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Analytic Hierarchy Process for Multi-Criteria Site Selection of Utility-Scale Solar and Wind Projects

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The deployment of renewable energy technologies is also a socio-political decision, in as much as it is a technical decision. This can explain the success and failure of many renewable energy projects in the world. The present study proposes a new decision-making criterion for assessment of potential sites for utility-scale solar and wind project deployment, using the analytic hierarchy process (AHP) methodology. Considering data availability, the proposed metrics include potential social impact, local market characteristics, existing local infrastructure, disaster and climate risk, policies, and wind/solar intensity. Furthermore, various experts from academe, industry, policy making, and finance were interviewed to formulate the prioritization scores. The results from a case study in the Philippines show that local wind and solar intensity is still the top priority across all stakeholders, followed by the presence of renewable energy policies, and vulnerability to disaster and climate risks. The least priority is potential social impact. The results are presented via a geographical information system (GIS) map. Furthermore, existing renewable energy installations in the Philippines are assessed using the resulting criteria. The proposed method should be useful for the development of a national strategic deployment plan for emerging alternative energy technologies, and should be important for sustainable regional development.

1. Introduction

Pushing for a renewable energy project is more challenging compared to conventional energy projects. There are plenty of barriers, and sometimes, the difficulty even lies on identifying these barriers. Worse, these problems only surface during the final stretch of implementation, upon public disclosure.

Plenty of cancellations for renewable energy projects have been reported in recent news globally. PV-tech (2016) reported a massive cancellation of future renewable energy projects in Brazil due to decreasing electricity demand, largely driven by decreasing GDP. In California, USA, Travis Air Force Base (2010) reported a cancelation of a potential solar PV project as well, citing potential social impacts – benefits to existing land users – as the reason. In Ontario, Canada, plenty of sources report about the recent cancellation of a wind turbine project. Wasaga Sun (2017) cited potential health and environmental impacts to adjacent neighbourhood as reasons, while The Canadian Press (2016) and The Star (2016) cited rising electricity prices for the cancellation. Finally, The Hindu (2016) reported the cancellation of renewable energy projects as well in many provinces of India, due to land availability, poor site access, and availability of transmission lines. In a recent study, while modelling transition roadmaps for 100 % clean energy in the United States, Jacobson et al. (2015) reported a potential loss of 3.9 million jobs in the conventional energy sector. However, he implied that though plenty of jobs will be affected, the net effect in the long term will be the creation of even more jobs. Job security due to renewable energy transition should also be considered in future decision models.

The examples above only show how complex approving utility-scale renewable energy projects can be. This is because there are many other important considerations beyond technical factors. As demonstrated by examples cited above, availability of policies, promise of job creation, societal acceptance, environmental considerations, and local market characteristics are very important as well.

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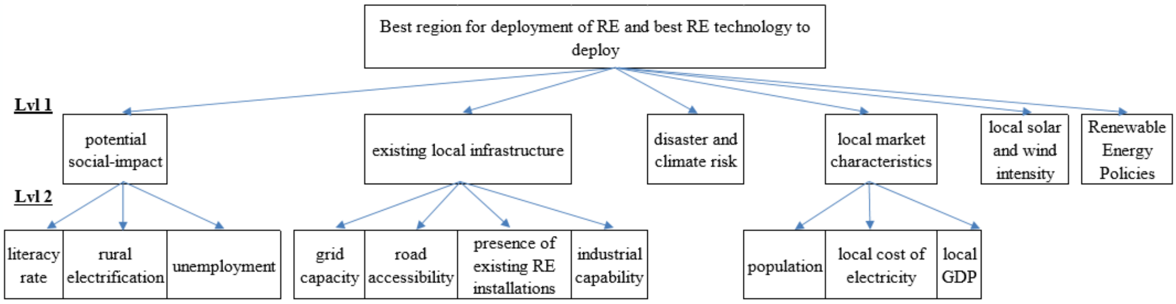


Figure 1: Final decision superstructure

The novelty of this study is in the infusion of socio-political and disaster risk factors in the decision model. This is combined with the usual techno-economic assessment used in the approval of large-scale renewable energy projects. Using the analytic hierarchy process (AHP), priority weights for each factor are obtained from a pool of experts. Particularly, the use of AHP gives the resulting decision model a practical aspect, benefitting from the actual experience of surveyed experts. For the purpose of site ranking for project deployment, the whole study is done within a spatial-based decision-making framework. The final results are presented using GIS maps. After developing the decision model, the criteria are applied to existing large-scale renewable energy projects in the Philippines for validation.

The rest of the paper is organized as follows: a literature review on AHP and site selection methodologies are presented in section 2, followed by a review of the methodology, results discussion, application to a case study for validation, and finally ending with conclusions and recommendations.

2. Literature review

2.1 The Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a decision-making tool for pairwise comparisons of specified criteria. Saaty (2008) developed this method as a means to quantify intangible factors relative to tangible ones. The relative scale of judgement indicates the prioritization of one element over another with respect to an attribute. In order for decisions to be made, decomposing the decision is done to generate priorities using the following steps: 1) define the problem and objectives; 2) create the decision structure hierarchy from the top, intermediate levels until the lowest level; 3) create a pairwise comparison matrix; 4) for every element, use the priorities for each comparison done in the level below; 5) Add the weighed values for every level and take the overall or global priority. Proceed with this process of weighing and adding until the bottom level.

There is a wide range of application for AHP. Kohara and Sugiyama (2016) used AHP as a tool for establishing countermeasure protocols in the event of a disaster. Furthermore, AHP may be enhanced with the use of optimization methods to address a specific type of objective. For instance, Sumabat et al. (2015) presented the use of AHP combined with multiple response surface analysis as a product design tool in terms of customer preferences and product property.

2.2 Site selection methodologies

Several methods on site selection had been done over the recent years. For instance, Ubando et al. (2015) used AHP to identify sites for microalgae production in the Philippines. On the other hand, the use of geographic information systems (GIS) was employed in the studies made by Miller and Li (2014). Nasehi et al. (2016) presented a combination of several methods for site selection. The authors used GIS in combination with fuzzy optimization and Analytical Network Process (ANP). Gigovi et al. (2017) used GIS, Multiple Criteria Decision Analysis (MCDA) and Multi-Attributive Border Comparison (MABAC).

The complexity of the model primarily depends on the data availability and accuracy as well as objective of the model to be created. Some limitations on the data availability may inhibit the full exploration and incorporation of other decision-support tools. As such, customization of site selection models is necessary for specific geographical conditions.

3. Methods and data

3.1 AHP

The process of AHP begins with the development of the decision superstructure (see section 3.2), which basically summarizes all the identified factors in the decision-making. Afterwards, for each level and subgroup, a set of pairwise comparisons are systematically created. These comparisons require the interviewed experts to choose between a pair of factors at a time, which is more important using a 9-point scale, with 1 being equally important and 9 with the other being extremely more important. The responses are recorded on a comparison matrix, and the priority vectors are obtained through simple matrix algebra techniques. A detailed discussion on the methodology is available in Saaty (2008).

3.2 Decision structure development

To finalize the decision structure to be used in the AHP survey, three experts (1 policy/project consultant, and 2 project engineers) were separately interviewed to provide feedback on the identified criteria. The final decision structure displayed in Figure 1 integrates experts' feedback. The description of the general factors identified in the decision structure are also provided below. The data for the factors are sourced from the Philippine Statistical Yearbook (2015).

Potential Social Impact refers to the potential of the project to improve the quality of lives of the population living near the project site. The following are assessed: literacy rate, rural electrification (% of houses with access to electricity) and unemployment rate. Existing Local Infrastructure considers the following: existing electrical grid capacity, road accessibility (% paved roads), presence of existing renewable energy installations, and current industrial capability of the region (no. of industrial establishments). Disaster and Climate Risk refers to the vulnerability of the site to climate-related and natural disasters such as landslides, heavy flooding, typhoons and earthquakes. The data is taken from United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA, 2011). Local Market Characteristics considers economic factors which could affect the demand for the project, such as local population, local cost of electricity and local GDP in the region. Local Solar and Wind Intensity, as the most basic requirement, considers the power-generating potential of a project site. Solar and wind maps from NREL are used as references. Lastly, Renewable Energy Policies weigh-in on the importance of local renewable energy policies such as feed-in tariff (FIT). Currently, the Renewable Energy Act of 2008 in the Philippines covers the whole country. Since spatial differentiation with regards to policy availability is not possible, this is only retained to obtain feedback from the respondents on the relative importance of policies in comparison to other factors.

3.3 Survey respondents

The survey had 20 respondents in the process. Four specific groups were targeted for the study: finance, policy making, industry and academe. The most responsive of the group were the industry practitioners with a total of 14 respondents. The rest of the group had two respondents each.

4. Results and discussion

4.1 Priorities of stakeholders

The priorities of each stakeholder group are summarized using a radar chart on Figure 2. The same is also presented in more detail in Table 1. The financial sector has a heavy inclination towards the presence of renewable energy policies. This is understandable as they seek security of large capital investment. On the other hand, industry practitioners are the ones to value potential social impact the most. With regards to local solar/wind intensity, the academe and industry practitioners agree on its importance. The policymakers prioritize the presence of existing local infrastructure and the presence of renewable energy policies. When aggregated, potential social impact, local market characteristics and existing local infrastructure appear as the least priorities. The aggregated criteria also show growing importance being given to disaster risk vulnerability, as it does not only endanger investment, but national energy security as well in case of energy project deployment in the area. The aggregated criteria afterwards is used to score the desirability of each region with regards to renewable energy investment.

4.2 Regional scoring

Figure 3 shows the solar (a) and wind (b) site desirability GIS maps. NCR, ARMM, CAR, regions 1, 4A, 4B, 6, 8 and 9 are among the regions consistently in the top. Although region 8 has the highest score for solar intensity, it had a lower score in local market characteristics, potential social impact, and disaster and climate risk than NCR and ARMM. An in-depth look shows that NCR (national capital region) is the top choice for solar renewable technologies, mainly because of its excellent market characteristics. It may have a below average score on solar intensity, but it has good scores on all other aspects. Looking at the wind category, Region 4B consistently ranked first among all stakeholders, with an overall composite score of 71.52 %. Region 4B has an average score for local market characteristics and disaster and climate risk, an above average on potential social impact, and a below average score on existing local infrastructure. What made the region stand out was its strong available wind intensity.

Considering regions with high solar intensities, regions 3, 5 and 12 did not make it to the top 5 because they scored below average in local market characteristics, disaster and climate risk, and existing local infrastructures. Looking also on regions with high wind intensity, only region 3 did not make it to the top 5 because of a low score in existing local infrastructure and an average score on local market characteristics. Evaluating the data based on the cost of electricity, regions CAR, 4B, 5, 6, and 7 have the highest scores, but regions 5 and 7 did not make it to the top 5 desirable sites (for both wind and solar) because of their low scores on existing local infrastructures. In terms of potential, there are regions which have very good solar and wind intensity, but have no or very little existing RE installations. These are regions 4B, 5, and 9.

5. Case study: application to existing renewable energy installations in the Philippines

5.1 Cadiz solar power plant, 132.5 MW, Region VI

The power plant is located in Cadiz, Negros Occidental, and was commissioned on March 3, 2016. It is the largest solar power plant in the country as of its commissioned date. The plant is situated in a region where the solar projects are not too desirable. Region 6 was ranked 9th overall among the regions, but it's solar intensity ranked 4th, explaining its approval. The main reason for its low desirability is its below average score on local market characteristics. However, this is addressed with the help of the renewable energy policies on feed-in tariffs (FIT). It can be sustained better if market characteristics are enhanced through government intervention.

5.2 SEPALCO solar PV farm, 50 MW, Region VIII

The project in Barangay Castilla, Palo, Leyte. The power plant was able to withstand record wind speeds of 70 m/s during typhoon devastations in 2013. This plant is a very good example of a good investment based on the study – having been situated in Region 8, which placed 3rd in aggregated ranking and placed 4th in solar intensity. This is a very good example of a climate risk ready RE technology that is now emerging in the Philippines.

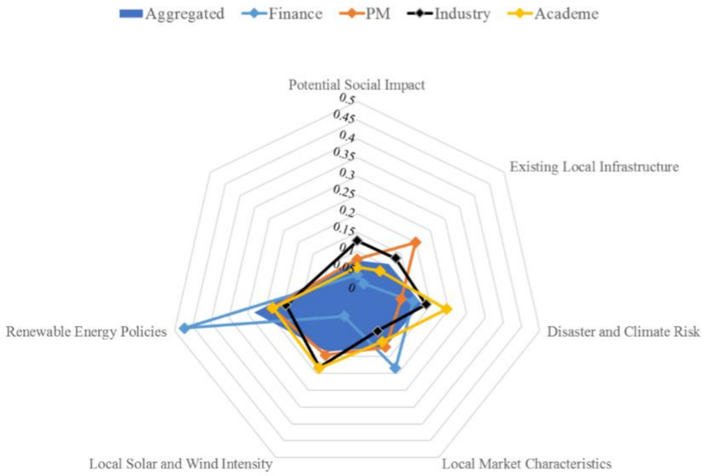
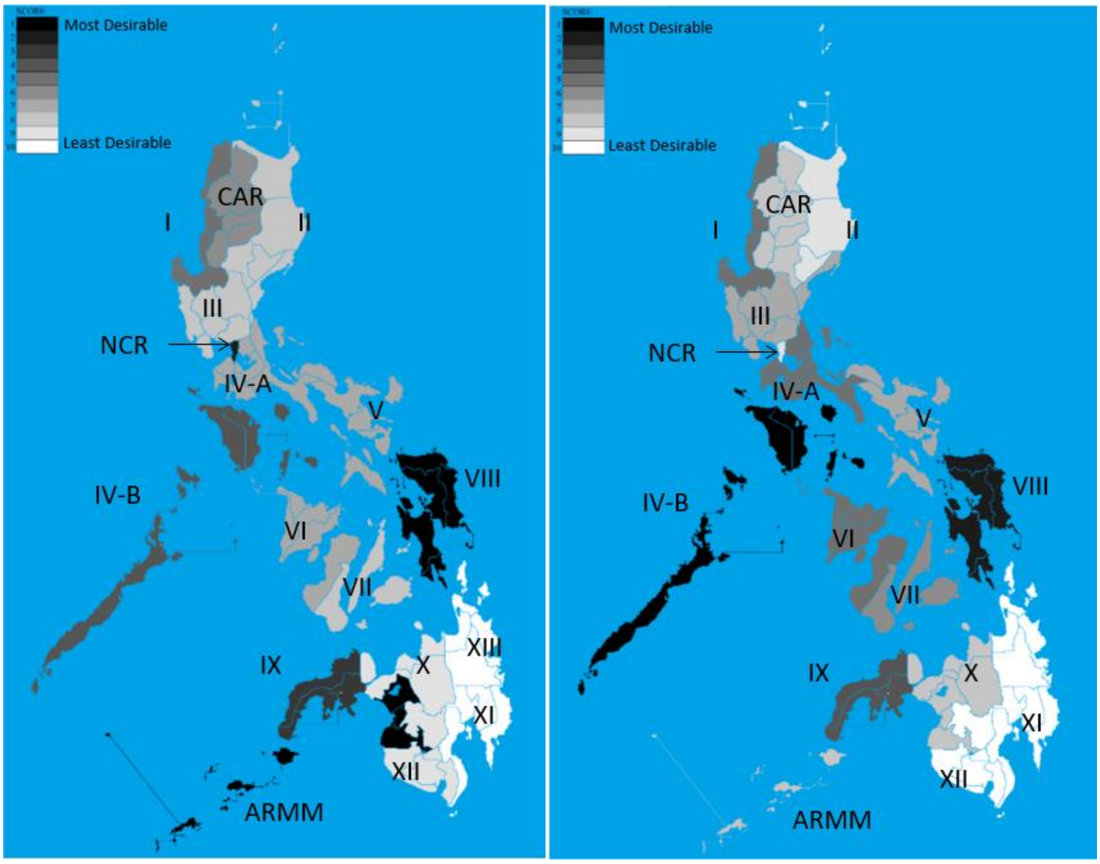


Figure 2: Priorities of various stakeholders in renewable project site selection

Table 1: Summary of final criteria from AHP

Decision Criteria	Aggregated	Policy Maker	Industry	Finance	Academe
Potential Social Impact	11.1 %	8.0 %	12.9 %	3.8 %	5.8 %
Literacy Rate	2.4 %	1.4 %	2.9 %	0.6 %	0.8 %
Rural Electrification	4.4 %	4.4 %	5.3 %	2.0 %	0.5 %
Unemployment	4.3 %	2.1 %	4.6 %	1.1 %	4.4 %
Existing Local Infrastructure	12.4 %	19.9 %	13.1 %	2.2 %	7.7 %
Grid capacity	3.7 %	9.6 %	3.2 %	0.7 %	4.4 %
Road accessibility	3.2 %	4.9 %	3.3 %	0.9 %	1.0 %
Presence of existing RE installations	1.9 %	2.6 %	2.2 %	0.3 %	0.7 %
Industrial capability	3.5 %	2.7 %	4.4 %	0.3 %	1.6 %
Disaster and Climate Risk	18.6 %	12.0 %	18.8 %	15.4 %	24.5 %
Local Market Characteristics	12.7 %	17.3 %	12.5 %	23.5 %	15.6 %
Population	2.5 %	3.2 %	2.7 %	2.7 %	2.9 %
Local cost of electricity	6.9 %	7.1 %	6.5 %	16.9 %	9.6 %
Local GDP	3.3 %	7.1 %	3.3 %	3.9 %	3.1 %
Local Wind and Solar Intensity	23.6 %	19.6 %	23.2 %	8.1 %	23.5 %
Renewable Energy Policies	21.7 %	23.3 %	19.5 %	47.1 %	23.0 %



(a) (b)

Figure 3: Final scoring of each region with regards to renewable energy project deployability for solar (a) and wind (b)

5.3 Burgos wind farm, 150 MW, Region I

The project, based in Ilocos Norte, Region 1, is an excellent selection. Region 1 placed 2nd in wind intensity, while placing 4th overall in the aggregated ranking. Although it scored poorly on potential social impact, disaster and climate risk and local market characteristics, it managed to score above average on existing local infrastructure. Because the stakeholders prioritize existing local infrastructure and local wind intensity, Region 1 still managed to have a desirable rating. Areas for improvement are disaster and climate risks, and local market characteristics.

5.4 Pililla wind farm, 54 MW, Region IV-A

The project is situated in Pililla, Rizal, Region 4A. Based on the study, the site where the wind farm is located is ranked 2nd overall. It may have scored poorly on potential social impact and disaster and climate risk, but it scored above average on existing local infrastructure, local market characteristics and local wind intensity. This project has the major factors for viability, and with the help of FIT policy, it is very likely to have a sustainable operation for years to come.

6. Conclusions and recommendations

The study proposed new decision-making criteria for site selection and ranking in utility-scale solar and wind energy projects. The novelty of the said criteria, is in consideration of the socio-political and disaster risk factors, which haven't been seen in previous studies. Per 20 expert interviewees, the most important consideration is the available solar/wind intensity, followed by the presence of renewable energy policies, and disaster and climate risk vulnerability. The top 3 factors reflect the stakeholders search for long term security and sustainability for their capital-intensive investment. In addition, potential social impact, the presence of existing renewable energy installations, and local market characteristics received an even ~12 % priority each, signifying also their importance in the decision-making process. In summary, it must be obvious that renewable energy development is more than a technical problem, but rather also a social, political, and economic problem.

Applying the criteria to existing RE installations in the Philippines validate the results and uncover the strengths and weaknesses of existing investments. The results may also be used to recommend potential government interventions to improve the sustainability of the existing projects. It must be noted that the responses would be sensitive to culture and various practices, and caution should be observed in applying the same criteria elsewhere. Lastly, growing importance of vulnerability to climate and disaster risks also came out of the results. Furthermore, plenty of improvements can still be done in the decision model, especially on the list of factors considered. Currently, it is limited to what data the authors have access to, and what they can quantify. There are surely more accurate and precise ways to assess, for example, potential social impact and disaster risk vulnerability.

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