factors and use of multi-criteria decision analysis procedure to assess and rank the proposed solar photovoltaic sites. The procedure captured allows for replication of the performed analysis in developing countries to exploit outside-in open innovation strategy. We believe liberalized open satellite data can be used within their own geographies of interest to support the local chains in achieving higher adoption of solar photovoltaic based renewable energy systems.

Keywords: Open Innovation, Big Data Analytics, Satellite Imagery, Solar Industry, Energy.

I. INTRODUCTION

Solar energy industry has been touted to be a beacon of hope for a clean-energy future across the world and has received special attention from developing countries such as India, which have put in place investments and enabling policies for large scale adoption of renewables to address their rising energy requirements [1]. However, the high initial investment cost associated with assessing the site options for installing solar energy infrastructure is one of the primary barriers that has to be tackled to accelerate its adoption for production of renewable energy [2].

To overcome such barriers, policymakers in the solar photovoltaic sector have constantly fiddled with creating catalytic policies as instruments to induce market growth. Inducing market growth was expected to trigger investments by firms operating in technology adoption and innovation sector [3]. Even with such elaborate efforts to solve persistent problems, new bottlenecks continued to arise. For instance, unaware of the workings of novel technology-based industries, funding agencies (e.g. banks) who had to invest in the solar photovoltaics value chain often viewed the investments as risky and were therefore reluctant to allocate capital [4]. Acknowledging the importance of the expansion of renewable energy, the policymakers in developing countries like India have been continuously attempting to tackle these bottlenecks using policy interventions which can incentivize investments by the private sector in solar photovoltaics [5].

Financing landscape is a bottleneck for solar energy projects and acts as a key barrier to scaling the production of renewable energy in India [6]. A report by the World Bank's International Finance Corporation found that local banks may be reluctant to lend to solar photovoltaic projects until they have evidence of successful projects [7]. Similarly, research conducted by

The Energy and Resources Institute for the Ministry of New and Renewable Energy of the Government of India captures the restrained participation of banks in the country owing to the lack of clarity and understanding of the solar photovoltaic industry as well as its associated risks [8].

One of the key issues contributing to restrained participation of financing institutions is the lack of reliable and objective data (e.g. irradiation data over time for different sites, history of performance of commercial solar projects, etc.) in the solar energy industry. Lack of objective data negatively influences the perception of funding agencies and their risk attitudes towards financing commercial scale solar energy plants [9]. This negative influence constraints local funding agencies from financing the solar energy projects and thereby pushes the projects to find foreign sources of capital for execution [10]. The phenomenon aligns with research in the policy landscape of renewable energy projects which suggests that the cost of capital increases with a perception of risk which then significantly influences the business case of a project [11].

Satellite imagery is a unique source of data that has the ability to provide global coverage. The notable transition of the space industry from an open innovation perspective is the move from its controlled nature of national space programs, which shackled satellite data with restrictions or made it expensive to procure, to a new era of open-access satellite data [12]. Examples of this include the 2008 decision of the US Geological Survey (USGS) to provide open and free access to the world's largest archive of Earth imagery collected by its Landsat satellite series, which goes back to the 1970s [13], and Europe's efforts to make its Sentinel satellite series data openly accessible [14]. These radical shifts in making data available have enabled the exploitation of satellite big data to create socio-economic applications [15].

We have recently witnessed the utilization of satellite imagery for open innovation to solve some of the challenges faced by stakeholders in the solar photovoltaic value chain. One of the prominent end-user examples of this is Google's Project Sunroof, which builds on top of the satellite images available through its own Google Earth engine to provide open access to a personalized analysis of installation options for solar panels to individual home owners in the US. Other examples of open data based innovation include estimation of solar energy potential at a country level [16], [17], estimation of rooftop solar photovoltaic potential [18], assessment of performance of various solar thermal power plant configurations [19], and deriving global solar radiation used for solar resource analysis [20].

In our paper, we are interested in exploring how open innovation using satellite big data analytics can plug the information gap by providing a granular assessment at the site level for solar photovoltaic projects. We use the region of Bangalore (a city in India) as the case study to demonstrate how satellite imagery can support a data-driven structured assessment process to perform photovoltaic site selection. We document how recently made available open data by National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) satellites[1] can be used to extract relevant information to independently assess the viability of solar photovoltaic projects. The satellite imagery combined with other data sources such as yearly radiation, dew point temperature, wind direction and wind speed were subjected to multi-criteria decision analysis to derive an overall suitability index score for each solar photovoltaic site.

---

[1] Satellite data is available on https://earthexplorer.usgs.gov/ and https://terra.nasa.gov/data/aster-data

The proposed solar photovoltaic installation sites in pure power generation terms varied from 2 MW to over 200 MW of energy. However, taking topographic, local weather factors and access to the sites into account, the overall site suitability scores for these sites varied from 0.22 to 0.35. Several of the high power generating proposed sites had a poor overall site suitability score than their counterparts generating less power. The end results showcase how satellite imagery combined with other sources of information can fill the gaps left by the lack of data to prioritize sites for solar photovoltaic projects. From a research standpoint, the case study shows how funding agencies and energy producers in the solar photovoltaic sector can adopt open innovation to support the expansion of renewable energy. From a practitioner's perspective, the case study showcases the potential of satellite imagery for funding agencies as well as site certification agencies to assess proposed potential sites for solar energy generation and narrow down the options for conducting a detailed resource-demanding field survey.

The rest of the paper is organized as follows. In the next section, we discuss literature on the recent developments of the solar industry in India, open innovation based on satellite data and elaborate some of the applications of satellite data in the solar industry. Following this, we discuss one of the key challenges in the adoption of photovoltaics in India and the problems faced by the funding agencies. In section III, we then highlight the methodology in utilizing open satellite data and explain its application in the context of decision-making by funding agencies, who support the financing of the photovoltaics value chain. In section IV, we present the case of assessment of photovoltaic sites in the Bangalore region. The results of adopting open satellite data analytics are discussed against their potential to tackle the present challenges of assessment of solar photovoltaic projects in India. In section V, the paper concludes by providing a foresight as to what the open innovation based on satellite data analytics holds for solar value chain.

II. LITERATURE REVIEW

Adoption of solar power sources is touted to support sustainable and socially equitable solution by meeting the rising demands of society's energy requirements against the backdrop of fighting climate change [21]. The solar industry has evolved mainly through market uptake support provisioned by policymakers [22]. In terms of industry growth, the production of photovoltaics in 2015 was estimated to be 200 times to that of 2000 with a Compound Annual Growth Rate (CAGR) of 40% [23]. The promise of sustainable energy through photovoltaics is found to also support social goals such as targeted poverty alleviation in developing countries [24]. Realizing the need to transition to renewables and its future potential, India has created an ambitious roadmap to install 20 million m^2 of photovoltaics by 2022 to generate 20,000 MW of energy under the Jawaharlal Nehru National Solar Mission (JNNSM) [25].

In our study of the adoption of photovoltaics in India we found that the focus of research from the perspective of stakeholders has been limited to studying broad issues within the industry value chain such as market formation and competencies [26], [27] or reviewing key determinants (e.g. policies, government initiatives) that influences the adoption [28], [29]. There is a dearth of studies which focus on the adoption specific bottlenecks faced within the downstream of the photovoltaic value chain (e.g. prioritization of potential sites for photovoltaic installation). In the present paper, we focus on the challenges faced by funding agencies supporting the downstream of the photovoltaics in India, which concerns the installation, construction, operation and maintenance of photovoltaics [30].

Open innovation on space-based assets has enabled the creation of products and services for socio-economic benefits. The best example of such an innovation based on satellite capability to fuel applications for economic growth and return is the evolution of navigation and timing applications based on the Global Positioning System (GPS). GPS started to be a U.S. Department of Defense project in 1978 which after two decades was made available for open global use [31]. The positioning, navigation and timing based on GPS became the backbone of several products and services in a wide array of industries that include financial, telecommunications, transportation, agriculture, etc.

More recently, the increase in computing capability and the decreased cost of computing has enabled the real-time and archival data captured by satellites to be turned into a prominent source for the development of products and services to deliver actionable intelligence for various industries [32]. Policymakers such as the European Commission have invested into creating satellites as public assets and make their data available as open sources to develop innovative products and services for societal benefits [33]. Such measures are not just specific to some regions but it is in itself a global trend of democratization of the satellite data with an intention to expand the range of participants and stakeholders creating actionable intelligence for societal transformation [34].

Within the realm of the solar industry, apart from the technological limitations of photovoltaics themselves (e.g. efficiency of solar cells), power generation through photovoltaics is strongly dependent on the local conditions of operations which in-turn depend on several variables such as cloud cover, atmospheric aerosol levels, and geographical features [35]. Satellite data has impacted the photovoltaics industry with its ability to independently map and measure variables that effect power generation over the entire Earth's surface. Some examples of these include estimation of daily [36] and interannual [37] global solar radiation and estimation of the influence of cloud cover [38] and aerosols [39] on photovoltaic installations. These sustained efforts have created a wealth of long-term open data sets such as National Solar Radiation Data Base (NSRDB) [40], which can be used to expand the adoption of renewable energy.

The utility of such data produced by satellites is in the creation of models for prediction, identification, forecasting, and optimization in the process of decision-making for the adoption of photovoltaics. Modelling of satellite data has impacted a wide range of activities in the solar industry including assessment of power generation potential on building rooftops [41], price-performance based comparison of technology choices within the realm of photovoltaics [42], forecasting of power output in complex grid-connected photovoltaic systems [43], and sizing of photovoltaics as stand-alone systems at potential sites [44]. In the present paper, we would like to showcase how data from satellites can be tailored for independent decision making in the solar industry value chain, more specifically for prioritizing potential photovoltaic sites. By keeping the focus of our lens on the challenges of the photovoltaics industry value chain in India, we hope to present a concrete view from an adoption perspective rather than glorifying the underlying technology itself.

In an exercise of characterizing commercial exploitation of solar potential in India, a World Bank study on the barriers to the development of solar industry in India highlighted the complex land usage approval processes, the lack of India's own investment in collecting solar radiation data and its link to financial closures as major issues to be resolved [45]. The effect of which is that the total lead time for independent approvals may take several months and therefore add to the time and cost uncertainties in the realization of projects. The World

Bank study highlights several administrative and scientific data related uncertainties creeping into decision-making, which may force policymakers to revise policies to enable the sector's growth. This may take various forms such as creating schemes for state-backed power purchase instead of market-tied consumption to create ease in the financing of these projects by banks. Therefore, the data and processes burden alongside the political and market pressures may easily push policymakers to get into a compulsive policymaking spiral [46].

From a practitioner's perspective, a recent paper assessing JNNSM [47] has concluded that policymakers in India have focused their efforts on the development of a measure for market support, and overlooked the important weaknesses in knowledge development and diffusion which could have facilitated a much more systematic engagement of stakeholders from the financial sector. The result is that stakeholders within the value chain may have no techno-economic insights needed to make the necessary decisions. Such weaknesses left behind within the value chain form a loose footing on which the industry then is forced to operate. This corroborates with the findings that key stakeholders in the photovoltaics value chain such as banks who provide the financial backing often have an inadequate understanding of the underlying fundamental techno-economic mechanics of photovoltaics and an insufficient lending history in the sector [48]. Banks then are forced to use an independent third-party in getting an assessment conducted, which further adds to delays and escalated costs of servicing the value chain. From a larger perspective of market evolution, such characteristics within the value chain may further drive policy makers into compulsive policymaking [46], where political convenience and preferential treatment by financial concessions (e.g. subsidies) drive their efforts rather than industry evolution [49].

INSERT FIGURE 1 HERE

Figure 1 provides an illustration of the typical lifecycle of a solar photovoltaic project which involves going through a number of steps before the final decision is made in erecting a solar photovoltaic plant. The process begins by kicking off an initial assessment of the potential site. During this initial assessment, the location in question has a number of factors that need to be evaluated for the fit and feasibility of the erection of a solar photovoltaic site. This includes considering solar energy related factors, land related aspects and access to the site related characteristics. The initial site selection is crucial for the viability of the project as it is at this point the confidence of the investors is gained to back the proposed project. Once the initial site assessment is concluded and a fit is found, the proposed project and the site undergoes a thorough analysis for the feasibility of the power plant by taking technical, social, environmental, political, energy policies, operating and maintenance aspects into account. Following such an analysis, the availability of land considering local rules and regulations, checks on site grid connectivity and all necessary compliances to setup and integrate into to the power supply network is ensured before the development of a solar photovoltaic plant. The focus of our work is limited to exploring the use of open satellite data to support the very first step of site identification and address the bottleneck of the lack of knowhow by funding agencies in independently being able to assess the proposed solar photovoltaic sites.

INSERT TABLE 1 HERE

Table 1 provides a selection of previous research which has attempted to use datasets based on solar radiation with secondary variables such as ambient temperature data, land-use and land terrain data or purely financial modeling-based assessment such as using the cost of electricity to draw insights for the adoption of solar energy. Researchers pursuing such studies have used these variables to provide insights at a large geographical level of a country or particular region within a country. However, these studies lack the necessary granularity level for assessing the sites. In our case study, we use several of the variables that researchers have used in the past to achieve the necessary granularity for assessing individual solar photovoltaic sites. The results can be used by the funding agencies for the first level processing of applications requisitioning financial support to realize solar photovoltaic farms. The solution acts as an initial screening which significantly reduces the time and costs incurred by the funding agencies of the solar industry value chain, who otherwise should have performed a resource-intensive survey of all the potential sites before processing the applications.

III. DATA AND ANALYSIS

We utilize the methodological foundations laid down by Eisenhardt [50] and Yin [51] in case studies. We study and document the assessment of potential photovoltaic sites in the Bangalore region in India to answer the research questions. Despite various normative nature of methodological points, case studies provide grounds to study the effect of information systems on users, organizations or the society [52]. In our case study research, the open innovation of using satellite data for assessing the potential of photovoltaic sites is based on understanding the contribution of the data to the research question itself [53]. Our choice of a single-case study in this paper allows us to answer different form of research questions such as "how", "what" and "why" through which we are able to analyze the operational challenges in assessment of photovoltaic projects faced by institutional investors in India.

The case study features an assessment of sites for the installation of photovoltaics in the Bangalore region in India. The primary sources of information for the assessment of photovoltaic projects used in this case study are the satellite imagery and data provided by Landsat 8 and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellites. Landsat 8 is a satellite in the Landsat program, which is run by the United States for four decades now. The Landsat represents the world's longest continuously running collection of space-based data, which was made open to public access in 2008 [13].[2] Similarly, ASTER is a joint US-Japan satellite flown in 1999 to gather data for creating detailed maps of the Earth's land surface temperature, reflectance, and elevation. Similar to Landsat's public access declaration, ASTER's data products have been made available to open access since 2016.[3] Our case study uses data made available during May 2018 and showcases how such openly available satellite data products can enable their adoption in developing countries who otherwise may not have had the resources or the intellectual property rights to build such complex systems that can offer information continuity for past several decades.

From the perspective of assessment of the power generation using photovoltaics, a broad range of factors that encompass climatic conditions, geological features and land access affect the decision making. Table 2 provides a list of key factors and the source from where the data have been taken for the assessment of photovoltaic sites in this study. The data from Landsat and ASTER have been used by researchers in cases such as a study of solar energy plants on land-cover patterns [54], modeling of solar radiation to explore solar energy potential [55], and estimating solar potential within different regions of a country [56]. In our study, we use the geological and access condition data from Landsat 8 and ASTER satellites respectively. The climatic conditions data is sourced from both ASTER and Automatic Weather Station (AWS) data. The AWS data in the case study was procured from a commercial vendor.

[2] Open access to Landsat's data products and documentation is available on https://landsat.usgs.gov/ (last accessed on 25 June 2019).
[3] Open access to ASTER's data products and documentation is available on https://asterweb.jpl.nasa.gov/ (last accessed on 25 June 2019).

INSERT TABLE 2 HERE

INSERT FIGURE 2 HERE

Figure 2 provides information extracted for various geological and climatic factors captured by the sensors onboard the ASTER satellite over the Bangalore region and plotted according to the geographic area of the city. The data from the sensors which have recently been made available openly form the basis of accurately quantifying the geological and climatic factors. All the geological and climatic factors captured in Figure 2 vary over the terrain. The variations include the total radiation received on the ground, height over the terrain of the region above mean sea level (captured through digital elevation model), changes in the slope of the terrain over the region, the airborne water vapor captured as dew point temperature, compass direction that a slope faces captured as aspect, variation of the wind speed, and the wind direction over the Bangalore region.

The underlying data is geo-referenced (i.e. tagged with latitude and longitude) and therefore provides accurate mapping of the changes over the Bangalore region for the factors. The geo-referenced satellite data for the Bangalore region is transformed into 70749 segments with an area of 2225 m^2 per segment using a combination of data classifier algorithms including Gaussian Naive Bayes, linear support vector machine, kernel-based support vector machine, decision tree, and random tree [57]. Each of the segments have codified identifiers which translates back into a location in Bangalore.

The MCDA uses the data extracted from the satellites as showcased in Figure 3 and performs the analysis over each of the 70749 segments. We intentionally do not focus on describing the technicalities of using data classifiers to calibrate and derive the baseline data for the attributes recorded in Table 2 from the underlying satellite data. Within the purview of this case study, we believe it is more meaningful to discuss as to how the baseline data after such technicalities is operationalized in the decision-making process to arrive at an assessment of proposed photovoltaic sites rather than describing the standardized computation techniques in satellite image processing.

INSERT FIGURE 3 HERE

Figure 3 shows an example of the geo-referenced data mapped as a histogram where the satellite data is transformed into arriving at the necessary attributes recorded in Table 2. The histograms use the frequency of the incident radiation as a standard reference against which all the factors are mapped to illustrate the distribution of the data based on the transposition from the satellite geo-referenced data. The geological factors in Figure 3 such as slope, aspect and height captured against the incident radiation directly affect the interaction between the radiation from the sun and surface of the Earth which in turn affects the output of the photovoltaics [58]. Similarly, local weather variables such as local radiation flux, temperature, wind speed and direction have a bearing on the thermal operating environment, which affects the output of the photovoltaics [59].

The underlying data from the geo-referenced satellite data as illustrated in Figure 2 and Figure 3 form the basis of extracting the quantitative values of factors listed in Table 2. Figure 4 provides a composite image from Landsat satellite of the Bangalore region. The land use and cover, road network and water resources are captured through this data. Similar to the ASTER data, the Landsat images are also geo-referenced and hence allow precise calculation of distances between the proposed sites for photovoltaics and the factors.

INSERT FIGURE 4 HERE

Within the list of the factors recorded in Table 2, no single factor will be sufficient enough to arrive at a decision on the selection of a site for the installation of photovoltaics. The synthesis of a wide array of factors listed in Table 2 poses information processing complexity in the decision making. To address this complexity in decision making, the satellite and allied data were processed using a Multiple Criteria Decision Analysis (MCDA) procedure. Within the MCDA framework, the Analytic Hierarchy Process (AHP) has been utilized to assign weights to each of the factors listed in Table 2 on the basis of the relative importance to power generation using the photovoltaics.

The use of AHP within the solar industry context is a well-accepted approach due to the wide range of factors that affect decision making. Kaya et. al, [60] showcase the detailed procedure of the application of AHP's governing equations in the context of renewable energy planning. Table 3 lists some of the important contributions to the literature in the solar industry by primarily using AHP to perform the necessary analysis. In our case, the baseline quantitative data for the AHP process is derived through the satellite data captured over the Earth's surface along the latitude and the longitude. The open data from the satellites form the foundation of the MCDA process and aid providing crucial information in identifying a number of functional factors and assessing their comparative importance for a potential site to install photovoltaics.

INSERT TABLE 3 HERE

We intentionally do not detail the AHP process since it has a well-established theoretical [61] and case study history [62] in management literature. Instead, we have provided the final weight assignment details in Table 4 and choose to discuss the matters of relevance specific to open innovation using satellite data in the viability assessment of photovoltaic projects. The final weights documented in Table 4 are generated using the pairwise comparison matrix [63]. The use of the sub-preferences within each factor as indicated in Table 4 ensures that the range of values within the factor is accounted for. For example, higher radiation intensity is preferable for generating more power and the three sub-preferences chosen within the recorded radiation reflects this order of preference within the factor. The primary criteria are based on the geological and climatic factors listed in Table 2. The secondary criteria documented in Table 4 takes into the account the access related factors alongside the weight calculated using the primary criteria to ensure that the evaluation is conducted on not just the factors directly affecting the power generation itself. From a methodological perspective of connecting the AHP to the problem at hand, the Simple Additive Weighting (SAW) is used to arrive at this evaluation criteria. SAW is an established metamodel for multiple criteria decision analysis [64], which in this case study is utilized to aggregate the weights to arrive at an overall site suitability index based on the relative importance of each of the functional factors listed in Table 2. The final computation of the site suitability index based on the AHP process generates end weights which lie between 0 and 1, corresponding to the "worst" and "best" sites, respectively.

INSERT TABLE 4 HERE

IV. RESULTS AND DISCUSSION

Table 5 provides the computed results based on open satellite data using the AHP. The ID number is created as a part of the segmentation process in the data analysis and it corresponds to a particular latitude and longitude of sites proposed in the Bangalore region. The proposed solar photovoltaic installation sites vary from 2 MW to over 200 MW of energy on the power generation factor (calculated using radiation, slope, aspect, height, wind speed, wind direction and dew point temperature into account), but their overall site suitability scores range from 0.22 to 0.35 respectively. The limited range of the overall site suitability index against the possible range of 0 to 1 can be attributed to a combination of geological and climatic conditions of the Bangalore region. The output of the analysis only ranks all the sites considered through a relative assessment and thereby makes it infeasible to propose absolute and generalizable minimum requirements of energy output and parameter values for selecting a site.

INSERT TABLE 5 HERE

As we discussed in the data and analysis section, the assessment of a potential photovoltaic site cannot be solely based on the key metric of how much power it is capable of producing. Factors such as the distance to road access, water access, height and slope of land have a bearing on the initial infrastructure and operating costs of the photovoltaic installation. Therefore, the end analysis using the open satellite data allows to take into account comprehensive factors that affect the overall investment and operations rather than produce an assessment based on a prominent output metric. Giving due consideration to these factors including the topographic, local weather variables and access to the sites, it is found that several of the high power generating proposed sites have a lower overall site suitability score than their smaller installation counterparts. The outcome of the analysis showcased in Table 5 reflects the scientific measurement of the confluence of the parameters in Table 2, which is able to provide an independent benchmark to institutional investors against the ones presented by the industry at the initial stage of project assessment.

The assessment of the solar photovoltaic sites as showcased in this study can be particularly useful for representatives in funding agencies (e.g. loan case officers of banks) in Bangalore who can rely on the scientific results generated through the data analytics process to make informed site-related choices. As captured by the study cited earlier by the International Finance Corporation and an Indian think-tank, the representatives have faced bottlenecks in decision-making due to an insufficient lending experience within their institutions [7]. A study of the functioning of the Indian Renewable Energy Development Agency (IREDA), which is primarily responsible for the penetration of solar photovoltaics in India, clearly establishes that these challenges are due to the lack of capacity in the funding agencies and its profound effect on the ability to realize photovoltaic projects [65]. The risk appetite for lending can substantially reduce making the cost of capital unreasonable for entrepreneurs to realize projects.

The reduced transaction time and costs attained through open innovation using satellite imagery can bring more certainty and accelerate the decision-making of funding agencies. This clearly demonstrates that the fundamental value of liberated data is its influence to support the transactions between stakeholders supporting the value chain [66]. Breaking the shackles of expensive or restricted access to new generation satellite data can enable the access to such insights for the funding agencies supporting the photovoltaic industry value chain. Therefore, the open innovation based on satellite big data allows invoking an independent source of truth, which otherwise might not have been possible owing to the barriers of access. The results from using the open satellite data for the initial site assessment can then be followed by the next steps within the lifecycle of realization of solar photovoltaic sites.

From the perspective of the assessment proposed in this case study, the availability of the data for any region and the ability to deploy the solution on a cloud platform allows replicating the site assessments for any region. Providing basic training to the funding agencies on how to access and interpret the end results of the data analytics process will build up institutional capacity and capabilities within the funding agencies. The cloud-based integration of the data analytics platform helps representatives from funding agencies to seamlessly integrate the platform into their daily workflow routines. The combination of open satellite data analytics with the cloud-based deployment clearly lubricates the overall process of exchange of information between the stakeholders. It also provides a foundation to scale-up the use of the end results in the overall lifecycle of the lending and recovery process of the funding agencies. For example, once the assessment of the proposed site is completed and a positive decision is made to provide credit, the open satellite data with the cloud-based delivery insights can be used to monitor the use of the credit by the borrowers. The open satellite data in this case allows for the periodic monitoring of the invested asset with the capacity to keep track of changes in construction and its alignment with the projected milestones in the use of the credit by the borrowers. Therefore, the applications are not just limited to the initial assessment of the potential photovoltaic sites but there is definite scope for scaling up the use of open satellite data for a deeper deployment in the entire cycle of credit lending and recovery. This represents the horizontal scalability of the underlying innovation.

In order to assess the vertical scalability of the underlying innovation using open satellite data, the entire lifecycle and the stakeholders involved in supporting the installation and commissioning of solar photovoltaics in India have to be studied. Independent certification firms are being used within the value chain to conduct energy and environmental safety audits of the proposed photovoltaic sites for future installation and operationalization. These certification firms are involved in independently assessing for any environmental risks of the plant before giving clearance to construction as well as in assessing the installed energy capacity of the photovoltaic sites. These assessments of site suitability, environmental risks as well as the periodic checks on the erection of the plant requires the certification firms to regularly monitor the site in question. Given that several of the photovoltaic sites are often remote, usage of open satellite data will help in recording the case history without visiting the actual site. From an operational perspective, the ability to monitor through the open satellite data allows efficient utilization of human resources by scheduling their site visits only when it is needed to confirm the observations made. Therefore, there is definite potential to exploiting technical, economic, social and environmental benefits from further horizontal and vertical penetration of the insights from open satellite data within the solar industry value chain.

To explore such avenues, we discuss the larger challenges in the renewable energy landscape of India and synergies to use open innovation based on satellite big data. From the power sector economics and renewable energy policy standpoint, the Indian renewable power adoption landscape currently has multiple drivers instead of a single large consolidated charter. Owing to the federal-state structure of governance in India, the motivations and the directions pursued by stakeholders within these institutions make the operational landscape complex at the value chain level. The bodies at the federal level involved are the Ministry of Power (in charge of policy for electric power), Ministry of New and Renewable Energy (promotion of renewables), IREDA (financing of federal projects), and Electricity Regulatory Commissions (regulatory affairs, tariffs and supervision of distribution licensees) [67]. More than ten state governments have taken upon themselves to independently pursue photovoltaic projects and have formed agencies within their governments to set policies and prices [68]. Therefore, the compulsion to drive adoption of renewable has varied pivots of interest within the country and can add to volatility in technical and economic challenges in prices, generation dispatch and power flows. These volatilities call for closer scrutiny of the location, volume and timing of renewable projects to minimize negative impacts and ensure a more balanced approach towards power generation and distribution [69]. There is visibly no single source of data within the country that consolidates information on the existing installations of photovoltaics alongside other sources of power generation. Tagging of power assets using a mix of open satellite data and other sources including press releases, newspaper articles, industry magazines, government reports, websites of sponsors, national regulatory agencies, power purchase contract awarding bodies, websites of multilateral agencies and annual reports can help consolidate insights for making key decisions on tariffs, future investments, subsidy allotment, and land lease agreements.

Policymakers have also identified photovoltaics as one of the key means of achieving rural electrification in India, which can act as a catalyst in boosting agricultural and industrial productivity [70]. To tackle the challenge of enabling the penetration of photovoltaics for rural electrification, Yadav *et al.* [71] suggest using a streamlined IT-enabled framework to provide preferential subsidy provision. Similarly, Chauhan *et al.* [72] studied off-grid rural electrification in Uttarakhand state of India and suggested a database for resource assessment of renewable energy sources such as solar, wind, small hydro and biomass. Information and insights generated using open data from satellites as demonstrated within this case study has the potential to be the foundation of such IT-enabled frameworks and databases. We believe there is scope to extend the use of open satellite data and cloud-based platforms to tag existing and planned power installations (including photovoltaics) at a consolidated national level. This can help tackle both technical and socio-economic issues of serving energy using renewables and can be a starting point towards achieving a dedicated portal towards the consolidation of all power sources and its distribution in the country. With the global rise of development of large-scale solar parks, there is an emerging policy and investment decision conflict on land use. Späth et al. [73] have underlined the tension that may emerge between renewable energy development using large-scale on-field photovoltaic generation and the preservation of agricultural land. This conflict may especially be of interest in developing countries since several of them have dense populations. We believe that the case study sheds light on how innovation using novel technologies such as big data analytics based on open data can be leveraged to tackle these emerging problems by providing holistic information to policymakers. The modelling of the utility of land based on the type of land, its current usage, and access to it has been taken into consideration in the site suitability assessment conducted in this case study. There is potential to extend the utility of land use classification model via satellite big data analytics to derive assessments to balance energy policy against the land preservation charter. This extension will provide a basis for decision making by policymakers that will be inclusive and informed of the natural environment.

V. CONCLUSION

Access to the initial investment necessary to set up solar energy infrastructure is one of the key issues that has to be effectively handled to accelerate its adoption for the production of renewable energy. Previous research has established that the financing landscape is a major bottleneck for the realization of solar energy projects and acts as a key barrier to scaling the production of renewable energy in India. Open innovation based on satellite imagery has potential to solve some of the challenges faced in the solar industry value chain. Using the case study of Bangalore city in India, we demonstrate how open innovation using satellite data can aid specifically in the assessment and prioritization of solar photovoltaic sites.

Satellite big data based open innovation creates a foundation for assessing proposed photovoltaic sites. Our paper presents evidence that recently made available open satellite data has the necessary granularity that can be used to assess the sites and prioritize them for selection for solar photovoltaics installation. This is the first step in the lifecycle of realizing a solar photovoltaic project which can be subsequently followed by the feasibility assessment of the power plant considering technical, operational, social, environmental, and political aspects. The proposed solution discussed can reduce the transaction time and costs between the funding agencies and the entrepreneurs. The study demonstrates the potential for using open innovation on the basis of liberated data to resolve bottlenecks in transactions between the funding agencies and the photovoltaics value chain. The procedure documented in this study can be replicated in other developing countries by relying on open innovation and liberalized satellite data within their own geographies of interest. The replication will support the value chains in the chosen geographies by removing the bottlenecks and thereby increase the adoption of solar photovoltaic based renewable energy systems.

A. Research implications

Within the Indian solar value chain context, our study provides a basis for researchers to explore the ability to provide granular assessments by moving away from only using single sources such as solar radiation data [74]. More importantly, studies that have cited the lack of data over the Indian subcontinent to explore data-backed decision making [1] and the lack of investments into data collection infrastructure impede their potential use for research [2]. These positions have the opportunity to be reviewed to utilize several of the foreign satellite data being now made available openly as we have done within our study. There are significant opportunities to study the uptake of results produced through satellite data by conducting interviews with financial representatives.

From the vantage point of adoption of open innovation, our study indicates that it is important for policymakers to be aware of liberalization of data sources in allied sectors that were previously locked away in the form of lack of access due to sharing restrictions or being too expensive to adopt. Post liberalization of such data sources, the information in them may lead to disruptive open innovations which can remove the previously existing bottlenecks in the processes within the value chain. The case study demonstrates how open data with new sources can lead to taking a comprehensive approach than just taking the obvious or most prominent (e.g. total power) factors into account for decision making.

B. Practice implications

Our study highlights the potential of satellite imagery as a source of independent information which can be tailored to provide insights to support the growth of sectors of critical importance for the socio-economic growth in developing countries. The opportunity and the challenge for the practitioners are in operationalizing such tools in the real world and building up the capacity required to seamlessly adopt such possibilities in their functioning. Further, the case study should provide motivation for practitioners in developing countries to exploit outside-in open innovation based on satellite imagery within other aspects of the solar industry value chain such as adding the information extracted into open national databases and striving for the integration of the extracted insights into energy policymaking at various levels of administration.

Research indicates that cyclical peddling of policymaking may arise to treat new bottlenecks as impetus is provided for pushing the adoption of novel technology innovations, which may lead to compulsive policy-making [46]. Adoption of open innovation based technology solutions from lateral sectors (in this case, space industry solutions into energy industry) can alleviate the bottlenecks by removing the information gaps. This in-turn has the potential to avoid compulsive policy-making and ensure effective functioning of stakeholders who support the value chain.

C. Limitations

Our analysis does not capture all the necessary socio-economic, operational or maintenance related aspects needed for decision making. The study also does not reflect on the views of the relevant stakeholders (e.g. financial representatives of banks) in their interest to adopt or absorb the proposed solution. Our contribution is limited to the initial assessment of a photovoltaic site and mainly focusses on the potential use of open satellite data for such an assessment. For the realisation of photovoltaic installations, subsequent feasibility analysis has to take into account the entire range of factors affecting the validity and execution of the project such as operating costs, policy aspects, political aspects, market aspects, maintenance costs, social aspects, etc. We have also not confirmed the availability of the data for the entire globe to test the scalability of the use of data within the databases of the satellites since the resources needed for such an exercise is quite large.

D. Future research

Within the realm of research based on open innovation, our case study only deals with the potential of open satellite imagery as a source for the assessment of photovoltaic sites. There is scope to study the effects of such open innovation in the adoption of open satellite data-based solutions in various real-world projects. Such a study can employ methods which may include collecting data through surveys or interviews with the relevant stakeholders within the solar industry value chain to explore what situational factors exist in the decision-making process. There are opportunities to also test the ability to scale the use of open satellite data using newer technologies such as machine learning to deliver better results in various activities within the photovoltaics value chain such as designing higher efficiency solar power plants [75] and large-scale installed capacity monitoring [76].

ACKNOWLEDGEMENTS

We would like to take this opportunity to thank SatSure for their efforts in allowing the authors to engage with their technical teams and their support in facilitating the analysis conducted within the scope of this paper. We appreciate the efforts of Mr. Ishan Tomar and Mr. Rashmit Singh in explaining the underlying data structure and technicalities involved in the process of satellite big data analytics.

REFERENCES

[1] K. Kapoor, K. K. Pandey, A. K. Jain, and A. Nandan, "Evolution of solar energy in India: A review," *Renew. Sustain. Energy Rev.*, vol. 40, pp. 475–487, Dec. 2014.

[2] Md. F. Ansari, R. K. Kharb, S. Luthra, S. L. Shimmi, and S. Chatterji, "Analysis of barriers to implement solar power installations in India using interpretive structural modeling technique," *Renew. Sustain. Energy Rev.*, vol. 27, pp. 163–174, Nov. 2013.

[3] J. Hoppmann, M. Peters, M. Schneider, and V. H. Hoffmann, "The two faces of market support—How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry," *Res. Policy*, vol. 42, no. 4, pp. 989–1003, May 2013.

[4] G. Wilkins, *Technology transfer for renewable energy: overcoming barriers in developing countries*. Earthscan, 2002.

[5] S. Jolly and R. P. J. M. Raven, "Field configuring events shaping sustainability transitions? The case of solar PV in India," *Technol. Forecast. Soc. Change*, vol. 103, pp. 324–333, Feb. 2016.

[6] S. K. Kar, A. Sharma, and B. Roy, "Solar energy market developments in India," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 121–133, Sep. 2016.

[7] International Finance Corporation, "A Project Developer's Guide to Utility-scale Solar Photovoltaic Power Plants," 2015.

[8] The Energy and Resources Institute, "Technical Manual for Banks & FIs on Grid-Connected Rooftop Solar Power," 2015.

[9] S. Umamaheswaran and S. Rajiv, "Financing large scale wind and solar projects—A review of emerging experiences in the Indian context," *Renew. Sustain. Energy Rev.*, vol. 48, pp. 166–177, Aug. 2015.

[10] G. K. Sarangi, *Green Energy Finance in India: Challenges and Solutions*. Asian Development Bank, 2018.

[11] P. Noothout, D. de Jager, L. Tesnière, and et al, "The impact of risks in renewable energy investments and the role of smart policies," European Commission, Brussels, 2016.

[12] M. A. Wulder and N. C. Coops, "Satellites: Make Earth observations open access," *Nature*, vol. 513, pp. 30–31, Sep. 2014.

[13] M. A. Wulder, J. G. Masek, W. B. Cohen, T. R. Loveland, and C. E. Woodcock, "Opening the archive: How free data has enabled the science and monitoring promise of Landsat," *Remote Sens. Environ.*, vol. 122, pp. 2–10, Jul. 2012.

[14] Z. Malenovský *et al.*, "Sentinels for science: Potential of Sentinel-1, -2, and -3 missions for scientific observations of ocean, cryosphere, and land," *Remote Sens. Environ.*, vol. 120, pp. 91–101, May 2012.

[15] R. Kitchin, *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences*. SAGE, 2014.

[16] O. Şenkal and T. Kuleli, "Estimation of solar radiation over Turkey using artificial neural network and satellite data," *Appl. Energy*, vol. 86, no. 7, pp. 1222–1228, Jul. 2009.

[17] R. A. Escobar *et al.*, "Estimating the potential for solar energy utilization in Chile by satellite-derived data and ground station measurements," *Sol. Energy*, vol. 121, pp. 139–151, Nov. 2015.

[18] R. Singh and R. Banerjee, "Estimation of rooftop solar photovoltaic potential of a city," *Sol. Energy*, vol. 115, pp. 589–602, May 2015.

[19] H. Broesamle, H. Mannstein, C. Schillings, and F. Trieb, "Assessment of solar electricity potentials in North Africa based on satellite data and a geographic information system," *Sol. Energy*, vol. 70, no. 1, pp. 1–12, Jan. 2001.

[20] L. F. Zarzalejo, J. Polo, L. Martín, L. Ramírez, and B. Espinar, "A new statistical approach for deriving global solar radiation from satellite images," *Sol. Energy*, vol. 83, no. 4, pp. 480–484, Apr. 2009.
[21] J. M. Pearce, "Photovoltaics — a path to sustainable futures," *Futures*, vol. 34, no. 7, pp. 663–674, Sep. 2002.
[22] E. G. Hansen, F. Lüdeke-Freund, X. I. Quan, and J. West, "Cross-National Complementarity of Technology Push, Demand Pull, and Manufacturing Push Policies: The Case of Photovoltaics," *IEEE Trans. Eng. Manag.*, pp. 1–17, 2018.
[23] A. Jäger-Waldau, "PV status report 2016," Joint Research Centre (European Commission), Study, Nov. 2016.
[24] H. Zhang, Z. Xu, C. Sun, and E. Elahi, "Targeted poverty alleviation using photovoltaic power: Review of Chinese policies," *Energy Policy*, vol. 120, pp. 550–558, Sep. 2018.
[25] I. Purohit and P. Purohit, "Techno-economic evaluation of concentrating solar power generation in India," *Energy Policy*, vol. 38, no. 6, pp. 3015–3029, Jun. 2010.
[26] S. Srinivasan, "Segmentation of the Indian photovoltaic market," *Renew. Sustain. Energy Rev.*, vol. 9, no. 2, pp. 215–227, Apr. 2005.
[27] A. Sahoo and G. Shrimali, "The effectiveness of domestic content criteria in India's Solar Mission," *Energy Policy*, vol. 62, pp. 1470–1480, Nov. 2013.
[28] A. Kumar, K. Kumar, N. Kaushik, S. Sharma, and S. Mishra, "Renewable energy in India: Current status and future potentials," *Renew. Sustain. Energy Rev.*, vol. 14, no. 8, pp. 2434–2442, Oct. 2010.
[29] R. Peter, L. Dickie, and V. M. Peter, "Adoption of photovoltaic power supply systems: A study of key determinants in India," *Renew. Energy*, vol. 31, no. 14, pp. 2272–2283, Nov. 2006.
[30] H. Wang, S. Zheng, Y. Zhang, and K. Zhang, "Analysis of the policy effects of downstream Feed-In Tariff on China's solar photovoltaic industry," *Energy Policy*, vol. 95, pp. 479–488, Aug. 2016.
[31] S. Kumar and K. B. Moore, "The Evolution of Global Positioning System (GPS) Technology," *J. Sci. Educ. Technol.*, vol. 11, no. 1, pp. 59–80, Mar. 2002.
[32] N. P. Nagendra and T. Segert, "Challenges for NewSpace Commercial Earth Observation Small Satellites," *New Space*, vol. 5, no. 4, pp. 238–243, Oct. 2017.
[33] P. Kempeneers and P. Soille, "Optimizing Sentinel-2 image selection in a Big Data context," *Big Earth Data*, vol. 1, no. 1–2, pp. 145–158, Dec. 2017.
[34] M. Craglia and L. Shanley, "Data democracy – increased supply of geospatial information and expanded participatory processes in the production of data," *Int. J. Digit. Earth*, vol. 8, no. 9, pp. 679–693, Sep. 2015.
[35] G. K. Singh, "Solar power generation by PV (photovoltaic) technology: A review," *Energy*, vol. 53, pp. 1–13, May 2013.
[36] N. Lu, J. Qin, K. Yang, and J. Sun, "A simple and efficient algorithm to estimate daily global solar radiation from geostationary satellite data," *Energy*, vol. 36, no. 5, pp. 3179–3188, May 2011.
[37] C. A. Gueymard and S. M. Wilcox, "Assessment of spatial and temporal variability in the US solar resource from radiometric measurements and predictions from models using ground-based or satellite data," *Sol. Energy*, vol. 85, no. 5, pp. 1068–1084, May 2011.
[38] R. Marquez, H. T. C. Pedro, and C. F. M. Coimbra, "Hybrid solar forecasting method uses satellite imaging and ground telemetry as inputs to ANNs," *Sol. Energy*, vol. 92, pp. 176–188, Jun. 2013.
[39] X. Li, F. Wagner, W. Peng, J. Yang, and D. L. Mauzerall, "Reduction of solar photovoltaic resources due to air pollution in China," *Proc. Natl. Acad. Sci.*, p. 201711462, Oct. 2017.

[40] M. Sengupta, Y. Xie, A. Lopez, A. Habte, G. Maclaurin, and J. Shelby, "The National Solar Radiation Data Base (NSRDB)," *Renew. Sustain. Energy Rev.*, vol. 89, pp. 51–60, Jun. 2018.
[41] N. Lukač, S. Seme, D. Žlaus, G. Štumberger, and B. Žalik, "Buildings roofs photovoltaic potential assessment based on LiDAR (Light Detection And Ranging) data," *Energy*, vol. 66, pp. 598–609, Mar. 2014.
[42] T. S. Viana, R. Rüther, F. R. Martins, and E. B. Pereira, "Assessing the potential of concentrating solar photovoltaic generation in Brazil with satellite-derived direct normal irradiation," *Sol. Energy*, vol. 85, no. 3, pp. 486–495, Mar. 2011.
[43] J. Shi, W. Lee, Y. Liu, Y. Yang, and P. Wang, "Forecasting Power Output of Photovoltaic Systems Based on Weather Classification and Support Vector Machines," *IEEE Trans. Ind. Appl.*, vol. 48, no. 3, pp. 1064–1069, May 2012.
[44] M. Benghanem and A. Mellit, "Radial Basis Function Network-based prediction of global solar radiation data: Application for sizing of a stand-alone photovoltaic system at Al-Madinah, Saudi Arabia," *Energy*, vol. 35, no. 9, pp. 3751–3762, Sep. 2010.
[45] South Asia Energy Unit, "Report on Barriers for Solar Power Development in India," Sustainable Development Department, The World Bank, 2010.
[46] J. Hoppmann, J. Huenteler, and B. Girod, "Compulsive policy-making—The evolution of the German feed-in tariff system for solar photovoltaic power," *Res. Policy*, vol. 43, no. 8, pp. 1422–1441, Oct. 2014.
[47] R. Quitzow, "Assessing policy strategies for the promotion of environmental technologies: A review of India's National Solar Mission," *Res. Policy*, vol. 44, no. 1, pp. 233–243, Feb. 2015.
[48] S. Chakraborty, P. Sadhu, and U. Goswami, "Barriers in the Advancement of Solar Energy in Developing Countries Like India," Social Science Research Network, Rochester, NY, SSRN Scholarly Paper ID 2884044, Oct. 2016.
[49] S. Srinivasan, "The Indian solar photovoltaic industry: a life cycle analysis," *Renew. Sustain. Energy Rev.*, vol. 11, no. 1, pp. 133–147, Jan. 2007.
[50] K. M. Eisenhardt, "Building Theories from Case Study Research," *Acad. Manage. Rev.*, vol. 14, no. 4, pp. 532–550, Oct. 1989.
[51] R. K. Yin, *Case study research: design and methods*. Sage Publications, 1994.
[52] B. Kaplan and D. Duchon, "Combining Qualitative and Quantitative Methods in Information Systems Research: A Case Study," *MIS Q.*, vol. 12, no. 4, pp. 571–586, 1988.
[53] N. Siggelkow, "Persuasion With Case Studies," *Acad. Manage. J.*, vol. 50, no. 1, pp. 20–24, Feb. 2007.
[54] M. M. Edalat and H. Stephen, "Effects of two utility-scale solar energy plants on land-cover patterns using SMA of Thematic Mapper data," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 1139–1152, Jan. 2017.
[55] S. Samanta, D. K. Pal, S. S. Aiau, and B. Palsamanta, "Geospatial modeling of solar radiation to explore solar energy potential in Papua New Guinea," *Spat. Inf. Res.*, vol. 24, no. 5, pp. 531–544, Oct. 2016.
[56] A. Suuronen *et al.*, "Optimization of photovoltaic solar power plant locations in northern Chile," *Environ. Earth Sci.*, vol. 76, no. 24, p. 824, Dec. 2017.
[57] Y. Qian, W. Zhou, J. Yan, W. Li, and L. Han, "Comparing Machine Learning Classifiers for Object-Based Land Cover Classification Using Very High Resolution Imagery," *Remote Sens.*, vol. 7, no. 1, pp. 153–168, Jan. 2015.
[58] H. T. Nguyen and J. M. Pearce, "Incorporating shading losses in solar photovoltaic potential assessment at the municipal scale," *Sol. Energy*, vol. 86, no. 5, pp. 1245–1260, May 2012.
[59] E. Skoplaki and J. A. Palyvos, "Operating temperature of photovoltaic modules: A survey of pertinent correlations," *Renew. Energy*, vol. 34, no. 1, pp. 23–29, Jan. 2009.

[60] T. Kaya and C. Kahraman, "Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul," *Energy*, vol. 35, no. 6, pp. 2517–2527, Jun. 2010.
[61] T. L. Saaty, "How to make a decision: The analytic hierarchy process," *Eur. J. Oper. Res.*, vol. 48, no. 1, pp. 9–26, Sep. 1990.
[62] W. Ho, "Integrated analytic hierarchy process and its applications – A literature review," *Eur. J. Oper. Res.*, vol. 186, no. 1, pp. 211–228, Apr. 2008.
[63] J. Barzilai, "Deriving weights from pairwise comparison matrices," *J. Oper. Res. Soc.*, vol. 48, no. 12, pp. 1226–1232, Dec. 1997.
[64] I. Kaliszewski and D. Podkopaev, "Simple additive weighting—A metamodel for multiple criteria decision analysis methods," *Expert Syst. Appl.*, vol. 54, pp. 155–161, Jul. 2016.
[65] A. Chaurey and T. C. Kandpal, "Assessment and evaluation of PV based decentralized rural electrification: An overview," *Renew. Sustain. Energy Rev.*, vol. 14, no. 8, pp. 2266–2278, Oct. 2010.
[66] U. Lichtenthaler, "Open Innovation in Practice: An Analysis of Strategic Approaches to Technology Transactions," *IEEE Trans. Eng. Manag.*, vol. 55, no. 1, pp. 148–157, Feb. 2008.
[67] A. K. Shukla, K. Sudhakar, P. Baredar, and R. Mamat, "Solar PV and BIPV system: Barrier, challenges and policy recommendation in India," *Renew. Sustain. Energy Rev.*, vol. 82, pp. 3314–3322, Feb. 2018.
[68] N. K. Sharma, P. K. Tiwari, and Y. R. Sood, "Solar energy in India: Strategies, policies, perspectives and future potential," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 933–941, Jan. 2012.
[69] D. Chattopadhyay, "Modelling renewable energy impact on the electricity market in India," *Renew. Sustain. Energy Rev.*, vol. 31, pp. 9–22, Mar. 2014.
[70] P. Loka, S. Moola, K. Polsani, S. Reddy, S. Fulton, and A. Skumanich, "A case study for micro-grid PV: lessons learned from a rural electrification project in India," *Prog. Photovolt. Res. Appl.*, vol. 22, no. 7, pp. 733–743, 2014.
[71] P. Yadav, P. J. Davies, and S. Abdullah, "Reforming capital subsidy scheme to finance energy transition for the below poverty line communities in rural India," *Energy Sustain. Dev.*, vol. 45, pp. 11–27, Aug. 2018.
[72] A. Chauhan and R. P. Saini, "Renewable energy based off-grid rural electrification in Uttarakhand state of India: Technology options, modelling method, barriers and recommendations," *Renew. Sustain. Energy Rev.*, vol. 51, pp. 662–681, Nov. 2015.
[73] L. Späth, "Large-scale photovoltaics? Yes please, but not like this! Insights on different perspectives underlying the trade-off between land use and renewable electricity development," *Energy Policy*, vol. 122, pp. 429–437, Nov. 2018.
[74] A. Singh, G. Vats, and D. Khanduja, "Exploring tapping potential of solar energy: Prioritization of Indian states," *Renew. Sustain. Energy Rev.*, vol. 58, pp. 397–406, May 2016.
[75] M. Şahin, Y. Kaya, M. Uyar, and S. Yıldırım, "Application of extreme learning machine for estimating solar radiation from satellite data," *Int. J. Energy Res.*, vol. 38, no. 2, pp. 205–212, 2014.
[76] D. Assouline, N. Mohajeri, and J.-L. Scartezzini, "Quantifying rooftop photovoltaic solar energy potential: A machine learning approach," *Sol. Energy*, vol. 141, pp. 278–296, Jan. 2017.
[77] I. Purohit, P. Purohit, and S. Shekhar, "Evaluating the potential of concentrating solar power generation in Northwestern India," *Energy Policy*, vol. 62, pp. 157–175, Nov. 2013.
[78] C. Sharma, A. K. Sharma, S. C. Mullick, and T. C. Kandpal, "Assessment of solar thermal power generation potential in India," *Renew. Sustain. Energy Rev.*, vol. 42, pp. 902–912, Feb. 2015.

[79] R. Mahtta, P. K. Joshi, and A. K. Jindal, “Solar power potential mapping in India using remote sensing inputs and environmental parameters,” *Renew. Energy*, vol. 71, pp. 255–262, Nov. 2014.
[80] M. R. Nouni, S. C. Mullick, and T. C. Kandpal, “Providing electricity access to remote areas in India: An approach towards identifying potential areas for decentralized electricity supply,” *Renew. Sustain. Energy Rev.*, vol. 12, no. 5, pp. 1187–1220, Jun. 2008.
[81] S. P. Sindhu, V. Nehra, and S. Luthra, “Recognition and prioritization of challenges in growth of solar energy using analytical hierarchy process: Indian outlook,” *Energy*, vol. 100, pp. 332–348, Apr. 2016.
[82] S. Sindhu, V. Nehra, and S. Luthra, “Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: Case study of India,” *Renew. Sustain. Energy Rev.*, vol. 73, pp. 496–511, Jun. 2017.
[83] P. Aragonés-Beltrán, F. Chaparro-González, J.-P. Pastor-Ferrando, and A. Pla-Rubio, “An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process)-based multi-criteria decision approach for the selection of solar-thermal power plant investment projects,” *Energy*, vol. 66, pp. 222–238, Mar. 2014.
[84] F. Ahammed and A. Azeem, “Selection of the most appropriate package of Solar Home System using Analytic Hierarchy Process model in rural areas of Bangladesh,” *Renew. Energy*, vol. 55, pp. 6–11, Jul. 2013.
[85] S. Luthra, S. Kumar, D. Garg, and A. Haleem, “Barriers to renewable/sustainable energy technologies adoption: Indian perspective,” *Renew. Sustain. Energy Rev.*, vol. 41, pp. 762–776, Jan. 2015.
[86] J. D. Nixon, P. K. Dey, and P. A. Davies, “Which is the best solar thermal collection technology for electricity generation in north-west India? Evaluation of options using the analytical hierarchy process,” *Energy*, vol. 35, no. 12, pp. 5230–5240, Dec. 2010.

Table 1 - Research focused on estimating solar potential

Author-Year	Summary of research	Primary data
I. Purohit et al., 2013 [77]	Evaluation of concentrated solar power generation potential in Northwestern India	Solar radiation
R. Singh et al., 2015 [18]	Estimating the total solar power potential of Mumbai over an entire year	Solar irradiance with ambient temperature
C. Sharma et al., 2015 [78]	State-wise assessment of total solar thermal power potential in India	Solar irradiance with wasteland data
R. Mahtta et al, 2014 [79]	Solar power potential mapping in India at a district level	Solar irradiance with land use and land terrain data
M. R. Nouni et al., 2008 [80]	Study on decentralizing electricity supply to provide better access to rural areas	Cost of electricity

Table 2 - Key factors affecting installation of photovoltaics

Assessment	Factor	Definition based on operational use	Source of Data
Geological	Land use and land cover	Larger the land area with lower land cover enables larger plant installation for higher power production capacity	Landsat 8
	Height	Higher altitude yield lower energy conversion efficiency since spectrum becomes blue-rich due to the Rayleigh scattering at higher elevations	ASTER
	Slope	Lower slope angles represent flatter geographical planes which lead to better exposure and electricity production	
	Aspect	South direction-based aspect allow higher power generation as the sun traverses this path in the northern hemisphere	
Climatic	Solar Radiation	Higher solar radiation provides more power generation capacity	Automatic Weather Station ASTER
	Dew point temperature	Large variations of dew point across season reduces solar intensity and weakens the power generation capacity	
	Wind direction	South direction-based air flow allows for better cooling of solar panels and provide for better operational efficiency of the panels themselves	
	Wind speed	Lower wind speeds provide brighter average irradiance conditions and provision better conditions for power generation	
Access	Road network	Closer access to road network reduces the cost to transport material and power	Landsat 8
	Water resources	Closer access to water reduces the cost of infrastructure needed to access it.	

Table 3 - Use of AHP in tackling challenges within solar industry

Author – Year	Application of AHP	Nature of factors
S. P. Sindhu et al., 2016 [81]	Study of barriers in implementation of solar energy	Institutional, technical, political and regulatory, social, cultural and behavioral, finance and cost of capital
S. Sindhu et al., 2017 [82]	Helping policymakers in the evaluation process of appropriate solar farm site selection	Social, technical, economic, environmental, political
Aragonés-Beltrán et al., 2014 [83]	Selection of solar-thermal power plant investment projects by a company	Political risks, energy policy, water supply, financing, solar radiation, costs, experience
F. Ahammed et al., 2013 [84]	Selection of package of solar home system for rural electrification	Cost, capability to meet the electricity demand, availability
S. Luthra et al., 2015 [85]	Identify major barriers in the adoption of renewable and green energy technologies in the India	Economic, financial, market, awareness, information, technical, ecological, geographical, cultural, behavioral, government issues
J.D. Nixon et al., 2010 [86]	Evaluation of the main existing solar thermal power collection technologies	Efficiency, compatibility with work fluid, reliability, availability, affordability, resource use, scalability

Table 4 - Primary and secondary criterion weight assignment with AHP

Criteria	Preference	Factor	Units	Weight	Sub-Preference	Minimum Range	Maximum Range	Sub-Weights
Primary	1	Radiation	W-h/m^2	0.44144968	1	3,651,010	3,081,260	0.28119708
					2	3,081,260	2,511,530	0.11401983
					3	2,511,530	1,941,800	0.04623277
	2	Slope	degree	0.19991571	1	0	3	0.11271503
					2	3	6	0.05265347
					3	6	10	0.02354735
					4	10	15	0.01099986
	3	Aspect	N/A	0.19991571	1	South	South	0.12734342
					2	South	South East	0.05163523
					3	South	South West	0.02093706
	4	Height	m	0.08609448	1	0	300	0.054840940
					2	300	500	0.022236912
					3	500	>500	0.009016626
	5	Wind Speed	Knots	0.04116625	1	0	0.5	0.026222306
					2	0.5	1	0.010632624
					3	1	1.5	0.004311318
	6	Wind Direction	N/A	0.02053759	1	East or West	East or West	0.01308215
					2	West to North East	East to South East	0.00530455
					3	East to North East	West to South West	0.00215089
	7	Dew Point Temperature	Celsius	0.01092059	1	N/A	10	0.01092059
Secondary	1	Primary Weight	N/A	0.62201091	1	0.28	0.3	0.006676453
					2	0.3	0.32	0.010744776
					3	0.32	0.34	0.018105542
					4	0.34	0.36	0.031161824

Criteria	Preference	Factor	Units	Weight	Sub-Preference	Minimum Range	Maximum Range	Sub-Weights
					5	0.36	0.38	0.053973863
					6	0.38	0.4	0.092895536
					7	0.4	0.42	0.156534119
					8	0.42	>0.42	0.251918799
	2	Area	Acres	0.24733354	1	0	2.5	0.15754789
					2	2.5	7	0.06388254
					3	7	>7	0.02590310
	3	Distance to Road	Km	0.09348329	1	0	3	0.020958196
					2	3	5	0.009790369
					3	5	8	0.004378386
					4	8	>8	0.002045310
	4	Distance to Water Source	Km	0.03717226	1	0	3	0.052707072
					2	3	5	0.024621475
					3	5	8	0.011011058
					4	8	>8	0.005143684

Table 5 - Results of select proposed sites from the AHP process for photovoltaic site assessment

ID	Height (m)	Slope (Degree)	Road Distance (km)	Water Distance (km)	Power (MW)	Final Criteria
12395	629	1	2.23	0.57	2.52	0.35
32061	916	2	2.72	1.7	2.72	0.35
32868	728	1	0.24	2.52	3.94	0.35
49658	872	0	1.19	0.6	2.98	0.35
57350	808	2	0.78	2.55	4.35	0.35
62832	654	2	0.24	0.93	2.7	0.35
8087	642	1	16.47	0.73	2.7	0.33
17014	669	2	5.73	1	2.49	0.33
32368	739	1	0.27	3.18	2.73	0.32
23754	683	1	4.28	3.36	4.13	0.31
17534	644	3	1.63	0.58	34.65	0.26
24691	686	2	0.33	0.5	2.46	0.26
5649	650	4	2	1	27.28	0.24
17018	715	5	0.15	1.32	34.9	0.24
18799	696	4	2.04	0.49	36.25	0.24
31443	895	1	3.57	0.91	3.22	0.24
67301	493	6	1.31	1.42	40.41	0.24
68262	489	6	0	2.17	277.3	0.24
19614	668	5	4.55	1.4	91.19	0.23
4008	639	4	21.14	0.46	172.15	0.22

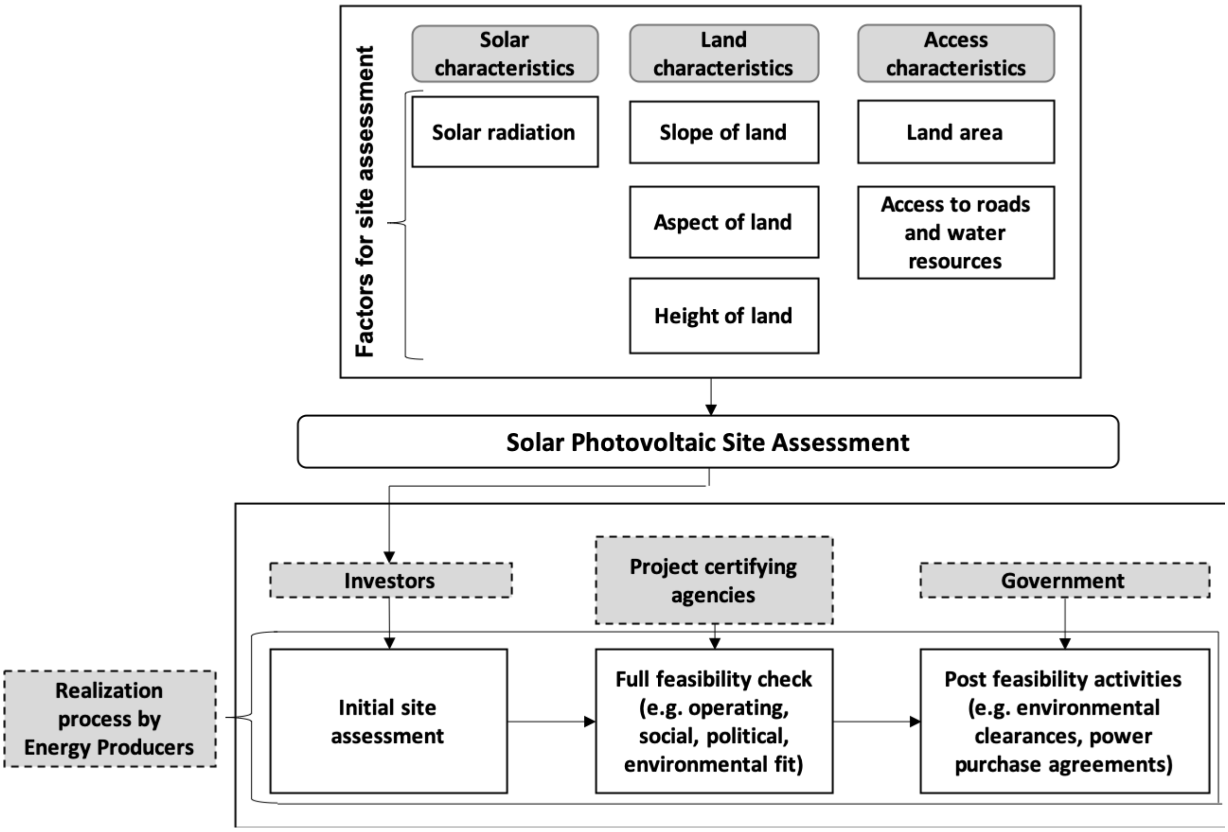

Figure 1 - Solar photovoltaic project lifecycle

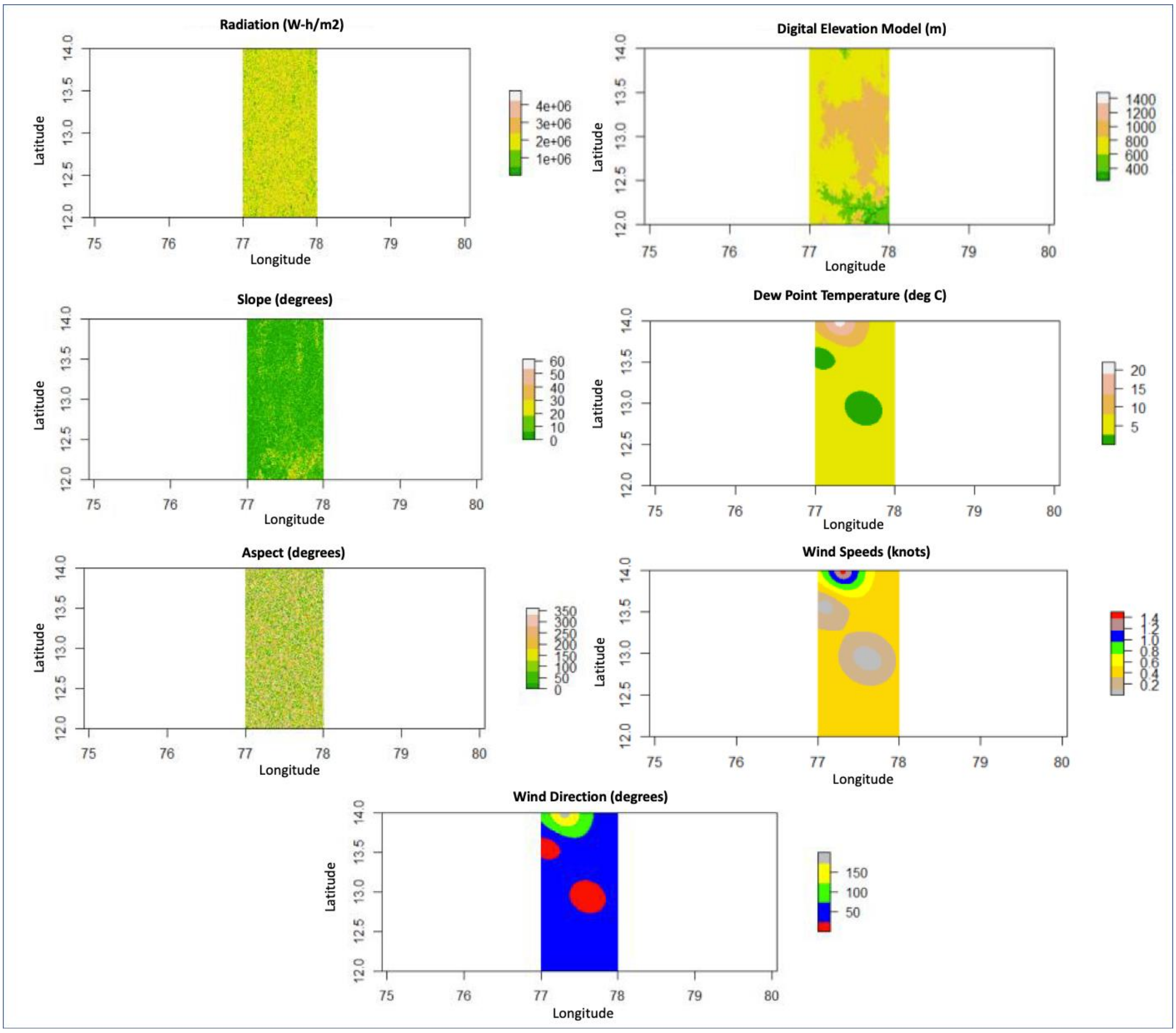

Figure 2 – Satellite derived data acquired over Bangalore region

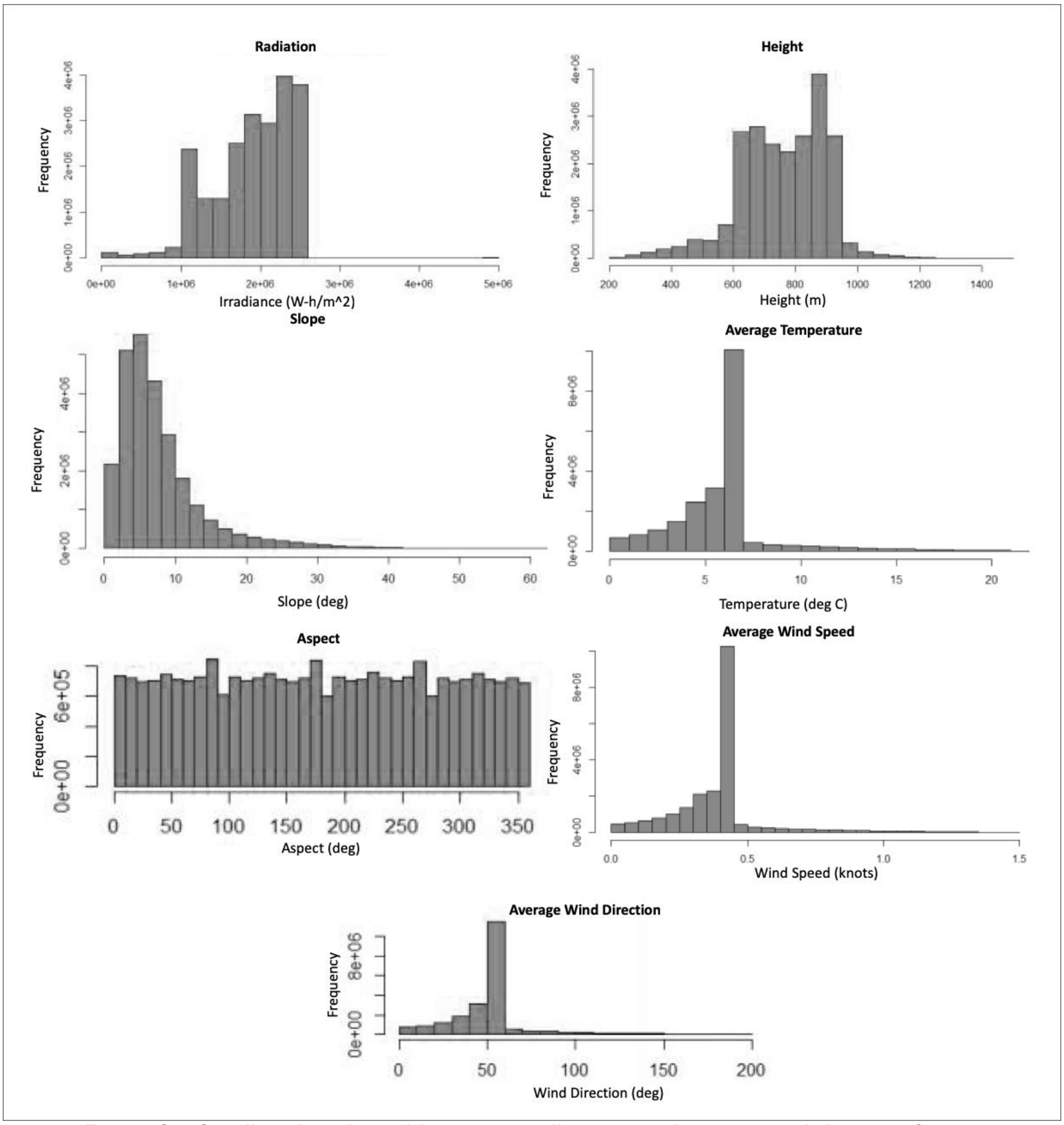

Figure 3 - Satellite data based histograms illustrating the extracted data on factors

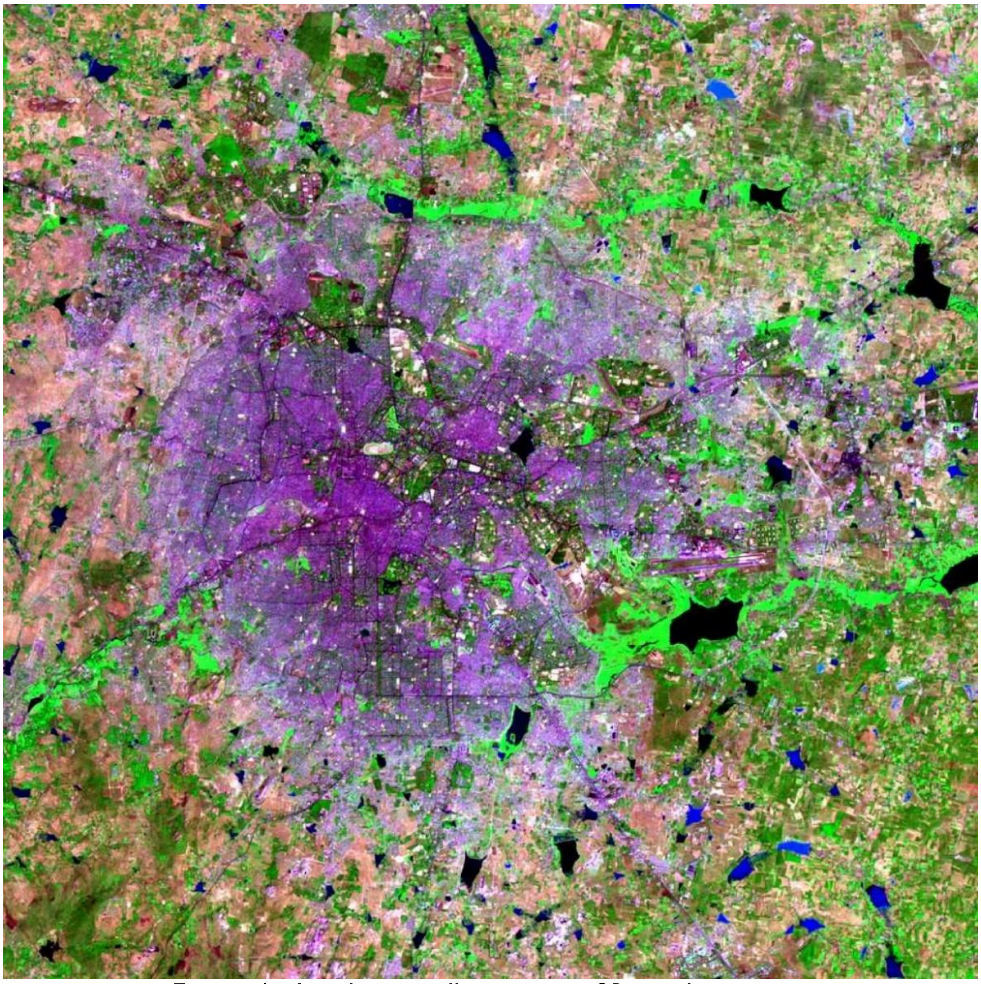

Figure 4 - Landsat satellite image of Bangalore region

[Index for colors: Trees and bushes (olive green), crops (pink to red), wetland vegetation (dark green to black), water (shades of blue), urban areas (lavender), bare soil (magenta, lavender, or pale pink)].