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A Comparative Analysis of Renewable Energy Resource in Sustainability Contexts using the Analytical Hierarchy Process (AHP) Approach in New Zealand

Abi Prionggo and Jessica Stephani

Auckland, New Zealand

abi.prionggo@gmail.com, jessica.sihombing@gmail.com

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ABSTRACT

Renewable energy resource is seen as a focal point for future energy systems due to their lasting presence and environmentally clean profile. Related to that, this study is carried out to see whether the Analytical Hierarchy Process (AHP) approach can be implemented to help comparing and determining a set of renewable energy resource that would provide optimum impacts, especially with regards to sustainability. As a representation of the elements of sustainable energy, twelve indicators are chosen which comprises of indicators from the technical, economic, social, and environmental dimensions. Meanwhile, the context of the energy sector of New Zealand serves as a case study for the comparative analysis. For weight attribution, two future development scenarios for the country's energy sector were identified: 1) The environmentally oriented Kea scenario; and 2) The Tui scenario that priorities economic stability and social welfare. As a result, for the Kea scenario, it is identified that wind power comes out as a preferable option due to its generally good performance across the environmental indicators. Meanwhile, in Tui scenario case, hydropower and geothermal energy come out as preferable options over other renewable energy resource as they are the two most economically competitive renewable energy resource in the current energy market. All in all, this study served as an example in developing a working framework for comparisons of renewable energy resource using the AHP methodology. The key lesson taken from the study is the importance of involvement of stakeholders throughout the process of such works in order to produce a sound analysis and insightful results.

1. INTRODUCTION

The global society is currently faced with a range of concerns associated with the energy sector including ever-growing global energy consumption, depletion of oil and gas resource, and the climate change. With all those challenges, renewable energy resource is seen as a focal point for future energy systems due to their lasting presence and environmentally clean profile.

However, despite those advantages, development of renewable energy resource remains a complex and challenging proposition as each of the renewable energy resource is also associated with range of technical, environmental, economic, and social concerns. Moreover, each society has a different and sometimes competing interest with regards to visions of development. Therefore, it is of utmost importance that utilization of renewable energy is conducted with a careful planning and development.

According to the National Science Board of the United States (2009), there are three sustainability elements of that needs to be fulfilled in sustainable energy systems, namely availability and reliability of supply, affordability, as well as environmental and safety concerns. Thus, development of renewable energy resource needs to take these elements as guidelines, in order to optimize their benefits with regards to sustainability aspects.

With that in mind, this study is carried out to figure out a working framework that can be implemented to help policy makers comparing and determining a set of renewable energy resource that would provide optimum impacts, especially with regards to the fulfilment of the three elements of sustainability. Specifically, this study aims to test the implementation of the Analytical Hierarchy Process (AHP) as a tool for the purpose of such comparisons.

As part of the methodology, the first essential process is to determine a set of sustainability indicators that could represents the three elements of sustainable energy. Afterwards, weightings can be attributed to the indicators according to country specific energy sector policies. Hence, a set of development scenarios need to be determined as a basis for the weight attributions.

Comparisons of renewable energy resource carried out in this study is conducted in New Zealand context. With more than 80% of renewable energy portion in the national electricity mix (Ministry of Business Innovation and Employment, 2019), New Zealand is one of the most progressive countries in renewable energy development and provides as an excellent case study for such comparative analysis. Ultimately, this study aims to serves as an example of implementation of such methodology for comparisons of renewable energy resource, identifying key challenges, and deriving key lessons to take from implementation of the methodology. Results from the study can also provide insights regarding the preferability of renewable energy utilization in New Zealand, and whether the current trajectories of the country's policy in the energy sector is aligned with findings from the study.

2. LITERATURE REVIEW

2.1 Energy and Sustainability

In their study, Tester et al. (2005) viewed sustainable energy as engines that power sustainable development. Specifically, they mentioned that sustainable development would never be achieved without an energy resource in place that contributes to the balance between the three pillars of sustainability (economic, social, and environmental). Achieving such balance would mean recontextualization of all elements of the energy resource including its uses, supply technologies, and efficiencies, hence the birth of the needs and concerns of sustainable energy (Tester et al., 2005).

With regards to the recontextualization of energy systems, the National Science Board of the United States (2009) has summarized and defined sustainable energy as energy resource that are "*affordable, safe, and available in sufficient quantity to enable continued economic and social development while promoting environmental stewardship*". The definition encapsulates the role that energy resource play in contributing to the balance between economic, social, and environmental aspects, which gave birth to the context of sustainable energy. However, the definition also implies that there are some elements that need to be fulfilled by energy resource to be considered as sustainable energy, as explained in the following passages.

2.1.1. Availability and Reliability of Supply

In their study, Evans et al. (2009) said that availability of renewable energy resource and their limitations to produce base power are the most important consideration in development of energy systems. Similarly, Demirtas (2013) even mentioned that the impact of availability of energy services goes far and wide and covers a whole range of dimensions including poverty, employment opportunities, education, and culture.

The first essential aspect with regards to availability is the renewability of energy source. According to Tester et al. (2005), each type of renewable energy is tied directly with three primary energy sources which serve as energy source for renewable energy resource that people know of. The common correlation between all those energy sources is that they are essentially limitless and available continuously without any point for depletion or degradation. However, while some type of renewable energy resource able to provide energy in a limitless manner, some others are considered as limited renewable resource as they require a sufficient practice of utilization to be continuously produced (Rybár, Kudelas, & Beer, 2015).

Besides renewability, another important aspect of availability of energy resource is reliability. An important aspect related to reliability of energy provisions is the concept of intermittency, which affects energy resource like wind and solar power. Both of those energy sources are heavily affected by variations, such as the amount of sunlight available in a given day or the ever-changing intensity of wind. With these concerns of reliability, integrating renewable energy into global grid systems remains a challenging proposition.

2.1.2. Affordability

Technical limitations, in general, always corresponds to the increase in costs for development. With all the technical limitations of renewable energy resource explained previously, another important consideration in development of a renewable energy resource is how affordable it is for power generation. Affordability means that the energy resource is not just physically available but is actually affordable to produce as well as accessible to society because they can afford to consume it (Iddrisu & Bhattacharyya, 2015).

As explained by Verbruggen et al. (2010), costs of development of renewable energy can be affected by a wide range of factors including geographical settings, local contexts, and maturity of technology. With all the limitations, affordability and cost-effectiveness of each renewable energy resource is very much dependent upon a given local context. Therein, lies the challenge of developing energy systems that is cost-effective and affordable while sufficiently manages the technical limitations of each renewable energy resource.

2.1.3. Environmental and Safety Concerns

Global climate change has risen to be one of the most pressing concerns that humanity faces presently. It is widely believed that the rapid global temperature raise is driven by the massive increase of greenhouse gas (GHG) emissions in the atmosphere. According to Owusu & Asumadu-Sarkodie (2016), the consumption of fossil fuels accounted for the majority of global anthropogenic GHG emissions, where concentrations had increased to almost 40% above pre-industrial levels in the 19^{th} century. Hence, a monumental shift is required in the energy sector in terms of shifting from the carbon heavy fossil fuels to the cleaner renewable energy (Bilgen et al., 2008).

Moreover, environmental concerns associated with renewable energy utilization are not only limited to GHG emissions. Some renewable energy resources can induce a wide range of environmental concerns which is also important considerations. For instance, development of hydropower has long known to bring major environmental concerns ranging from flooding, changing water features, and damaging local biodiversity (U.S. Energy Information Administration (EIA), 2018) (Leahy, 2019).

2.2 The AHP Methodology

The Analytical Hierarchy Process is a multi-criteria decision analysis approach developed by Thomas L. Saaty in the 1970s. The AHP method works around the concept of hierarchy, which in essence means decomposition of a complex problem into a hierarchical structure (Pohekar & Ramachandran, 2004). The general framework of the AHP method according to Raith (2020) is illustrated in the figure below.

Figure 1. General framework of the AHP method (Raith, 2020)

3. SUSTAINABILITY INDICATORS FOR RENEWABLE ENERGY RESOURCE

As defined by the National Science Board of the United States (2009), there are four key components or aspects that makes up a sustainable energy, namely technical, economic, social, and environmental aspects. In this study, three indicators were chosen to represent each of the sustainability aspect, which in total combines for a total of twelve sustainability indicators. These indicators were chosen due to varying reasonings including suggestions from literatures, possibility to operationalize, and availability of data and information. With that said, these chosen indicators are not fixed, and other indicators can be added or replaced in future studies to represent the dimensions of sustainability. The following figure illustrate the sustainability indicators used in this study, which is used for the implementation of the AHP framework.

Figure 2. Sustainability indicators, modified from the National Science Board of the United States (2009)

4. CURRENT UTILIZATION OF RENEWABLE ENERGY RESOURCE IN NEW ZEALAND

4.1 Overview of New Zealand Energy Sector

With an ever-changing global energy landscape, New Zealand faces a significant set of challenges with regards to the national energy sector. Firstly, it needs to find continuous sources of energy to meet the national energy demand and to power the growing economy (New Zealand Business Council for Sustainable Development, 2005). According to New Zealand Business Council for Sustainable Development (2005), the country's national energy demand has almost tripled over the last 30 years.

In order to meet the ever-growing energy demand, New Zealand utilizes a wide range of energy sources, ranging from oil and gas, coals, as well as renewable energy. As of 2020, the Total Primary Energy Supply of New Zealand is 902.55 PJ, which is almost double the national energy demand (Ministry of Business Innovation and Employment, 2020b). However, with the increasingly rapid growth of energy demand, New Zealand need to use its current energy source more optimally as well as utilize a more diverse source of energy to stay ahead of the curve.

4.2 GHG Emissions and Renewable Energy in New Zealand

Over the course of decades, the New Zealand annual GHG emissions have been rising steadily (Ministry for the Environment, 2020). As documented by Ministry for the Environment (2020), annual GHG emissions in the country rose by about by 24% between the year 1990 to 2018, and the country's gross GHG emissions in 2018 were 78.9 million tonnes of carbon dioxide equivalent (Mt CO_2 e).

With that situation, the New Zealand government has sought to reduce the remissions generated from the energy sector, which, hascontributed significantly to the country's overall GHG emissions (41% in 2018) (Ministry for the Environment, 2020). Aligned with that, there is a strong political will in New Zealand for a continued growth in the renewable power generation sector (Walmsley et al., 2014). In 2020, the New Zealand government set a 100% renewable electricity target for the electricity sector to be met by 2030 (NZ Labour Party, 2020). The government have also established the Climate Change Response (Zero Carbon) Amendment Act which stipulates and institutionalizes the government's target of net-zero emission by 2050 (Ministry of Business Innovation and Employment, 2020b).

As of 2019, the share of renewable energy in the country's power generation is 82.4%, which is the third highest share of renewable electricity generation among OECD (Organisation for Economic Co-operation and Development) countries (Ministry of Business Innovation and Employment, 2020b). In light with the government targets, renewable power generation in the country is expected to continue to grow over the next few years.

4.3 Performance of Renewable Energy in New Zealand

With the situation as explained previously, this study aims to examine whether utilization of renewable energy resource in New Zealand has been conducted in a sustainable manner. The following figure shows the summary of all the data and information gathered with regard to renewable energy utilization in New Zealand, correspond to the sustainability indicators listed in the previous section of the paper. The information was gathered from numerous case studies conducted within New Zealand, or outside of it as a reference (due to limitation of data).

It should be noted as well that some of the indicators work in a positive orientation, while others in negative orientation. Positive orientation means that the higher the score is, the more preferable the renewable energy resource it is. Meanwhile, the negative orientation works in an opposite manner.

Table 1. Summary of New Zealand Renewable Energy Performance

Sustainability Indicators		Unit	Renewable Energy Resource				
			Hydropower	Geothermal Energy	Wind Power	Solar Power	Bioenergy
Technical Indicators	Generation Efficiency	%	75	12	30	20	42
	Capacity Factor	%	65	91.5	45	17	42
	Resource Longevity	-	2	2	3	3	2
Economic Indicators	Levelized Cost of Electricity (LCOE)	NZD/MWh	105	75	87.5	160	140
	Regional Value Added	Million NZD/MW	0.59	0.35	0.39	0.85	0.45
	Economic Lifetime	Years	50	30	25	25	30
Social Indicators	Job Creations	Jobs/MW	5.45	1.96	1.14	4.32	6.31
	Social Issues	-	7	4	3	2	6
	Social Acceptability	-	2	4	3	4	2
Environmental Indicators	Life-cycle Emissions	g of CO2 eq/KWh	13	76	8	61.5	17.1
	Ecological Impacts	-	8	4	3	3	7
	land Use	ha/MW	33.3	16.2	28.6	17.6	40.4

(white)	Normal Indicators
(yellow)	Inversed Indicators

5. FUTURE DEVELOPMENT SCENARIOS, WEIGHTINGS, AND CALCULATIONS

5.1 Normalization of Scores

As shown in the table above, some of the indicators work in a positive orientation, while others in negative orientation. Hence, in order to obtain comparability across variables, normalization approach should be carried out. Among a range of normalization approaches, the method of **rescaling** or **Min-Max** is used. In the method, a minimum and maximum point within the scale is identified, and used as a reference for the rescaling approach (Weziak-bialowolska, 2014). In this study, a scale of 1 (lowest) – 5 (highest/most positive) will be used for presentation of data with a pre-determined maximum and minimum point. The result of the data normalization is summarized in the table below. Renewable energy that acquired the best and worst scores for each of the indicators is highlighted in **green** and **red** colors.

Table 2. Rescaled performance scores (scale 1 (negative) – 5 (positive)) (source: calculation by author)

Sustainability Indicators		Score for Renewable Energy Resource				
		Hydropower	Geothermal Energy	Wind Power	Solar Power	Bioenergy
Technical Indicators	Generation Efficiency	4.0	1.5	2.2	1.8	2.7
	Capacity Factor	3.6	4.7	2.8	1.7	2.7
	Resource Longevity	3.0	3.0	5.0	5.0	3.0
Economic Indicators	Levelized Cost of Electricity (LCOE)	3.5	4.3	4.0	2.1	2.6
	Regional Value Added	3.4	2.4	2.6	4.3	2.8
	Economic Lifetime	5.0	5.0	2.1	2.1	2.7
Social Indicators	Job Creations	4.1	2.1	1.7	3.5	4.6
	Social Issues	2.2	3.4	3.8	4.2	2.6
	Social Acceptability	2.6	4.2	3.4	4.2	2.6
Environmental Indicators	Life-cycle Emissions	4.0	1.4	4.4	1.3	3.6
	Ecological Impacts	1.8	3.4	3.8	3.8	2.2
	land Use	2.3	3.7	2.7	3.6	1.8

5.2 Future Scenarios of the New Zealand Energy Sector

In order to determine weightings for the AHP methodology, a set of future development scenarios and priorities can be used as a point of reference. With regards to this study, it should be noted that due to limitation in time and information, the weightings according to relevance are only applied to the four main indicators – technical, economic, social, and environmental. Meanwhile, all the sub-indicators are regarded to have the same relevance towards each other. Therefore, each of the sub-indicators within an indicator will have the same weightings attributed.

With that in mind, the BusinessNZ Energy Council (2019) has prepared two scenarios of New Zealand's energy future to 2060. While the scenarios cover topics of the wider energy industry, some key points related to renewable energy can be used by the author to formulate the order of relevance and weightings for the indicators. It is also important to note that the weightings are developed as interpretations from the author and are not part of the scenarios by BusinessNZ Energy Council (2019). Details of each scenario is explained as follows.

5.2.1. The Kea Scenario

According to BusinessNZ Energy Council (2019), the Kea scenario envisions a future where climate change is viewed as the most significant concern that the society face. As such, New Zealand intends to move faster than the rest of the world when acting on climate change. Thus, climate change and environmental concerns in general are given the utmost priority with regards to policy making.

Furthermore, it is interpreted that in Kea scenario the New Zealand government and society choose to sacrifice economic growth to enable a more widespread utilization of low carbon technology, specifically renewable energy. Higher taxes and charges are given to the conventional energy industry, which in turn is being burdened to the society. The fund gained from such taxes is then repurposed to invest in research and development for accelerated technical maturity of renewable energy technology as well as providing incentives and subsidies for its penetration into the market.

Hence, from the information, it can be interpreted that the order of relevance for the sustainability indicator is environmental, technical, social, and economic, respectively. From the order of relevance, the weightings for each of the indicators can be determined. The breakdown of the comparison matrix used for the Kea scenario as well as the consistency ratio can be seen in the following table.

Table 3. Kea scenario comparison matrix (source: calculation by author)

Comparison Matrix	Technical	Economic	Social	Environmental	Relative Weightings	Consistency Ratio
Technical	1	4	3	0.33	**0.268**	**0.06877**
Economic	0.25	1	0.33	0.20	**0.071**	
Social	0.33	3	1	0.25	**0.141**	
Environmental	3	5	4	1	**0.520**	

Hence, with the relative weightings acquired from the calculation above, the decision tree and the associated total weightings for each of the sub-indicators can be seen in the figure below.

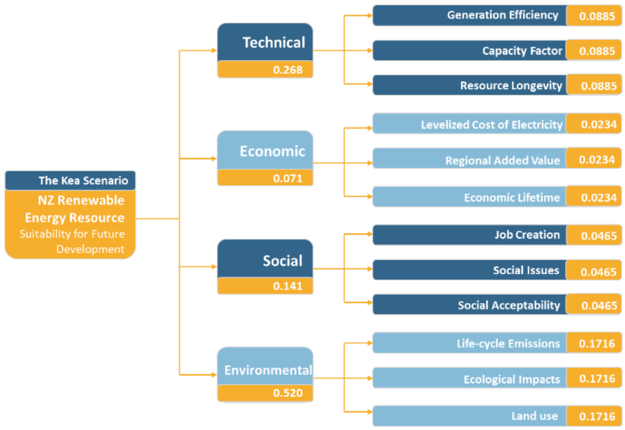

Figure 3. The Kea scenario decision tree (source: calculation by author)

5.2.2. The Tui Scenario

As opposed to the Kea, the framework of the Tui scenario is much more pragmatic in nature. In BusinessNZ Energy Council (2019) report, it is explained that people in the Tui scenario views climate change as only one of several competing challenges. In the scenario, the economy and welfare of the people remain priorities for the government and the society alike.

Furthermore, it is interpreted that at least in the near term, the focus of the government in the Tui scenario remains ensuring economic growth and welfare of people. As such, the government does not actively pursue penetration of low-carbon technology into the market and let the market grow incrementally. Meanwhile, businesses and consumers alike only adopt carbon-efficient technologies when they become price competitive. Hence, the technical maturity of renewable technologies is also achieved at a far slower manner compared to the Kea scenario.

From such a scenario, it can be interpreted that the order of relevance of indicators in the Tui scenario is economic, social, technical, and lastly the environmental indicator. The comparison matrix and consistency ratio for the calculation of the Tui scenario is presented in the following table.

Table 4. Tui scenario comparison matrix (source: calculation by author)

Comparison Matrix	Technical	Economic	Social	Environmental	Relative Weightings	Consistency Ratio
Technical	1	0.25	0.33	3	**0.141**	**0.06877**
Economic	4	1	3	5	**0.520**	
Social	3	0.33	1	4	**0.268**	
Environmental	0.33	0.20	0.25	1	**0.071**	

With the relative weighting acquired as shown above, the decision tree for the Tui scenario which shows the total weightings for each sub indicators are illustrated in the figure below.

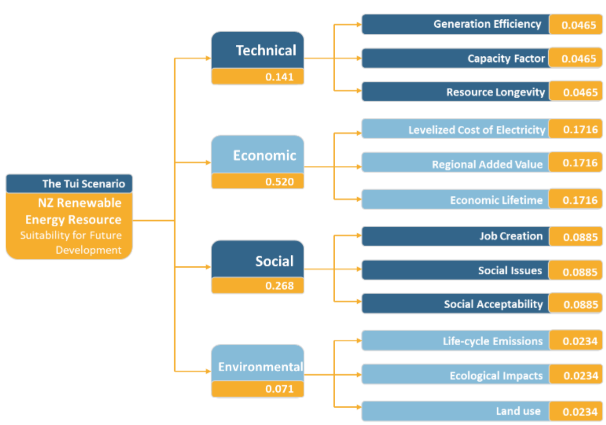

Figure 4. The Tui scenario decision tree (source: calculation by author)

6. RESULTS AND DISCUSSIONS

After the calculation is carried out, the following results are identified for both the Kea and Tui scenarios. The key insights to be taken from the implementation of the AHP approach is that the two different scenarios produce a quite different makeup of preferability of renewable energy resource.

6.1 The Kea Scenario

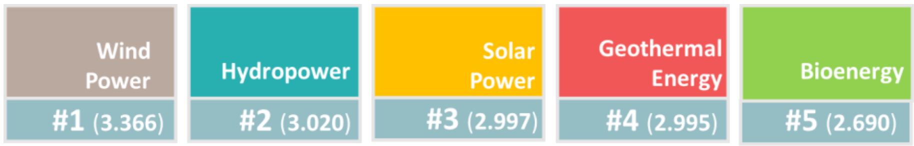

Figure 5. Order of preferability for renewable energy resource in the Kea scenario (source: calculation by author)

As the Kea scenario put a very strong emphasis on the climate change and other environmental concerns, it is understandable that wind power comes out on top in the order of preferability for the Kea scenario. In the environmental indicators, wind power acquires the best score in life-cycle emissions with only around 8 g of CO_2 eq/KWh of emissions generated. It also induces the least ecological impacts compared to other renewable energy resources.

An interesting thing to note here is that hydropower, solar power, and geothermal energy all acquire very similar final scores, unlike wind power which leads quite significantly. This shows that each of the renewable energy resource can be strong options when the government intend to develop non-carbon intensive energy systems, which is a focal priority in the Kea scenario. It is also important to note that the Kea scenario sought accelerated technical maturity for renewable energy technologies, which gives an edge for hydropower and geothermal energy as they achieve good scores across the technical indicators.

While hydropower comes out among the preferable options for the Kea scenario, there are some caveats associated with it. Firstly, while hydropower obtains a relatively good score in the land use indicator, it is important to understand that the score of land use for hydropower is obtained from smaller hydropower projects, which is the current focus of development for New Zealand. For larger hydropower projects, the amount of land required for the projects can be much higher, especially for the reservoir. Hydropower would also potentially cause a wide range of concerning ecological impacts, which really need to be put into consideration by policy makers.

Hence, the key insight to be taken from the analysis is that wind power, hydropower, solar power, and geothermal energy are all viable options as a focal point for non-carbon intensive development in the New Zealand power generation sector. However, among all of them, wind power comes out as the most preferable option for the vision of environment-oriented development which serves as the framework for the Kea scenario.

6.2 The Tui Scenario

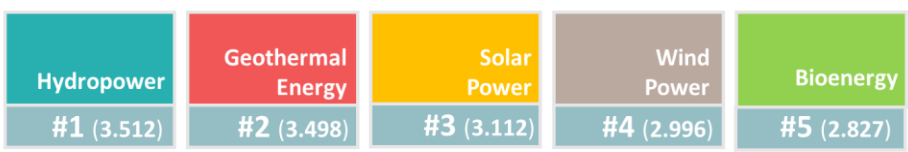

Figure 6. Order of preferability for renewable energy resource in the Tui scenario (source: calculation by author)

As shown in the figure above, hydropower and geothermal energy come out as the two most preferable options in the Tui scenario. As the Tui scenario is focused on economic growth, hydropower and geothermal both excel as they currently have the lowest generation costs (LCOE) compared to other renewable energy resource. Hydropower and geothermal power plants have also contributed to power generation sector in New Zealand for far longer than others, which illustrate their long expectancy of economic lifetime. However, hydropower likely edge out geothermal by a bit, as shown in the figure above, due to greater regional added value based on the data used in this study.

Meanwhile, other renewable energy resource including wind power, solar power, and bioenergy are positioned lower, mainly due to their currently higher generation costs compared to the technically mature hydropower and geothermal energy. In particular, solar power stands out as the costliest option with its highest LCOE among all the renewable energy resource analysed. With regards to LCOE, it should be noted that the cost of wind power generation in New Zealand is already competitive with hydropower and geothermal energy, and the reason why it falls below solar power in the order of preferability is likely due to the regional value-added indicator.

The key insights to be taken from the order of preferability in Tui scenario is that older, more mature energy resource like hydropower and geothermal energy remain preferable when economic considerations become a focus for policy making. However, the overall cost of generation for renewable energy technology is on an ever-decreasing trend (Zeller, Delgado, Reid, & Panerali, 2020). Therefore, it is possible that technologies like solar and wind power to be more cost-competitive within the next decades and thus, able to attract businesses and consumers without the government's intervention, which aligns with the idea of the Tui scenario.

7. CONCLUSIONS AND RECOMMENDATIONS

Reflecting on the objective, this study is an attempt to find out a framework that can be used to compare various renewable energy resource in the perspective of sustainability. This study tried to define and dissect sustainability into key indicators that are comparable through quantified means. From there, it is apparent the complexities of such undertaking as energy and sustainability are a highly subjective matter and converting them into comparable values might degrade their dimensions.

Throughout all the stages of the study, some of key lessons that can be derived are:

1. **Defining the dimensions of sustainability and identifying indicators that aligned with such dimensions are the most crucial part of the study.** As definitions and understanding of sustainability may differ between societies, it would be beneficial if such comparative works begin with the process of gathering inputs from policy makers and industry practitioners. With such process, it is hoped that the selected indicators would truly capture aspects of sustainability that are being visioned by a particular society.

2. During the operationalization of this study, **identifying data and information that are usable and comparable has proven to be most challenging.** For future works, it is advisable that the data used for comparative analysis are taken from a singular source or project that is similar in size for each renewable energy resource. That way, the study would be able to produce a true comparability between the renewable energy resource.

3. With regards to the implementation of the AHP**, the scenarios used as baselines for weightings are an important part of the methodology,** which would really shape the result of the comparison. In this study, the weightings are derived by interpreting key points from given scenarios. However, inputs or directions from stakeholders is preferable as it would produce weightings that truly captures interests of the society.

4. Lastly, as mentioned previously, **the conversion of qualitative indicators into comparable values is another key point of comparative analysis in this field**. Hence, rather than taking reference from other studies as shown in this study, it would be more credible if definitions of the scoring metric as well as assessments for each of the renewable energy resource is carried out according to inputs from related stakeholders.

From all the key lessons above, one key recommendation to be drawn is that **the involvement of policy makers or stakeholders is essential throughout the process of such comparative analysis**. All in all, this study has provided an example for operationalization of such analysis into working steps that is doable and replicable for future works in this subject. While the working step of this study can serve as a baseline, matters like the selection of sustainability indicator or preference with regards to weightings are to be defined according by policy makers/stakeholders according to the context of their society.

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