Multi-criteria analysis for renewable energy generation: A case of Tokyo

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Abstract. A multi-criteria analysis to determine the most suitable renewable energy technology in Tokyo, Japan, is presented in this study. Several criteria have been considered for the analysis including technical, social, economic, and environmental. Sensitivity analysis has been done to check the solidity of the data used in the analysis. The results show that the solar photovoltaic technology is preferred in Tokyo, followed by wind and biomass energy.

1. Introduction
Nowadays, most countries have realized the urgency of environmental issues, such as the unfavorable impact of fuel on the environment. These issues might reconsider their preferences within the energy sector, and accidents that happened at the Chernobyl and Fukushima nuclear power plant have reestablished global attention to renewable energy. A particular country, such as Japan, has abandoned nuclear technologies and substituted them with coal-fired power plants of which leads to greenhouse-gas emissions increase in the year 2014 [1, 2]. To encounter negative public opinion on nuclear technologies while also attempting to reduce the greenhouse-gas emissions, Japan has focused on renewable energy. Especially in Tokyo, the largest city in Japan, of which the energy-derived greenhouse gasses emissions are approximately equivalent to the amount of Austria [3]. Also, Japan aims to increase its renewable penetration to 9% in 2020 [4].

In order to determine technology development within the energy sector, economic, environmental, social, and technological criteria should be analyzed. Several studies assessed energy sector development within a scope of country or city using various multicriteria decision-making methods [5-11]. As an effort to reduce greenhouse gasses emissions in Tokyo, this paper is aimed to determine the most suitable renewable energy technology by assessing economic, environmental, social, and technological criteria.

2. Alternatives
Renewable energy sources use natural resources, such as sunlight, wind, rain, tides, waves, and geothermal energy [5]. This section provides a brief description of the renewable energy alternatives for the city of Tokyo.
Solar energy is a promising alternative since Japan is one of the leading solar power manufacturers in the world. The Japanese government encourages the implementation of solar energy in various scale throughout the country [12]. Additionally, the government offers subsidies for solar photovoltaic (PV) installation in households. Solar PV systems are flexible and can be installed on the buildings thus the land use could be minimal. However, the energy produced by solar PV is far more expensive than from other renewable energy sources [2].

In 2013, Tokyo was produced around 1.8 million tons of combustible waste as a fuel for biomass plant [13]. One kind of those waste is food waste of which 6000 tons a day can be produced in Tokyo alone [14]. The best technology to handle the food waste is methane fermentation which is also powerful to cope with global warming. This technology is under the objective of Tokyo Super-Eco Town Project to achieve more efficient disposal waste and encourage the development of environmental-related industries [15]. However, the technology requires high investment costs at commercial scale and might cause an odor nuisance [16].

Wind power technology has been considered as an alternative due to a severe nuclear crisis in Japan that now is pushing the technology to the front to meet the country’s future energy demand [17]. Wind power is considered cost-effective, the power price of land-based utility-scale is one of the lowest among other energy sources [18]. Also, it does not emit greenhouse gas emission which can cause environmental damage. However, its initial investment is higher even though the cost has decreased dramatically in the past ten years. Its turbine might also cause noise and aesthetic pollution. Other renewable energy technologies such as hydropower and geothermal have been excluded from this paper. Even though Japan has a considerable hydropower potential, the large-scale installation requires an extensive land-use, while the small-scale one has been reported as less efficient [19]. Geothermal is also worth to consider due to its tremendous potential in Japan. However, further studies showed that the drawbacks of geothermal including long construction time which might take four to 7 years to complete [20]. Thus, it might sound unrealistic to have geothermal as an alternative to achieve Tokyo’s goal to reduce its emissions in the near future.

3. Methodology
The procedural steps for multi-criteria analysis (MCA) may include: (i) determining the decision context; (ii) identifying the alternatives; (iii) identifying the objectives and criteria; (iv) specifying the performance of each alternative against the criteria by creating evaluation matrix; (v) assign weighting to each of the criteria; (vi) calculating dominance scores including quantitative and qualitative data; (vii) examining the results; and (viii) conducting sensitivity analysis [21]. Several MCA procedures are distinguished each other by the techniques to process the necessary information in the evaluation matrix. Direct analysis is used in this paper of which the initial step can be to check if any of the alternatives are dominated by others. To do this, dominance scores are calculated separately for quantitative and qualitative data. Then, the quantitative and qualitative dominance scores are calculated to generate the overall dominance scores.

Due to the project constraints, the weighting process, of which usually involves reasoned inputs by stakeholders, was done by reasoned judgment and literature review by the authors. While the criteria weights are extracted subjectively, the sensitivity analysis is then conducted to analyze how variation of criteria weights might affect the results [9]. In this paper, the analysis was conducted using two techniques: (i) criterion exclusion; and (ii) turning points. Criterion exclusion was undertaken by excluding specific criteria and re-examining the decision output [6]. Meanwhile, the turning points technique was obtained through increasing or decreasing weight of specific criteria and lowering the others evenly until the first ranking changes.

3.1 MCA decision model
After analyzing the energy generation potential and conducting extensive literature, an MCA-based decision model has been formulated. The goal of the decision model is selection, evaluation, and ranking of renewable energy technologies for electricity generation in Tokyo to contribute in
achieving the 2020 Japan’s goal. Four criteria and seven sub-criteria were identified that have a direct impact on the goal of the decision model. Description of criteria from social, economic, technical, and environmental aspects is presented in Table 1.

| Criteria     | Sub-criteria             | Description                                                                                   | Reference |
|--------------|--------------------------|-----------------------------------------------------------------------------------------------|-----------|
| Social       | Job creation             | Renewable energy projects generate employment potential especially for the local communities | [22]      |
|              |                          | Alternative that creates more job opportunities is considered better (+)                      |           |
|              | Quality of life          | Renewable energy projects contribute to noise, traffic, odors, and visual to the local communities | [22]      |
|              |                          | Alternative that less creates bad impacts on the quality of life is considered better (+)      |           |
| Economic     | Capital cost             | Capital cost consists of total expense occurred in establishing a power plant.                 | [22]      |
|              |                          | Alternative that has less capital cost is considered better (-)                              |           |
|              | Electricity cost         | Expected cost of the electricity generated by power plant.                                     | [23]      |
|              |                          | Alternative that can generate electricity at a lower cost is considered better (-)             |           |
| Technical    | Energy generation        | Amount of energy sources potential which can be generated.                                     | [22]      |
|              | potential                | Alternative that has more resource available is considered better (+)                          |           |
|              | Land-use                 | Total available energy generated per area used.                                                | [22]      |
|              |                          | Alternative that occupies less area is considered better (-)                                  |           |
| Environmental| Greenhouse gasses        | Greenhouse gasses released by power plant operations.                                          | [22]      |
|              | emissions                | Alternative that emits less emission is considered better (-)                                 |           |

Table 2 presents quantitative and qualitative data related to job creation, quality of life, capital cost, cost of electricity, energy generation potential, land use, and greenhouse gasses emission. It should be noted that some data used in the table are adapted from other countries since the country-specific data are not available. However, the same technology is likely to have similar relative requirements when implemented in a different country [7].

In social criterion, job creation sub-criterion was assessed through the data from California Clean Energy Future [24]. While the quality of life data sub-criterion was identified based on each alternative’s noise, traffic, odors, and visual pollution [15, 25-29]

In economic criterion, electricity cost is based on Japan data in euro/kWh [30]. The capital of-of various technologies is based on US data in euro/MWh [31].

The energy generation potential in technical criterion was calculated on an annual basis [32]. Meanwhile, the land use data were collected from US data in km²/GWh [33].
In the environmental criterion, the greenhouse gasses emission includes carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons. The emission data are median numbers expressed in carbon dioxide equivalent [34] and represent overall emissions during the technology lifecycle.

| Criteria         | Sub-criteria                     | Solar PV | Biomass | Wind | +/- | Dimension | W |
|------------------|----------------------------------|----------|---------|------|------|-----------|---|
| Social           | Job creation                     | 2.1      | 10.55   | 0.47 | +    | jobs/MWa  | 6 |
|                  | Quality of life                  | ++       | +       | +++  | +    | qualitative | 9 |
| Economic         | Capital cost                     | +++      | +       | ++   | -    | qualitative | 17|
|                  | Electricity cost                 | 0.275    | 0.175   | 0.215| -    | euro/kWh   | 15|
| Technical        | Energy generation potential      | 3878     | 478     | 52   | +    | GWh/year   | 20|
|                  | Land-use                         | 35       | 1000    | 100  | -    | km²        | 8 |
| Environmental    | Greenhouse gasses emissions      | 48       | 230     | 11   | -    | gCO₂       | 25|

3.2 Weighting
Weighting is determined by the authors based on the objective of the decision model. The total weights distributed is 100. Social criterion, which is not directly linked to the primary objective, is allocated 15 weights. Meanwhile, the economic criterion is given 32 weights since both the capital and electricity costs are assumed to be the most important one. The environmental criterion is assigned 25 weights since the objective is to reduce the greenhouse gasses emissions. Lastly, the technical objective is given 28 weights due to its importance in producing energy.

4. Result and discussion
Based on the overall dominance score, results indicate that solar PV as the preferred alternatives, followed by wind and biomass energy. The result might be attributed to the abundance of solar potential and low land requirement. Despite having the lowest scores in the economic criterion, low greenhouse gasses emissions of solar PV have outweighed such economic considerations for this particular MCA objective.
Wind energy alternative takes the second place with the best scores in the environmental criterion. However, wind energy scores in energy generation potential, job creation, and land-use are lower than solar PV alternative. These factors have reduced the overall dominance score of wind energy.
Lastly, biomass, which placed in the third position, has been scored as the best in job creation and electricity cost aspects. However, its low score in greenhouse gasses emissions and energy generation potential might put it as the last preferred alternative.
Based upon the turning points technique in the sensitivity analysis, the most sensitive sub-criterion is quality of life while the most robust is capital cost aspect.
Criterion exclusion technique is conducted for job creation and quality of life sub-criterion. Job creation assessment is considered to be relatively unreliable due to the lack of data for the Japan-specific location. The quality of life score is also found to be less reliable since it is consisted of several different data to determine the qualitative score. The result from this technique shows that the criterion exclusion provides a slight change to the preferred alternatives. Solar and wind energy change the rank position due to the exclusion of quality of life aspect. It shows that the aspect is essential and a reliable data source is needed to provide a better consideration between wind and solar alternative. Meanwhile, the exclusion of job creation aspect does not give any change to the rank.
5. Conclusion
Determining the most appropriate alternative to reduce greenhouse gasses emissions while coping with Japan’s 2020 goal is a complicated process. MCA might help to answer the objective; however, further research is needed to generate a more reliable result. Future work includes examining other renewable energy system alternatives and adding more aspects to the decision model. Other techniques to process the evaluation matrix are also worth to be conducted. Lastly, the weighting process could be done by involving inputs from various stakeholders. Thus, more objective results can be obtained.

6. References
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Acknowledgments
We gratefully acknowledge the funding from USAID through the SHERA program - Centre for Development of Sustainable Region (CDSR).