Multicriteria assessment of renewable energy sources under uncertainty: barriers to adoption

Tseng, M-L., Ardaniah, V., Sujanto, R. Y., Fujii, M. & Lim, M

Original citation & hyperlink:
Tseng, M-L, Ardaniah, V, Sujanto, RY, Fujii, M & Lim, M 2021, 'Multicriteria assessment of renewable energy sources under uncertainty: barriers to adoption', Technological Forecasting and Social Change, vol. 171, 120937.
https://doi.org/10.1016/j.techfore.2021.120937

DOI 10.1016/j.techfore.2021.120937
ISSN 0040-1625
ESSN 1873-5509

Publisher: Elsevier

Multicriteria assessment of renewable energy sources under uncertainty: barriers to adoption

Ming-Lang Tseng

- Institute of Innovation and Circular Economy, Asia University, Taiwan
- Department of Medical Research, China Medical University Hospital, China Medical University, Taiwan
- Faculty of Economic and Management, University Kebangsaan Malaysia, Malaysia

Email: tsengminglang@gmail.com; tsengminglang@asia.edu.tw

Viqi Ardaniah

- Department of Business Administration, Asia University, Taiwan
- English Programme, Universitas Airlangga, Indonesia

Email: viqiardaniah@gmail.com; viqiardaniah@fib.unair.ac.id

Raditia Yudistira Sujanto

- Department of Business Administration, Asia University, Taiwan
- Department of Communication, Universitas Aisyiyah Yogyakarta, Indonesia

Email: sujanto.raditia@unisayogya.ac.id; sujanto.raditia@gmail.com

Minoru Fujii

- Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES), 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan

Email: m-fujii@nies.go.jp

Ming K. Lim

- College of Mechanical Engineering, Chongqing University, China
- Faculty Research Centre for Business in Society, Coventry University, United Kingdom

Email: ac2912@coventry.ac.uk

Multicriteria assessment of renewable energy sources under uncertainty: barriers and adoption

Abstract

This study contributes by identifying a set of factors serving as barriers and facilitators to the adoption of renewable energy sources under uncertainty to provide an understanding of renewable energy sources in Indonesia. Previous studies have neglected to identify the factors serving as barriers to the adoption of renewable energy sources through contextual interrelationships and uncertainty. The attributes need to be assessed with multiple criteria, but contextual attributes have interrelationships and qualitative descriptions. Hence, this study applies the fuzzy Delphi method to arrive at a valid set of barriers to the adoption of renewable energy sources based on qualitative information and linguistic preferences. These qualitatively valid attributes are interrelated; hence, this study uses the fuzzy decision-making trial and evaluation laboratory method to visualize the interrelationships among attributes under uncertainty. This study compares the adoption of and barriers to the adoption of renewable energy sources. The results indicate that adoption is driven by technical capabilities and that the main barrier is technical analysis. In practice, the adoption criteria are institutional, policy and technical analysis aspects, and the main barriers to achieving sustainable electricity generation are development funding, licensing procedures, groundwater pollution and investment cost.

Keywords: renewable energy source adoption; renewable energy source barrier; fuzzy Delphi method; fuzzy decision-making trial and evaluation laboratory

Multicriteria assessment of renewable energy sources under uncertainty: barriers to adoption

1. Introduction

Renewable energy sources (RESs) are generally alternatives to nonsustainable sources for future energy generation, and their use is rapidly growing due to their environmental friendliness (Adelaja, 2020). Although RESs offer a solution to environmental concerns, their benefits remain uncertain. Previous studies have identified the uncertainties around and barriers to the adoption of RESs by energy firms (Aberilla et al., 2020; Asante et al., 2020; Chachuli et al., 2021). Specifically, Tumiran et al. (2021) argued that RES adoption requires firms to innovate. Razmjoo et al. (2021) emphasized firms' technical analysis of environmental impacts as a barrier to RES adoption. In Indonesia, innovation and technical analysis capabilities are lacking, as evidenced by the underutilization of 89% of the country's total RES stock (Sugiawan & Managi, 2016; Pratama et al., 2017). Many studies address barriers to RES adoption from multiple perspectives, including policy and finance. Nindhia et al. (2021) suggested that institutional policy support is important for firms to build innovation capability and take financial actions. Martin & Rice et al. (2021) argued that financial actions are affected by firms' innovation capability and technical analysis. This study addresses innovation capability, technical analysis, environmental impacts, financial actions and institutional policy as multiple perspectives on RESs.

The ongoing development of RESs to generate energy in various geographical regions has been supported by encouraging innovation capabilities and the technical analysis of hybrid technology, minimizing costs through financial activities, and improving policies to reduce environmental impact (Karytsas & Choropanitis, 2017; Ramos & Rouboa, 2020; Razmjoo et al., 2021). It is essential that the technological, social, economic, and environmental perspectives be analyzed to encourage RES practices (Luthra et al., 2016). A combination of technologies can be used to integrate various resources and potential renewable sources to deliver high-quality performance (Aberilla et al., 2020; Osorio et al., 2020). Martin & Rice (2021) emphasized that renewable energy policies are developed by considering social benefits and the need to mitigate unpredictable environmental impacts. Social benefits include the high employment resulting from RES utilization, and unpredictability is linked to the effects of renewable technology installation (Cuesta et al., 2020; Rabaia et al., 2021). Yao et al. (2020) argued that unpredictability emerges from RES availability in nature, which affects costs. Previous studies have found that innovation needs to be supported by policies and the technical analysis of environmental impact (Hille et al., 2020; Pitelis et al., 2020). However, Tabrizian (2019) highlighted that innovation capability has become a driver for developing RES policies to facilitate RES adoption. Innovation requires the consideration of environmental impacts to support technical analysis and can minimize barriers and increase RES adoption (Assi et al., 2021; Razmjoo et al., 2021). There is a need to clarify the interrelationships between innovation capabilities, technical analysis, and environmental impacts and to understand how they accelerate RES adoption by understanding the barriers to adoption.

RES adoption demands the integration of various perspectives into an assessment of the uncertainties linked to the effects and complexities of RESs (Karytsas & Choropanitis, 2017; Diógenes, et al., 2020; Zimmerman & Reames, 2021). Indeed, the use of RESs frequently entails difficulties due to multiple attributes, since renewable energy is related to innovation, R&D, technology systems, and environmental pollution (van der Loos et al., 2020; Assi et al, 2021). The interrelationships between attributes that constitute barriers to RES adoption are often heterogeneous, and increasing RES utilization affects investment depending on the country context (Akram et al., 2021). Previous studies have shown that these difficulties are often associated with the barriers to and challenges in applying RESs to the electricity sector (Du et al., 2019; Shah et al., 2019; Asante et al., 2020).

Many perspectives have been adopted in the study and proposal of RESs. This study seeks to find valid attributes of RES utilization in the Indonesian context. Hence, the fuzzy Delphi method (FDM) is applied to validate measured attributes with qualitative information and linguistic preferences (Ocampo et al., 2018; Deveci et al., 2020; Tseng et al., 2020). To visualize the interrelationships among attributes, because the RES measures in the system are usually correlated, the fuzzy decision-making trial and evaluation laboratory (fuzzy DEMATEL) method is used to visualize causal interrelationships (Wu et al., 2020). This study employs the FDM and fuzzy DEMATEL to explore the barriers to adopting renewable energy via a multicriteria assessment. The objectives of this study are as follows:

- To identify the barriers to RES adoption using qualitative information and linguistic preferences
- To visualize the interrelationships between the attributes of the barriers to RES adoption under uncertainty
- To present the barriers to RES adoption for practical improvement

This study theoretically and practically contributes to the RES literature by (1) validating a set of barriers to RES adoption to expand the RES measures for better decision-making; (2) visualizing the causal interrelationships among attributes given qualitative information and linguistic preferences; and (3) providing practical guidelines to improve RES adoption in Indonesia.

This study is organized into six sections. The first section contextualizes the study by presenting the background to RES and highlighting aspects of previous studies. Section 2 gives a literature review on RESs along with the barriers to RES adoption, including the proposed method and measures. Section 3 describes the FDM and fuzzy DEMATEL as used in this study. Section 4 presents the results on the barriers to RES adoption. Section 5 draws theoretical and practical implications. The final section highlights the conclusion, limitations of this study, and recommendations for future studies.

2. Literature Review

This section summarizes the RES literature. The proposed methods and measures are presented.

2.1 Renewable Energy Sources

RESs are naturally renewable energy sources existing in a local environment, including wind, solar, water, geothermal, biomass and ocean energy, that are utilized to reduce economic costs and environmental impact and improve social welfare (Du et al., 2019; Ramos & Rouboa, 2020; Yao et al., 2020). Environmental impact must be considered for all sectors through the phases of production, processing, distribution and consumption (Mukuve & Fenner, 2015; Perez

& Garcia-Rendon, 2020; Sharif et al., 2020). Karytsas & Choropanitis (2017) highlighted that RESs need to be optimized by considering their institutional and policy aspects, taking the appropriate financial actions, and performing technical analysis to facilitate the acceptance of renewable energy technology. Osorio et al. (2020) argued that studies of RESs must include interconnected technologies, technology conversion, reliability, survivability, and cost efficiency if their results are to be applied to implement financial actions. As part of the financial aspect of investment, decisions regarding the investment level must consider the type of natural resource available, as the maximization of wind and geothermal power is preferred (Karatop et al., 2020). Sirin & Yilmaz (2020) showed that renewable energy generating technologies drive employment and decrease environmental impact, although frictions are emerging, including the growing share of power supply technologies and market price uncertainty. Neglecting RES provisions can increase the challenges posed by environmental impacts, ranging from emission reduction and land use to noise pollution (Cuesta et al., 2020; Tawalbeh et al., 2020). Hence, it is important to determine the attributes that must be overcome to address the imbalance between energy demand and energy supply, create job opportunities, and manage costs.

There are always barriers to RES adoption in practice. Asante et al. (2020) argued that RES practices are impeded by policy, regulatory and political conditions, the market situation, geography, and institutional capacity, such as human resource skills and coordination capability. Dranka et al. (2020) emphasized that the inadequate use of RESs has a serious impact on overall system costs, leading to future cost uncertainty throughout the entire process. Improper RES-driven technologies lead to market price volatility and cause instability in welfare provision (Sirin & Yilmaz, 2020). Shah et al. (2019) argued that political instability, low political drive within the government to deploy RESs, and different priorities and mindsets create difficulties to employing renewable energy technologies. Navon et al. (2020) suggested that RESs be integrated to minimize power loads and maximize distribution networks and generation units. Appropriate RES practices, including proper adoption, are critical due to their effects on economic costs, environmental pollution, and social conditions (Chen et al., 2019; Sirin & Yilmaz, 2020; Razmjoo et al., 2021)

Previous studies have attempted to underline the linkage between RESs and environmental impact, economic support, technology innovation, and the improvement of social conditions (Assi et al., 2021; Mahalik et al., 2021; Tolliver et al., 2020). However, these studies did not consider how to balance those attributes that can accelerate or impede RES adoption. Despite Asante et al.'s (2020) efforts to identify the attributes of RES barriers through social, economic, and technical analysis, understanding of the relationship between RES adoption and particular barriers is limited. In addition, previous studies have focused on demonstrating the insufficient understanding of the attributes of barriers to RES adoption (Shah et al., 2019; Adelaja, 2020). The literature linking RES adoption with barrier attributes is still under development. This study presents the barriers to RES adoption.

2.2. The Barriers to RES Adoption

RES adoption represents an innovation that gives individuals and firms opportunities to use various technology combinations and requires policy support (Hille et al., 2020; Dhirasasna & Sahin, 2021). Mahalik et al. (2021) argued that individuals' education levels affect whether they choose to intensively utilize the energy generated from various renewable sources and encourage the effective and intensive use of RES technologies. Education will stimulate awareness and knowledge of energy security among firms and consumers and motivate them to adopt RESs. In practice, firms and organizations integrate RES adoption with business strategies and investments for sustainability. RES adoption is based on social awareness and knowledge, as these affect people's use of RES technologies (Stavrakas et al., 2019; Alipour et al., 2020; Kim et al., 2020). Cuesta et al. (2020) asserted that social acceptance is a fundamental piece of RES system optimization, as acceptance is affected by emerging environmental impacts, such as noise, visual disturbance and electromagnetic interference. Furthermore, social acceptance is required to drive innovation that leads to improvements in RES policies (Tabrizian, 2019). RES technology combinations cannot neglect community needs, planning, or policies that bring social benefits and coordination among actors (Quirapas & Taeihagh, 2020; Martin & Rice, 2021). These technology combinations lead to innovations that impact environmental policies (Pitelis et al., 2020). Hence, RES adoption depends on the needs of individuals and firms, hybrid technology, environmental impacts and policies.

In practice, the barriers to RES adoption vary with contextual conditions (Shah et al., 2019; Ganiyu et al., 2020; Zimmerman & Reames, 2021). The barriers to RES adoption are linked to economic conditions, political situations consisting of nepotism, corruption, or geopolitics at the international level, and stakeholders' perceptions of RES (Scholten & Bosman, 2016; Asante et al., 2020; Tseng et al., 2020). The combination of technologies required for RES adoption, system technologies, such as distribution systems and design, and system types constitute barriers to adoption (Karytsas & Choropanitis, 2017; Pompili et al., 2021). The barriers to RES adoption exist in contexts generated by government administrative structures, human resources, articulated knowledge, and innovation (Njoh et al., 2019; Barquet et al., 2020; van der Loos et al., 2020). Rabaia et al. (2021) observed that unpredictable environmental impacts can hinder RES practices. Quirapas & Taeihagh (2020) emphasized that bureaucratic disinterest impedes RES adoption by leading to ineffective and inefficient responses to changes in RES-based technologies. However, the barriers to RES adoption can be minimized by applying technical analysis to understand environmental impact (Razmjoo et al., 2021). Thus, the emerging barriers must be analyzed by considering various contexts.

2.3. The Proposed Method

Various methods have been applied in previous studies to investigate RES practices. Karytsas & Choropanitis (2017) employed surveys to understand the social obstacles to renewable energy technology adoption and identify actions for boosting RES technology adoption. Shah et al. (2019) ranked the barriers impeding renewable energy application using a fuzzy analytical hierarchy process. Asante et al. (2020) applied a ratio analysis method and multicriteria decision-making to categorize and rank the barriers to renewable energy development. Dhirasasna & Sahin (2021) adopted system dynamic modeling and sensitivity analysis to formulate scenarios based on greenhouse emissions, consumer willingness to adopt RESs and consumer perceptions of RESs and determined the attributes supporting the adoption of renewable energy technology. Razmjoo et al. (2021) conducted a case study to explore electricity production by investigating sustainable renewable energy systems.

The contextual conditions required for RES practices that build sustainable renewable energy technologies are often neglected (Jain et al., 2020; Stephens & Robinson, 2021). Context is related to local attributes, including the government, private industry, educational institutions, and innovation systems or, specifically, innovation policies (Plank & Doblinger, 2018; Lerman et al., 2021; Samant et al., 2020). Such local attributes drive innovation capabilities, which in turn can optimize renewable energy use. The level of emissions from RESs is related to contextual aspects, such as population density, as a large population leads to high energy consumption (Shah et al., 2019; Asante et al., 2020). The causal interrelationships remain uncertain, as RESs are concerned not only with technical issues, institutions, and innovation but also with environmental issues and various complex attributes. Asante et al. (2020) suggested that other alternative attributes need to be considered, as countries present context-based differences related to socioeconomics, geography, and politics. Considering attributes from multiple perspectives can better reveal interrelationships and help determine the drivers of and barriers to RES adoption.

This study employs qualitative and quantitative approaches to determine a valid set of RES attributes considering multiple aspects and outlines the causal interrelationship among these aspects. The FDM is applied to obtain consensus on identified issues by integrating expert knowledge (Ocampo et al., 2018). The FDM aims to screen out the unreliable attributes of qualitative information by addressing uncertain and vague judgments in the decision-making process and determining levels of importance (Deveci et al., 2020; Tseng et al., 2020). The attributes revealed through the group decision-making process are valued by using fuzzy DEMATEL to calculate the weight of each attribute and clarify the causal interrelationships between attributes (Wu et al., 2020). Luthra et al. (2016) applied this method as an effective tool to identify the interrelationships among attributes of RES technology and formulate appropriate strategies; however, fuzzy DEMATEL involves subjectivity and data vagueness. Lin et al. (2018) used fuzzy DEMATEL to divide attributes into causal attributes and effect attributes and presented the levels of importance in the cause-effect interrelationships. This study applies this proposed method to establish a valid set of attributes for the barriers to RES adoption and to recognize the cause-and-effect attributes.

2.4. The Proposed Measures

When barriers to RES adoption are studied, the interrelationships among attributes are often neglected, leading to the absence of cause-and-effect attributes. Hence, identifying the barriers to RES adoption requires the consideration of causal interrelationships between attributes, as emerging risks can affect the implementation of RES technology (Lin et al., 2018; Chen et al., 2019). Renewable energy is vital for achieving sustainable development, but reducing environmental impact involves social and economic issues, political and regulatory conditions, and institutional and geographical circumstances (Asante et al., 2020). A valid set of attributes from the social, economic, environmental, and technological perspectives is presented that result in five aspects and 20 criteria used to determine the barriers to RES adoption, as shown in Table 1.

The social perspective is complex and requires the government to establish policies guiding RES practices. Institutional and policy measures (A1) are needed to reduce information and technology gaps and promote the expansion of renewable energy knowledge in educational institutions by adopting a top-down approach and adequately utilizing human resources (Stavrakas et al., 2019; Adelaja, 2020; Asante et al., 2020). Jeong & Ramírez-Gómez (2018) claimed that planning policies are vital to optimizing and promoting RES technologies in ways that contribute to low transportation costs. A well-planned policy for RES development can be supported by efficient licensing procedures (C1) that involve support from local and national communities to facilitate RES technology operations (Karytsas & Choropanitis, 2017; Stephens & Robinson, 2021). Shah et al. (2019) discussed the importance of skilled and trained human resources (C2) with adequate education, as this can facilitate the successful structuring of renewable energy. Goodess et al. (2019) explained that institutional capacity building (C3) fosters collaboration and engagement among internal and external stakeholders and partners. Collaboration drives institutional coordination (C4), which fosters interactions to share information and develop an understanding of RES practices and activities (Sanderink & Nasiritousi, 2020)

From a technological perspective, RES practices are strengthened through technical analysis (A2) to achieve better supply and demand and innovation capabilities (A3), representing knowledge combinations (Andersen & Gulbrandsen, 2020; Razmjoo et al., 2021). Asante et al. (2020) suggested that technical skills (C5) help with RES technology installation and maintenance and lead the government to improve RES infrastructure. Su et al. (2020) stressed that the reliability of supply (C6), achieved by the analysis of reliability at the customer, system and resource levels, can address the uncertainty and complexity of RESs. Technical analysis also motivates firms to implement maintenance strategies in service and maintenance facilities (C7) for timely ordering and scheduling to minimize costs (Shayesteh et al., 2018). Accelerating innovation capabilities requires innovation drivers (C8) and the integration of government, universities, and firms in knowledge transfer, as problems in RES practices cannot be solved by a single actor (Lerman et al., 2021). Plank & Doblinger (2018) highlighted that R&D funding (C9) for innovation reflects a firm's financial situation, innovation activities and innovation resources. Funding is needed to strengthen R&D activities (Chachuli et al., 2021). Innovation requires the exploration of technology (C10) for utilization and deployment, which affects the policy cost and the design of technology (C11) for standardization (Shayesteh et al., 2018; Andersen & Gulbrandsen, 2020).

The barriers to RES adoption are influenced by financial action (A4), which can lead to renewable energy consumption and R&D activities for renewable energy development (Assi et al., 2021). Yang & Park (2020) promoted financial incentives (C12) to motivate firms to take financial action to save RESs, reduce pollution, and engage in green behavior to reduce environmental impact. Razmjoo et al. (2020) explained that investment costs (C13) need to be prioritized and weighted for cost effectiveness and economically justified; this analysis can provide useful indicators for stakeholders. In addition to the investment cost, operating cost (C14), which includes fixed and variable costs, is reduced to achieve economic benefits, as the installation cost (C15) of RESs is recouped (Karytsas & Choropanitis, 2017; Dranka et al., 2020). The installation cost depends on RES availability and the relevant regulations.

Environmental impact (A5) contributes to successful RES practices, as carbon emissions (C16) are used as the basis for carbon reduction regulations such as carbon pricing policies and carbon taxes (Liu et al., 2020). Chavez-Rodriguez et al. (2018) considered fossil fuel savings (C17) that can be achieved from the four largest sectors, the household, industry, public, and transport sectors.

RESs pose lower risk than fossil fuels during transport, storage and operation (C18), which should be anticipated in the early stage among the interventions considered when policies are made (Versteeg et al., 2017; Quirapas & Taeihagh, 2020). Groundwater pollution (C19) is reduced as thermal power is optimized for technology development and heterogeneous environmental regulations are established (Karytsas & Choropanitis, 2017; Pan & Tang, 2021). Thermal radiation risk (C20) is reduced by transitioning from fossil fuel energy use to thermal energy use via fully electric vehicles (Yazawa & Shakouri, 2021).

*****Insert table 1*****

3. Method

This section covers the industrial background of electricity generation in Indonesia and describes the FDM and fuzzy DEMATEL.

3.1 Industrial Background

Indonesia has hydro, steam, combined-cycle, gas turbine, diesel, and geothermal energy generation capacities. The country's energy demand is predicted to reach more than 800,000 GWh by 2027, while the peak load is estimated to reach 140,000 MW by 2027 (Agency, 2011). Consequently, an imbalance between energy supply and demand is emerging, motivating the use of various RESs to generate sustainable electricity and address current challenges. The inconsistency in RES operation has kept the penetration level of renewable energy very low. RES generation also faces operational uncertainty, and the power system output fluctuates: output cannot be accurately and consistently predicted. Despite attempts to use RESs for power generation and the legislation of climate policies, Indonesia's high dependency on fossil fuel continues, along with a rapid increase in carbon emissions. This situation has worsened given the lack of convenient and affordable energy conversion and storage technology. RES technology is greatly affected by innovation capabilities. Indonesian electricity firms face not only these complex challenges to achieving sustainable electricity generation but also issues in adopting RESs linked to environmental impact, technical analysis, policy support, and financing.

Although electricity firms have established plans and targets for the adoption of RESs for power generation, it is difficult for them to identify the attributes that can accelerate or impede such adoption. It is challenging to identify the relationships between policies, innovation capability, technical analysis, financing, and environmental attributes that encourage RES adoption and explore the essential practices that firms must incorporate to attain sustainable performance since barriers to adoption are more commonly addressed than facilitators. This study interviewed 15 experts from electricity firms in Indonesia to understand the barriers to RES adoption. These face-to-face interviews prevented invalid results and allowed ambiguous points to be clarified. For this purpose, this study interviewed experts in state-owned Indonesian electricity companies, first identifying two experts, who were then asked to recruit others. Ultimately, the interviews included fifteen experts, including directors, managers, senior analysts and evaluators, who had adequate knowledge of RESs and sustainability performance within their company (see Table 2)

3.2. The Fuzzy Delphi Method

The questionnaire was sent in two phases between November and December 2020. Along with the questionnaire, a cover letter explaining the purpose and significance of the study was emailed to the targeted experts.

The FDM method combines fuzzy set theory and the Delphi method and is used to handle expert reference limitations and enhance the quality of questionnaires (Ishikawa et al. 1993). The method is used to have experts validate a proposed set of attributes based on linguistic references and offers an effective evaluation process assessment, with advantages such as reducing the survey time while not requiring a large sample of responses (Bui et al., 2020). In the FDM, the attributes in the questionnaire are collected from the literature and then redefined and regrouped on the basis of the semantic structure (Dawood et al., 2021). Despite the small number, the experts who responded to the questionnaire were sufficient to ensure the robustness of the FDM (Padilla-Rivera et al., 2021).

Assuming there are n experts on the committee, the analytical procedure starts with expert x, who is asked to evaluate the importance of attribute y as $p = (a_{xy}; b_{xy}; c_{xy})$, $x = 1, 2, 3, \ldots, n$; $y = 1, 2, 3, \ldots, m$, where p_y is the weight of y presented as $p_y = (a_y; b_y; c_y)$ with $a_y = min(a_{xy})$, $b_y = \left(\prod_1^n b_{xy}\right)^{1/n}$, and $c_y = max(c_{xy})$. Next, the expert's linguistic preferences are translated into triangular fuzzy numbers (TFNs) (shown in Table 2).

*****Insert Table 2*****

The convex combination values use ε as:

$$u_y = a_y - \varepsilon(c_y - b_y),$$
$$p_y = x_y - \varepsilon(b_y - \varepsilon a_y),$$
$$b = 1,2,3, \ldots, m \quad (1)$$

where $\varepsilon = [0,1]$ to indicate whether the experts' perceptions are positive or negative. $\varepsilon = 0.5$ is usually considered as a general condition.

The fuzzy evaluation is converted into exact numbers H_y as:

$$H_y = \int(u_y, p_y) = \sigma[u_y + (1 - \sigma)p_y] \quad (2)$$

where σ indicates an expert's optimistic equilibrium assessment.

Next, the threshold is obtained as $T = \left(\sum_{y=1}^{m} H_y\right)/m$ to refine the valid attributes from the original set.

If $H_y \geq T$, attribute b is valid. If not, it must be removed.

3.3. Fuzzy DEMATEL

Fuzzy DEMATEL uses defuzzification to translate qualitative information into fuzzy linguistic data. The fuzzy membership functions $\tilde{e}_{ij}^k = (\tilde{e}_{1ij}^k, \tilde{e}_{2ij}^k, \tilde{e}_{3ij}^k)$ are utilized to obtain the total weighted values. Specifically, the left and right values are computed using the minimum and maximum fuzzy numbers. The crisp values are then arranged in a total direct relation matrix to map a diagram to simplify the analytical result. Finally, certain attributes are allocated to the cause-and-effect groups signifying the structural interrelationships and critical effects among them.

An attribute set $Q = \{q1, q2, q3, \cdots, qn\}$ is proposed, and certain pairwise comparisons are used to generate the mathematical relationships. The analysis obtains crisp values from the TFNs using linguistic scales from very low influence to very high influence (as shown in Table 2). Supposing that there are k experts who join the evaluation process, $\tilde{e}^k_{ij}$ represents the fuzzy weight of the i^{th} attribute's influence on the j^{th} attribute as assessed by the k^{th} expert.

The fuzzy numbers are summarized using:

$$Q = \left(q\tilde{e}^k_{1ij}, q\tilde{e}^k_{2ij}, q\tilde{e}^k_{3ij}\right) = \left[\frac{(e^k_{1ij} - min\, e^k_{1ij})}{\Delta}, \frac{(e^k_{2ij} - min\, e^k_{2ij})}{\Delta}, \frac{(e^k_{3ij} - min\, e^k_{3ij})}{\Delta}\right] \quad (3)$$

where $\Delta = \max e^k_{3ij} - \min e$.

The left (l) and right (r) normalized values are computed using

$$\left(l^n_{ij}, r^n_{ij}\right) = \left[\frac{(qe^k_{2ij}}{\left(1 + qe^k_{2ij} - qe^k_{1ij}\right)}, \frac{qe^k_{3ij}}{\left(1 + qe^k_{3ij} - qe^k_{2ij}\right)}\right]. \quad (4)$$

The normalized crisp values (nc) are calculated using:

$$nc^k_{ij} = [l^k_{ij}(1 - l^k_{ij}) + (r^k_{ij})^2]/(1 - l^k_{ij} + r^k_{ij}) \quad (5)$$

The synthetic crisp values are accumulated from the individual perspectives of the k respondents using:

$$\tilde{e}^k_{ij} = (nc^1_{ij} + nc^2_{ij} + nc^3_{ij} + \cdots + nc^3_{ij})/k \quad (6)$$

The $n \times n$ initial matrix of direct relations (IM) is acquired in a pairwise comparison form, in which $\tilde{e}^k_{ij}$ addresses the influence of attribute i on attribute j as $IM = [\tilde{e}^k_{ij}]_{n \times n}$.

The normalized direct relation matrix (U) is generated as

$$U = \tau \otimes IM$$

$$\tau = \frac{1}{\max\limits_{1 \le i \le k} \sum_{j=1}^{k} \tilde{e}^k_{ij}} \quad (7)$$

The interrelationship matrix (W) is then obtained using:

$$W = U(I - U)^{-1} \quad (8)$$

where W is $[w_{ij}]_{n \times n}$ $i, j = 1, 2, \cdots n$

The driving power (D) and dependence power (R) values are assimilated from the total row and column values of the interrelationship matrix using

$$D = [\sum_{i-1}^{n} w_{ij}]_{n \times n} = [w_i]_{n \times 1} \quad (9)$$

$$R = [\sum_{j-1}^{n} w_{ij}]_{n \times n} = [w_j]_{1 \times n} \quad (10)$$

As a result, the attributes are situated in the cause-effect diagram by deriving $[(D + R), (D - R)]$, , which in turn produces horizontal and vertical vectors. First, $(D + R)$ denotes the attributes' importance, whereby the attribute with the highest $(D + R)$ value is the most important among the sets. Second, the attributes are classified into cause-and-effect groups based on their $(D - R)$ values, which are positive or negative. If the $(D - R)$ value is positive, the attribute is allocated to the cause group; otherwise, it is allocated to the effect group.

4. Results

The Delphi method sorts the invalid attributes. Table 1 presents the valid attributes. The linguistic preferences are transformed to TFNs, as shown in Table 3. The TFNs are defuzzified into crisp values (see Appendix 3). Table 3 presents the FDM results for the aspects using Equations (1) and (2). The threshold T is 0.437038.

*****Insert Table 3*****

The defuzzification process follows Equations (3)-(6) using the center of gravity method. $\tilde{e}_{ij}^{k}$ is divided by a total of K experts, for instance, (0.72 + 0.667 + 0.720 + 0.667 + 0.700 + 0.720 + 0.720 + 0.667 + 0.667 + 0.720 + 0.720 + 0.667 + 0.678 + 0.720 + 0.720)/15= 0.721 (see Table 4).

***** Insert Table 4*****

Table 5 presents the total direct relationship matrix for an aspect, employing Equations (7)-(8).

*****insert table 5*****

Equations (9)-(10) are used to draw the cause-effect diagram based on (D+R) and (D-R) (see Table 6). (D+R) is presented on the horizontal axis to indicate prominence, and (D-R) is presented on the vertical axis to show the influence relationship.

*****Insert Table 6*****

Equations (9)-(10 are repeated to obtain the cause-effect diagram based on (D+R) and (D-R) for the criteria). Table 7 shows the minimum and maximum values for the prominence and influence of the criteria.

***** Insert Table 7*****

Table 8 shows that environmental impact (A5) presents the smallest gap, 0.267, between the values of RES adoption and RES barriers. This result indicates that environmental impact is the most important and the most difficult aspect of RES adoption.

***** Insert Table 8*****

Table 9 shows that skilled and trained human resources (C2) have the highest gap value (1.467) and that groundwater pollution (C19) has the lowest gap value (0.200), indicating that the more important a criterion is, the more difficult its implementation.

***** Insert Table 9*****

Figure 1 presents the causal interrelationships among aspects. In RES adoption, a strong relationship exists between institutions and policy (A1), technical analysis (A2), environmental impact (A5) and innovation capabilities (A3). Weak interrelationships are observed between financial actions (A4) and environmental impact (A5), institutions and policy (A1) and environmental impact (A5), institutions and policy (A1) and technical analysis (A2), and technical analysis (A2) and environmental impact (A5).

Regarding RES barriers, the strongest interrelationship is observed between technical analysis (A2) and environmental impact (A5). A moderate interrelationship is found between institutions and policy (A1) and environmental impact (A5) and between technical analysis (A2) and environmental impact (A5). Weak interrelationships are found between technical analysis (A2) and financial actions (A4) and between innovation capabilities (A3) and institutional and policy capabilities (A1). The interrelationships between institutions and policy (A1) and environmental impact (A5) are also weak.

***** Insert Figure 1*****

Figure 2 shows that the licensing procedure (C1) and R&D funding (C9) are the most important criteria in RES adoption, while groundwater pollution (C19) and investment cost (C13) are the most vital barriers to RES adoption.

***** Insert Figure 2*****

5. Discussion

This study offers theoretical and managerial insights by determining the attributes that affect RES adoption and the barriers to achieving sustainable electricity performance to increase social welfare, improve economic costs, reduce environmental impacts and optimize technology. Previous studies have failed to address environmental conditions from the perspective of cause and effect in RES adoption by the electricity sector; thus, this study fills a gap in the literature. This section discusses the theoretical and managerial implications of the results.

5.1 Theoretical Implications

This study offers evidence supporting the following shortcomings in RES adoption. The causal interrelationships among social, economic, environmental and technological attributes need to be addressed to accelerate RES adoption and reduce the barriers to adoption (Luthra et al., 2016). RES adoption is related to institutions and policy, technical analysis, innovation capabilities, financial actions, and environmental impact factors. The group of causes supporting RES adoption consists of institutions and policy, environmental impact, and technical analysis. For the barriers to RES adoption, the group of causes includes institutions and policy and technical analysis but not environmental impact, which belongs to the effect group. The results emphasize that environmental attributes must be addressed to achieve sustainable electricity performance in a dynamic context.

This study finds that major causal interrelationships exist between institutions and policy, technical analysis, environmental impacts and innovation capabilities in RES adoption. Institutions and policy, technical analysis, and environmental impact are the causal attributes for enhancing RES adoption. The results suggest that innovation resources and R&D should be encouraged as causal attributes even though innovation capabilities are also an effect (van der Loos et al., 2020; Assi et al., 2021). Innovation is developed in conjunction with knowledge and administrative structure, which reduce the risks in generating energy (Njoh et al., 2019; Barquet et al., 2020). Institutions and policy, technical analysis, and environmental impact are enhanced by improving innovation capabilities for better RES adoption (Andersen & Gulbrandsen, 2020; Asante et al., 2020; Razmjoo et al., 2021). Innovation capabilities are developed by legitimizing new technology through communication among individuals (Tabrizian, 2018). Innovation enables existing systems to operate well, quickly, and inexpensively (Assi et al., 2021). Environmental impact, which concerns natural resource volatility and environmental conditions, such as geography and topography, needs to be considered in RES adoption (Asante et al., 2020; Yao et al., 2020). RES adoption requires social awareness and knowledge of the environmental impact, as these support the institutions, policies and technical analysis that promote innovation capabilities (Stavrakas et al., 2019; Kim et al., 2020). In summary, this finding indicates that, despite being an effect, innovation capabilities can motivate the implementation of the institutional, policy, technical analysis, and environmental impact factors that accelerate RES adoption.

Technical analysis and institutions and policy are the major barriers to RES adoption; however, technical analysis has the strongest interrelationship with environmental impact. The findings also reveal that environmental impact is an effect attribute that influences innovation capabilities, another effect attribute, and enhances technical analysis. Potentially beneficial environmental impact is limited when policy design, policy support and technical analysis are neglected (Tolliver et al., 2020; Razmjoo et al., 2021). Environmental impact is the major effect driving better performance of the causal attributes even though financial action, an effect attribute, has a weak relationship with technical analysis. Barriers to RES adoption emerge from political issues and corruption in institutions and policymaking (Scholten & Bosman, 2016; Asante et al., 2020); thus, enhancing institutions and policymaking can both pull and push improvements to environmental impact. This study also confirms that the technical analysis of RES technology can drive a moderate reduction in emissions. For example, inadequate technology impedes the development of RES technology, as new technologies involving RESs are not installed, contributing to worsening environmental impacts (Karytsas & Choropanitis, 2017; Asante et al., 2020). Hence, prioritizing the technical analysis of RES technology and strengthening institutions and policies are essential to identifying and reducing the barriers to adoption. This study shows that environmental impact, as an effect attribute, is vital for improving technical analysis as a causal attribute. The barriers to RES adoption are reduced, starting with environmental impact, by increasing environmental awareness and knowledge, integrating various RESs, and strengthening financial actions that promote technical analysis.

Environmental impact is a key causal attribute in RES adoption and is also an effect attribute in the barriers to RES adoption due to the dynamic context in which RES technology is employed. Environmental impact is driven by bureaucratic conditions. Inefficient government responses and geographical conditions impede the adoption of RES-based technologies (Asante et al., 2020;

Quirapas & Taeihagh, 2020). The economic conditions of a country contribute to its financial support of environmentally friendly technology investment (Karytsas & Choropanitis, 2017; Asante et al., 2020). Technological knowledge, technology components and educational level determine whether communities adopt RESs (Adelaja, 2020; Mahalik et al., 2021). These contextual conditions are important and serve as determinants influencing the design of plans and targets. The current environmental impact as a causal attribute needs to be understood from the perspective of the availability and quality of RESs in nature. As an effect attribute, environmental impact is related to emissions, noise pollution, and visual disturbances. Environmental impact is related to both technical analysis and institutions and policy, which can influence innovation capabilities. However, the identification of the environmental impacts that foster or hinder RES adoption remains unsatisfactory. Thus, this attribute is a priority for the proper development of RESs and the RES management system.

5.2. Managerial Implications

The results indicate that R&D funding (C9) is to help electricity firms accelerate RES adoption. This finding supports the theoretical framework concerning the need to improve innovation and reflects the current electricity performance in Indonesia, highlighting the means to achieve sustainable electricity generation by utilizing RESs. In practice, as Indonesia lacks energy conversion and storage technology, R&D funding should be provided to develop technologies for converting and storing renewable energy for electricity consumption. When R&D funding is provided, firms can engage in innovation activities and improve their innovation capabilities. Such funding may also be used to increase system flexibility and ensure a continuous renewable energy supply. Thus, certain guidelines are offered to help Indonesian electricity firms allocate funding for developing RESs to attain sustainable performance through following several steps. First, provide R&D funding to support innovation activities and innovation capabilities, and build policy supporting R&D during this phase. Firms need to collaborate with more stakeholders to obtain policy support and improve their innovation performance; through this process, firms can gain opportunities to build a reputation for adopting RESs. Such a reputation can create an investment climate that supports RES adoption.

Licensing procedures (C1) foster RES adoption but depend on contextual conditions, such as politics, geography and topography, and economic and social circumstances; however, firms are required to comply with procedures and permits at the national or regional level. To conform to these procedures, firms should consider engaging in community support by convincing communities of the positive social welfare and environmental impacts. In addition to establishing procedures supporting RES adoption, the Indonesian government must provide an efficient bureaucratic licensing procedure for firms to expand RES use and for stakeholders to allocate more consumption. Procedures should be aligned with renewable energy policies that are flexibly adjusted to changes in the RES market.

Groundwater pollution (C19) is related to fossil fuel mining, which impacts water quality, and must be addressed, as Indonesia still highly relies on fossil fuels to generate electricity despite efforts to utilize RESs. Groundwater conditions must also be considered to maximize the thermal heat coming from the earth. In other words, the use of groundwater offers opportunities to develop RES-generated power even though its quality has been affected by activities associated with fossil fuel mining. For instance, an Indonesian manufacturing company utilizes heat from water for cooling, heating, and lighting without consuming government-provided electricity. Although effective approaches to change this barrier into an opportunity for utilizing polluted water need further investigation, firms should start investing in relevant sustainable activities that can reduce RES barriers and adoption.

Investment cost (C13) is affected by policy measures related to the high cost of RES technology implementation and firms' available financial resources. The cost of investment in electricity generation has not yet been counterbalanced with predictable output results. Fluctuations in electricity system output emerge due to the uncertain operation of RES-based power generation, leading to high operational costs and low renewable energy penetration from power plants. Inconsistent power plant operation, limited financial resources, inflexible policies, and the low impacts of RES policy on economic growth in Indonesia have discouraged stakeholders from increasing investment; these conditions may aggravate the barriers to RES adoption. Firms and stakeholders in the electricity sector should be motivated by policy measures, including incentives and refunds. Risk analysis of investments and evaluation of the necessary resources to ensure a stable supply for sustainable electricity generation can also be enhanced. To address the barriers to adopting sustainable electricity, this study recommends that collaboration among stakeholders be optimized to increase investment, as such efforts can encourage RES utilization. This study also proposes integrating investment risk analysis to achieve sustainable electricity generation.

Understanding of the causal interrelationships among the barriers to RES adoption provides specific guidelines to help Indonesian electricity firms achieve sustainable performance. The practices highlighted by the two most prominent criteria are the key activities to be prioritized by firms. The outlined causal interrelationships show firms how to prioritize their efforts stage by stage to improve their efficiency in adopting RES practices for sustainable electricity. Firms should efficiently incorporate alternative resources to improve the sustainability of their plans and targets.

6. Conclusion

The use of RESs for sustainable electricity generation is often considered without addressing the environmental attributes that can facilitate or hinder implementation, which creates a gap in the measurement of the facilitators of and barriers to RES adoption. A set of attributes that facilitate or hinder RES adoption needs to be identified. The interrelationships among these attributes must be addressed, as RESs play a critical role in building sustainable electricity. This study proposes five aspects and twenty criteria from the social, economic, environmental, and technological perspectives to assess the barriers to RES adoption. The measurement of these criteria used qualitative and quantitative techniques. The FDM was employed to determine the valid attributes by converting linguistic preferences into crisp values. Fuzzy DEMATEL was then applied to identify the interrelationships among the causal attributes and effect attributes and was used to support the sustainability performance of electricity firms.

In this study, theoretical implications are proposed. The causal interrelationships identified reveal that institutions and policy, technical analysis, and environmental impact are the causal attributes supporting RES adoption, while institutions, policy adoption and technical analysis are causal attributes hindering RES adoption. In particular, (1) the three causal attributes supporting RES adoption are strongly affected by innovation capabilities, as the effect attribute, driving improvements in the causal attributes; (2) technical analysis, as a causal attribute, is strongly affected by environmental impacts, an effect attribute, and the barriers to RES adoption; and (3) environmental impact is both a cause and an effect because it can push and pull other attributes to support or impede RES adoption. Environmental impact and innovation capabilities should be considered for better decision-making, according to the findings confirming their important position in the interrelationships among attributes. Environmental impact and innovation are related, and emphasis is needed on how to increase innovation in all phases of electricity generation. Innovation contributes to the emergence of effective RES technologies and economic improvement, which promotes RES adoption and reduces barriers.

For managerial implications, the significant criteria that act as both drivers and facilitators of RES adoption include R&D funding, licensing procedures, groundwater pollution, and investment costs. In RES operation, greater attention must be given to the contextual conditions of RESs. In practice, these criteria are addressed to present guidelines for stakeholders, including electricity firms and governments at the national and local levels. Stakeholders should consider cost in the initial stage of accelerating transition. Targets should be supported by sufficient procedures, as actions for sustainable electricity generation are strengthened by R&D funding. In the long term, managers should increase funding for further fundamental research focusing on technologies that can reduce pollution.

The limitations of this study relate to the theory and the method adopted. First, the proposed attributes were selected from the literature; thus, the set of attributes that represent the barriers to RES adoption may not be comprehensive. Further studies should undertake a systematic review to gather additional attributes for better measurements. Second, the number of experts was limited to fifteen, causing possible bias. Future studies should expand the number of experts to overcome this issue. Third, the electricity sector was selected to evaluate the barriers to RES adoption, limiting the generalizability of the findings. Another sector employing RESs, such as transportation, should be considered to facilitate the generalization of the results. Since electricity generation is also influenced by RES availability, further studies should attempt to predict RES quality and availability using more advanced technologies, such as artificial intelligence.

Acknowledgments

This study is partially supported by MOST 108-2221-E-468 -004 -MY2, Ministry of Science and Technology, Taiwan.

References

1. Aberilla, J. M., Gallego-Schmid, A., Stamford, L., & Azapagic, A., 2020. Design and environmental sustainability assessment of small-scale off-grid energy systems for remote rural communities. Applied Energy 258, 114004.
2. Adelaja, A. O., 2020. Barriers to national renewable energy policy adoption: Insights from a case study of Nigeria. Energy Strategy Reviews 30, 100519.
3. Agency, J. I. C., 2011. Project for the Master Plan Study of Hydropower Development in

Indonesia: Final Report. II.

4. Akram, R., Chen, F., Khalid, F., Huang, G., Irfan, M., 2021. Heterogeneous effects of energy ef fi ciency and renewable energy on economic growth of BRICS countries : A fixed effect panel quantile regRESion analysis. Energy 215, 119019.
5. Alipour, M., Salim, H., Stewart, R., Sahin, O., 2020. Predictors, taxonomy of predictors, and correlations of predictors with the decision behaviour of residential solar photovoltaics adoption: A review. Renewable and Sustainable Energy Reviews 123, 109749.
6. Andersen, A. D., Gulbrandsen, M., 2020. The innovation and industry dynamics of technology phase-out in sustainability transitions: Insights from diversifying petroleum technology suppliers in Norway. Energy Research and Social Science 64, 101447.
7. Asante, D., He, Z., Adjei, N. O., Asante, B., 2020. Exploring the barriers to renewable energy adoption utilising MULTIMOORA- EDAS method. Energy Policy 142, 111479.
8. Assi, A. F., Zhakanova Isiksal, A., Tursoy, T., 2021. Renewable energy consumption, financial development, environmental pollution, and innovations in the ASEAN + 3 group: Evidence from (P-ARDL) model. Renewable Energy 165, 689–700.
9. Barquet, K., Järnberg, L., Rosemarin, A., Macura, B., 2020. Identifying barriers and opportunities for a circular phosphorus economy in the Baltic Sea region. Water Research 171, 115433.
10. Bui, T. D., Tsai, F. M., Tseng, M. L., Wu, K. J., Chiu, A. S., 2020. Effective municipal solid waste management capability under uncertainty in Vietnam: utilizing economic efficiency and technology to foster social mobilization and environmental integrity. Journal of Cleaner Production 259, 120981.
11. Chachuli, F. S., Mat, S., Ludin, N. A., Sopian, K., 2021. Performance evaluation of renewable energy R&D activities in Malaysia. Renewable Energy 163, 544–560.
12. Chavez-Rodriguez, M. F., Carvajal, P. E., Martinez Jaramillo, J. E., Egüez, A., Mahecha, R. E. G., Schaeffer, R., Szklo, A., Lucena, A. F. P., Aramburo, S. A., 2018. Fuel saving strategies in the Andes: Long-term impacts for Peru, Colombia and Ecuador. Energy Strategy Reviews 20, 35–48.
13. Cuesta, M. A., Castillo-Calzadilla, T., Borges, C. E., 2020. A critical analysis on hybrid renewable energy modeling tools: An emerging opportunity to include social indicators to optimise systems in small communities. Renewable and Sustainable Energy Reviews 122, 109691.
14. Chen W. C., Chen, W. K., Chen, C. W., Lo, C.C., 2019. An empirical study of willingness to renewable energy installation using importance-performance analysis: the case of Taiwan. Journal of Industrial and Production Engineering 36, 451-460.
15. Dawood, K. A., Sharif, K. Y., Ghani, A. A., Zulzalil, H., Zaidan, A. A., Zaidan, B. B., 2021. Towards a unified criteria model for usability evaluation in the context of open source software based on a fuzzy Delphi method. Information and Software Technology 130, 106453.
16. Deveci, M., Özcan, E., John, R., Covrig, C. F., Pamucar, D., 2020. A study on offshore wind farm siting criteria using a novel interval-valued fuzzy-rough based Delphi method. Journal of Environmental Management 270, 110916.
17. Dhirasasna, N. N., Sahin, O., 2021. A system dynamics model for renewable energy technology adoption of the hotel sector. Renewable Energy 163, 1994–2007.
18. Dranka, G. G., Ferreira, P., Vaz, A. I. F., 2020. Cost-effectiveness of energy efficiency

investments for high renewable electricity systems. Energy 198, 117198.
19. Du, H., Huang, P., Jones, P., 2019. Modular facade retrofit with renewable energy technologies: The definition and current status in Europe. Energy and Buildings 205, 109543.
20. Fragkos, P., Laura, H., Soest, V., Schaeffer, R., Reedman, L., Macaluso, N., Evangelopoulou, S., De Vita, A., Sha, F., Qimin, C., Kejun, J., Mathur, R. Shekhar, S., Dewi, R. G., Diego, S. H., Oshiro, K., Fujimori, S., Park, C., Safonov, G., Iyer, G., 2021. Energy system transitions and low-carbon pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States. Energy 216, 119385.
21. Goodess, C. M., Troccoli, A., Acton, C., Añel, J. A., Bett, P. E., Brayshaw, D. J., De Felice, M., Dorling, S. R., Dubus., L., Penny, I., Percy., B., Ranchin, T., Thomas, C., Trolliet, M., Wald, L., 2019. Advancing climate services for the European renewable energy sector through capacity building and user engagement. Climate Services 16, 100139.
22. Hille, E., Althammer, W., Diederich, H., 2020. Environmental regulation and innovation in renewable energy technologies: Does the policy instrument matter? Technological Forecasting and Social Change 153, 119921.
23. Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., Mieno, H., 1993. The max-min Delphi method and fuzzy Delphi method via fuzzy integration. Fuzzy sets and systems 55, 241-253.
24. Jain, M., Siva, V., Hoppe, T., Bressers, H., 2020. Assessing governance of low energy green building innovation in the building sector: Insights from Singapore and Delhi. Energy Policy 145, 111752.
25. Jeong, J. S., Ramírez-Gómez, Á., 2018. Optimizing the location of a biomass plant with a fuzzy-DEcision-MAking Trial and Evaluation Laboratory (F-DEMATEL) and multi-criteria spatial decision assessment for renewable energy management and long-term sustainability. Journal of Cleaner Production 182, 509–520.
26. Karatop, B., Taşkan, B., Adar, E., Kubat, C., 2020. Decision analysis related to the renewable energy investments in Turkey based on a Fuzzy AHP-EDAS-Fuzzy FMEA approach. Computers and Industrial Engineering 151, 106958.
27. Karytsas, S., Choropanitis, I., 2017. Barriers against and actions towards renewable energy technologies diffusion: A Principal Component Analysis for residential ground source heat pump (GSHP) systems. Renewable and Sustainable Energy Reviews 78, 252–271.
28. Kim, H., Park, S., Lee, J., 2020. Is renewable energy acceptable with power grid expansion ? A quantitative study of South Korea's renewable energy acceptance. Renewable and Sustainable Energy Reviews 139, 110584.
29. Lerman, L. V., Gerstlberger, W., Ferreira Lima, M., Frank, A. G., 2021. How governments, universities, and companies contribute to renewable energy development? A municipal innovation policy perspective of the triple helix. Energy Research and Social Science 71, 101854.
30. Lin, S., Li, C., Xu, F., Liu, D., Liu, J., 2018. Risk identification and analysis for new energy power system in China based on D numbers and decision-making trial and evaluation laboratory (DEMATEL). Journal of Cleaner Production 180, 81–96.
31. Liu, J., Bai, J., Deng, Y., Chen, X., Liu, X., 2020. Impact of energy structure on carbon emission and economy of China in the scenario of carbon taxation. Science of the Total Environment

762, 143093.
32. Luthra, S., Govindan, K., Kharb, R. K., Mangla, S. K., 2016. Evaluating the enablers in solar power developments in the current scenario using fuzzy DEMATEL: An Indian perspective. Renewable and Sustainable Energy Reviews 63, 379–397.
33. Mahalik, M. K., Mallick, H., Padhan, H., 2021. Do educational levels influence the environmental quality? The role of renewable and non-renewable energy demand in selected BRICS countries with a new policy perspective. Renewable Energy 164, 419–432.
34. Martin, N., Rice, J., 2021. Power outages, climate events and renewable energy: Reviewing energy storage policy and regulatory options for Australia. Renewable and Sustainable Energy Reviews 137, 110617.
35. Mukuve, F. M., Fenner, R. A., 2015. Scale variability of water, land, and energy resource interactions and their influence on the food system in Uganda. Sustainable Production and Consumption 2, 79–95.
36. Navon, A., Kulbekov, P., Dolev, S., Yehuda, G., Levron, Y., 2020. Integration of distributed renewable energy sources in Israel: Transmission congestion challenges and policy recommendations. Energy Policy 140, 111412.
37. Nindhia, T. G. T., McDonald, M., Styles, D., 2021. Greenhouse gas mitigation and rural electricity generation by a novel two-stroke biogas engine. Journal of Cleaner Production 280, 124473.
38. Njoh, A. J., Etta, S., Essia, U., Ngyah-Etchutambe, I., Enomah, L. E. D., Tabrey, H. T., Tarke, M. O., 2019. Implications of institutional frameworks for renewable energy policy administration: Case study of the Esaghem, Cameroon community PV solar electrification project. Energy Policy 128, 17–24.
39. Ocampo, L., Ebisa, J. A., Ombe, J., Geen Escoto, M., 2018. Sustainable ecotourism indicators with fuzzy Delphi method – A Philippine perspective. Ecological Indicators 93, 874–888.
40. Osorio, J. D., Panwar, M., Rivera-Alvarez, A., Chryssostomidis, C., Hovsapian, R., Mohanpurkar, M., Chanda, S., Williams, H., 2020. Enabling thermal efficiency improvement and waste heat recovery using liquid air harnessed from offshore renewable energy sources. Applied Energy 275, 115351.
41. Padilla-Rivera, A., do Carmo, B. B. T., Arcese, G., Merveille, N., 2021. Social circular economy indicators: Selection through fuzzy delphi method. Sustainable Production and Consumption 26, 101–110.
42. Pan, D., Tang, J., 2021. The effects of heterogeneous environmental regulations on water pollution control: Quasi-natural experimental evidence from China. Science of the Total Environment 751, 141550.
43. Perez, A., Garcia-Rendon, J., 2020. Integration of non-conventional renewable energy and spot price of electricity: A conceptual analysis for Colombia. Renewable Energy 167, 146-161.
44. Pitelis, A., Vasilakos, N., Chalvatzis, K., 2020. Fostering innovation in renewable energy technologies: Choice of policy instruments and effectiveness. Renewable Energy 151, 1163–1172.
45. Plank, J., Doblinger, C., 2018. The firm-level innovation impact of public R&D funding: Evidence from the German renewable energy sector. Energy Policy 113, 430–438.
46. Pratama, Y. W., Purwanto, W. W., Tezuka, T., McLellan, B. C., Hartono, D., Hidayatno, A.,

Daud, Y., 2017. Multi-objective optimization of a multiregional electricity system in an archipelagic state: The role of renewable energy in energy system sustainability. Renewable and Sustainable Energy Reviews 77, 423–439.

47. Pompili, M., Calcara, L., D'Orazio, L., Ricci, D., Derviškadić, A., He, H., 2021. Joints defectiveness of MV underground cable and the effects on the distribution system. Electric Power Systems Research 192, 107004.
48. Quirapas, M. A. J. R., Taeihagh, A., 2020. Ocean renewable energy development in Southeast Asia: Opportunities, risks and unintended consequences. Renewable and Sustainable Energy Reviews 137, 110403.
49. Rabaia, M. K. H., Abdelkareem, M. A., Sayed, E. T., Elsaid, K., Chae, K. J., Wilberforce, T., Olabi, A. G., 2021. Environmental impacts of solar energy systems: A review. Science of the Total Environment 754, 141989.
50. Ramos, A., Rouboa, A., 2020. Renewable energy from solid waste: life cycle analysis and social welfare. Environmental Impact Assessment Review 85, 106469.
51. Razmjoo, A., Gakenia Kaigutha, L., Vaziri Rad, M. A., Marzband, M., Davarpanah, A., Denai, M., 2021. A Technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce CO2 emissions in a high potential area. Renewable Energy 164, 46–57.
52. Samant, S., Thakur-Wernz, P., Hatfield, D., 2020. Does the focus of renewable energy policy impact the nature of innovation? Evidence from emerging economies. Energy Policy 137, 111119.
53. Sanderink, L., Nasiritousi, N., 2020. How institutional interactions can strengthen effectiveness: The case of multi-stakeholder partnerships for renewable energy. Energy Policy 141, 111447.
54. Scholten, D., Bosman, R., 2016. The geopolitics of renewables; exploring the political implications of renewable energy systems. Technological Forecasting and Social Change 103, 273–283.
55. Shah, S. A. A., Solangi, Y. A., Ikram, M., 2019. Analysis of barriers to the adoption of cleaner energy technologies in Pakistan using Modified Delphi and Fuzzy Analytical Hierarchy Process. Journal of Cleaner Production 235, 1037–1050.
56. Sharif, A., Mishra, S., Sinha, A., Jiao, Z., Shahbaz, M., Afshan, S., 2020. The renewable energy consumption-environmental degradation nexus in Top-10 polluted countries: Fresh insights from quantile-on-quantile regRESion approach. Renewable Energy 150, 670–690.
57. Sirin, S. M., Yilmaz, B. N., 2020. Variable renewable energy technologies in the Turkish electricity market: Quantile regresion analysis of the merit-order effect. Energy Policy 144, 111660.
58. Stavrakas, V., Papadelis, S., Flamos, A., 2019. An agent-based model to stimulate technology adoption quantifying behavioural uncertainty of consumers. Applied Energy 255, 113795.
59. Stephens, S., Robinson, B. M. K., 2021. The social license to operate in the onshore wind energy industry: A comparative case study of Scotland and South Africa. Energy Policy 148.
60. Sugiawan, Y., Managi, S., 2016. The environmental Kuznets curve in Indonesia: Exploring the potential of renewable energy. Energy Policy 98, 187–198.
61. Tabrizian, S., 2019. Technological innovation to achieve sustainable development—

Renewable energy technologies diffusion in developing countries. Sustainable Development 27, 537–544.

62. Tawalbeh, M., Al-Othman, A. Kafiah, F., Abdelsalam, E., Almomani, F., Alkasrawi, M., 2020. Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook. Science of the Total Environment 759, 143528.
63. Tolliver, C., Keeley, A. R., Managi, S., 2020. Policy targets behind green bonds for renewable energy: Do climate commitments matter? Technological Forecasting and Social Change 157, 120051.
64. Tseng, M. L., Chang, C. H., Lin, C. W. R., Nguyen T. T. H., Lim, M., 2020. Environmental responsibility drives board structure and financial performance: A cause and effect model with qualitative information. Journal of Cleaner Production 258, 120668
65. Tumiran, Putranto, L. M., Sarjiya, Pramono, E. Y., 2021. Maximum penetration determination of variable renewable energy generation: A case in Java–Bali power systems. Renewable Energy 163, 561–570.
66. van der Loos, Negro, S., Hekkert, M., 2020. International markets and technological innovation systems: The case of offshore wind. Environmental Innovation and Societal Transitions 34, 121-138.
67. Versteeg, T., Baumann, M., Weil, M., Moniz, A., 2017. Exploring emerging battery technology for grid-connected energy storage with Constructive Technology Assessment. Technological Forecasting & Social Change 115, 99-110.
68. Wu, Y., Liao, M., Hu, M., Lin, J., Zhou, J., Zhang, B., Xu, C., 2020. A decision framework of low-speed wind farm projects in hilly areas based on DEMATEL-entropy-TODIM method from the sustainability perspective: A case in China. Energy 213, 119014.
69. Yang, S., Park, S., 2020. The effects of renewable energy financial incentive policy and democratic governance on renewable energy aid effectiveness. Energy Policy 145, 111682.
70. Yao, Y., Xu, J.-H., Sun, D.-Q., 2020. Untangling global levelised cost of electricity based on multi-factor learning curve for renewable energy: wind, solar, geothermal, hydropower and bioenergy. Journal of Cleaner Production 285, 124827.
71. Yazawa, K., Shakouri, A., 2021. Fuel-burning thermoelectric generators for the future of electric vehicles. Energy Conversion and Management 227, 113523.
72. Zimmerman, M., Reames, T., 2021. Where the wind blows: Exploring barriers and opportunities to renewable energy development on United States tribal lands. Energy Research & Social Science 72, 101874.

Tables

Table 1. The RES adoption and barrier attributes

Aspects	Criteria		Description	References
Institutional and policy (A1)	C1	Licensing procedures	Bureaucratic permit procedures are shortened due to social license and community support.	Karytsas et al. (2017); Shah et al. (2019); Stephens & Robinson (2021) Asante et al., 2020, Goodess et al (2019); Sanderink &Nasiritousi (2020); Stavrakas et al., 2019
	C2	Skilled and trained human resources	Human resources are required to be skillful and trained for the renewable energy development	
	C3	institutional capacity building policy	Institution capacity building is strengthened to identify renewable energy issues through engagement, feedback and evaluation mechanism	
	C4	Institutional coordination	Coordination among institutions requires commitment, planning, knowledge and strengthens partnership for renewable energy.	
Technical Analysis (A2)	C5	technical skill	technical human resource skill	Razmjoo et al., (2021); Asante et al., (2020); Su et al. (2020); Shayesteh et al. (2018)
	C6	Supply reliability	Renewable energy supply can satisfy the energy demand along with its fluctuation and mitigate the environmental impacts	
	C7	Service and maintenance facilities	Suitable technical capacity for technology service and maintenance involves maintenance strategy, planning, and schedule.	
Innovation capabilities (A3)	C8	Driver of innovation	Technology innovation is directed more strategic, promoted for renewable energy consumption, supported by government, universities and companies.	Andersen & Gulbrandsen (2020); Lerman et al. (2021); Su et al., (2021) ;Plank & Doblinger (2018) ; Lie et al. (2019); Wang et al. (2020)
	C9	research and development funding	The R&D funding shifted to independent expenses represents the firm's financial situation	
	C10	Technology exploration	Exploring the technology in renewable energy provides supports for the RE design and	

			needs to be employed prior to projects.	
	C11	Design shape of technology	The technology design is shaped based on standard than custom representing intermittency and renewable energy fluctuation	
Financial action (A4)	C12	Financial Incentives	The financial incentives include loans with low rates, grants, subsidies, tax reduction, leasing, shared saving.	Karytsas & Choropanitis (2017); Asante et al., (2020); Shah et al. (2019); Yang et al. (2020); Karatop et al. (2020) Dranka et al. (2020); Yue et al. (2020)
	C13	Investment cost	The amount of initial investment cost is based on prioritization and risk analysis	
	C14	Operating cost	Operating costs depend on the electricity price and affect the emission reduction	
	C15	installation cost	Installation cost depends on the installation type such as open, closed, vertical, horizontal and installation size like high and small	
Environmental impact (A5)	C16	carbon emission	Carbon emission reduction is determined by indicators set from policy makers and capital generation	Liu et al., (2020); Razmjoo et al. (2021) Karytsas et al., (2017); Chavez-Rodriguez et al. (2018); Quirapas & Taeihagh (2020); Pan & Tang (2021) Yazawa & Shakouri (2021)
	C17	fossil fuel saving	Fossil fuel saving is resulted from the substitution effects from non to renewable energy and from the highly fossil fuel consumed sectors.	
	C18	Risks during transport storage and operation	Risks can be avoided during transport, storage, and operation depending on the local regions	
	C19	Ground water pollution	Renewable energy is promoted in all electrified energy sectors to reduce ground water pollution that needs a market-based environmental regulation.	
	C20	Thermal radiation risk	Thermal radiation from fossil fuels is reduced and converted to be efficient to improve air quality	

Table 2. FDM transformation table of linguistic terms

Linguistic terms (adoption/barriers)	Corresponding triangular fuzzy numbers (TFNs)
Extreme	(0.75, 1.0, 1.0)
Demonstrated	(0.5, 0.75, 1.0)
Strong	(0.25, 0.5, 0.75)
Moderate	(0, 0.25, 0.5)
Equal	(0, 0, 0.25)

Table 3. The FDM results for Aspects

Aspects	u_y	p_y	H_y	Decisions
A1	0.013019	0.861981	0.434245	Unaccepted
A2	-0.01296	0.887961	0.44074	Accepted
A3	0.013019	0.861981	0.434245	Unaccepted
A4	0.019117	0.855883	0.432721	Unaccepted
A5	-0.01756	0.892558	0.441889	Accepted
A6	-0.01756	0.892558	0.441889	Accepted
A7	-0.00196	0.876959	0.437990	Accepted
A8	0.019117	0.855883	0.432721	Unaccepted
A9	0.033258	0.841742	0.429185	Unaccepted
A10	-0.02902	0.904015	0.444754	Accepted
	Threshold		0.437038	

Table 4. Aspects' defuzzied crisp values

	A1	A2	A3	A4	A5
A1	0.721	0.554	0.599	0.494	0.563
A2	0.580	0.857	0.562	0.429	0.574
A3	0.492	0.475	0.807	0.441	0.499
A4	0.484	0.347	0.487	0.721	0.499
A5	0.505	0.604	0.623	0.606	0.684

Table 5. RES adoption aspects' total direct relation matrix

	A1	A2	A3	A4	A5	D
A1	3.242	3.253	3.551	3.047	3.227	16.319
A2	3.292	3.466	3.646	3.115	3.331	16.849
A3	2.918	2.975	3.355	2.794	2.958	15.000
A4	2.710	2.714	3.009	2.702	2.750	13.885
A5	3.246	3.353	3.649	3.167	3.351	16.766
R	15.407	15.761	17.210	14.826	15.616	3.153

Table 6. RES adoption aspects' prominence and relation axis for the cause and effect group

	D	R	D+R (Cause)	D-R (Effect)
A1	16.319	15.407	31.726	0.912
A2	16.849	15.761	32.610	1.088
A3	15.000	17.210	32.210	(2.210)
A4	13.885	14.826	28.710	(0.941)
A5	16.766	15.616	32.382	1.150
Max			32.610	1.150
Min			28.710	(2.210)
Average			31.528	0.000

Table 7. RES adoption Criteria's prominence and relation axis for the cause and effect group

	D	R	D+R (Cause)	D-R (Effect)
C1	7.943	6.834	14.778	1.109
C2	7.534	7.127	14.660	0.407
C3	6.563	6.870	13.433	(0.307)
C4	7.416	6.870	14.286	0.546
C5	6.610	7.085	13.695	(0.475)
C6	6.528	7.140	13.669	(0.612)
C7	6.090	6.893	12.983	(0.803)
C8	6.166	7.212	13.378	(1.046)
C9	8.032	7.242	15.274	0.790
C10	7.057	6.953	14.010	0.104
C11	6.201	7.053	13.254	(0.853)
C12	7.446	7.086	14.532	0.360
C13	7.309	7.040	14.350	0.269
C14	7.305	7.692	14.997	(0.387)
C15	6.775	7.195	13.970	(0.420)
C16	7.155	7.004	14.159	0.151
C17	7.836	6.587	14.422	1.249
C18	6.769	7.213	13.982	(0.443)
C19	7.397	6.616	14.014	0.781
C20	6.179	6.601	12.781	(0.422)
Max			15.274	1.249
Min			12.781	(1.046)
Average			14.031	0.000

Table 8. The adoption and barriers gap in the Aspects

Aspects	Adoption	Barriers	Gaps
A1	4.400	3.867	0.533
A2	4.200	3.600	0.600
A3	4.133	3.733	0.400
A4	4.133	3.733	0.400
A5	4.600	4.333	0.267

Table 9. The adoption and barrier gap in the criteria

	Adoption	Barriers	Gaps
C1	4.333	3.267	1.067
C2	4.067	2.600	1.467
C3	3.733	2.867	0.867
C4	3.933	2.933	1.000
C5	3.867	2.867	1.000
C6	3.733	3.267	0.467
C7	3.533	3.067	0.467
C8	3.533	3.000	0.533
C9	4.133	3.133	1.000
C10	3.800	3.267	0.533
C11	3.467	2.867	0.600
C12	3.800	2.667	1.133
C13	4.000	3.333	0.667
C14	3.933	3.133	0.800
C15	3.733	3.200	0.533
C16	3.733	3.333	0.400
C17	4.200	3.533	0.667
C18	3.733	2.933	0.800
C19	3.867	3.667	0.200
C20	3.800	3.400	0.400

Figures

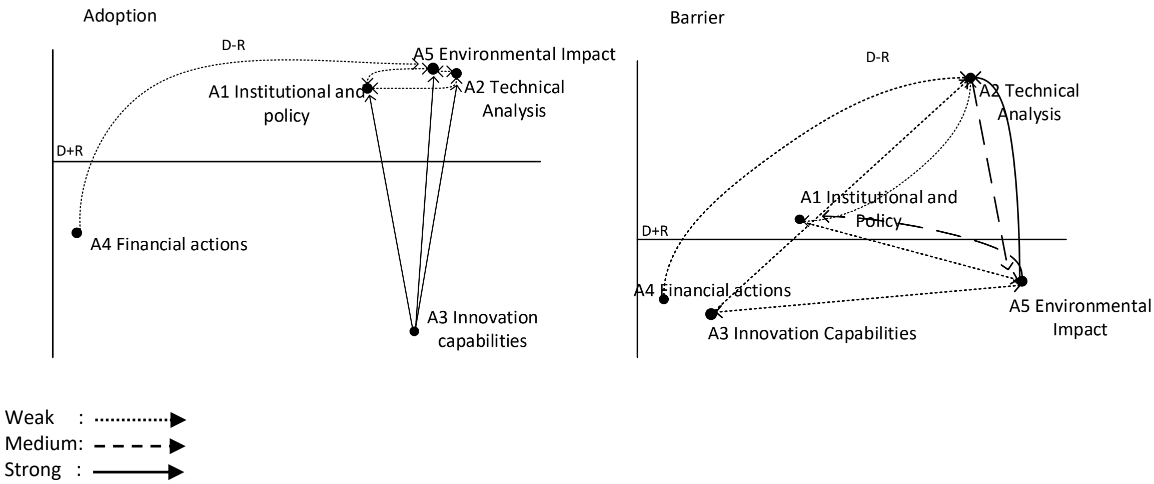

Figure 1. The RES adoption and barrier aspects' causal interrelationships

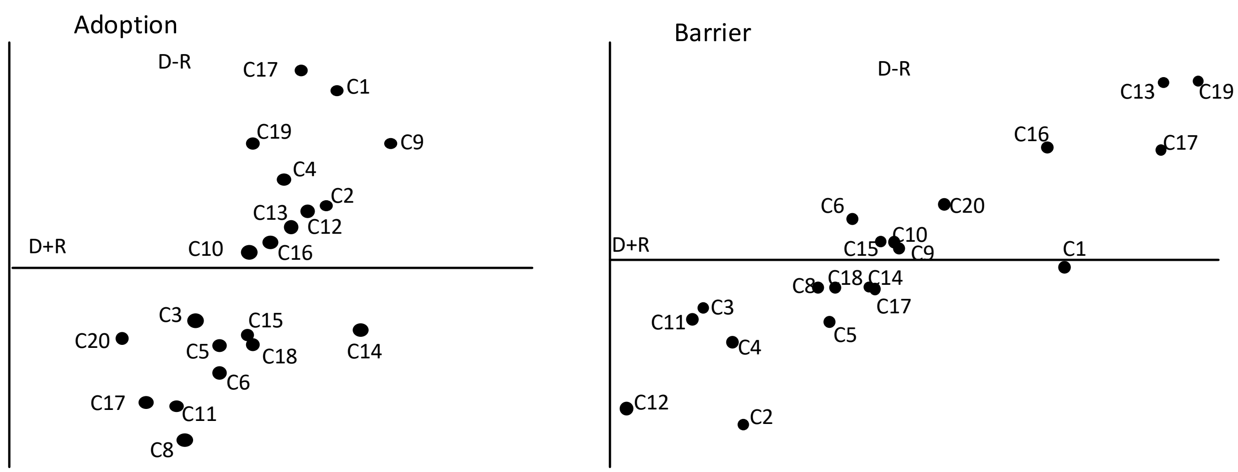

Figure 2. The RES adoption and barrier criteria

Appendices

Appendix 1 Initial Proposed RES attributes

Aspects	Original Criteria (OC)		Description	References
Political and Regulatory (A1)	OC1	Regulatory framework	regulatory framework affects investments in the renewable energy expansion.	Asante et al. (2020); Goodess et al. (2019); Karytsas & Choropanitis, (2017); Shah et al. (2019); Sanderink & Nasiritousi (2020); Stavrakas et al., 2019
	OC2	Public and private cooperation	Private and public cooperation is needed to reduce geopolitical competition and mistrust as strategic priorities.	
	OC3	Partnership development	Developing partnership is to create new business model.	
	OC4	Development plan creation	Creation of a strategic development plan	
Institutional and policy (A2)	OC5	Licensing procedures	The number of documents in bureaucratic permit procedures is reduced.	Karytsas & Choropanitis, (2017); Stephens & Robinson (2021)
	OC6	Skilled and trained human resources	Human resources are required to be skillful and trained for the renewable energy development	
	OC7	institutional capacity building policy	Institution capacity building is strengthened to identify renewable energy issues.	Asante et al., 2020, Goodess et al. (2019)
	OC8	Institutional coordination	Coordination among institutions requires commitment, planning, knowledge	Sanderink & Nasiritousi (2020).
Information Availability (A3)	OC9	Information about technology benefit	Stakeholders must know objective information how technology brings benefits	Karytsas & Choropanitis (2017);
	OC10	stakeholders' information awareness	Level of information awareness from the stakeholder affects technology diffusion.	Karytsas & Choropanitis, (2017); Zografakis et al. (2011)
	OC11	Information collection and evaluation	Information about the technology demands to be collected and evaluated	
Technological Actions (A4)	OC12	Guideline publication	Guidelines for installers, suppliers, maintainers need to be published	
	OC13	Certifications establishment	Certification for the design, installation and reference data is encouraged.	
	OC14	technical Standard establishment	Standards for the design, installation, and reference data are established	
	OC15	technical trainings	Training for designers, installers and policy makers in a period	
	OC16	Infrastructure development	Infrastructure is developed for design and installation	
	OC17	Stakeholder Coordination	Coordination among installers, designers and other stakeholders for more efficient system	
	OC18	Planning system installation	Planning system installation in all units	
	OC19	Technology and installation Improvement	Technology and installation process need to be improved to reduce the installation cost	Karytsas & Choropanitis (2017)
Technical Analysis (A5)	OC20	technical skill	technical human resource skill	Razmjoo et al. (2021); Asante et al. (2020); Su et al. (2020); Shayesteh et al. (2018)
	OC21	Supply reliability	Renewable energy supply can meet the energy demand and mitigate the environmental impacts	
	OC22	Service and maintenance facilities	Suitable technical capacity for technology servicing and maintenance	
	OC 23	driver of innovation	Technology innovation is directed more strategic and user-driven forms.	Andersen & Gulbrandsen (2020);

Innovation capabilities (A6)	OC 24	research and development funding	The fund of research and development for innovation is shifted from related parties to independent expenses.	Lerman et al. (2021); Su et al. (2021) ;Plank & Doblinger (2018)
	OC 25	Technology exploration	Technology exploration within projects is undergone prior to projects	
	OC 26	Design shape of technology	The design of technology is shaped based more on standard than custom.	
Financial action (A7)	OC 27	Financial Incentives	The financial incentives include loans with low rates, grants, subsidies, tax reduction, leasing, shared saving.	Karytsas & Choropanitis, (2017); Asante et al. (2020); Shah et al. (2019); Karatop et al. (2020) Dranka et al. (2020); Yao et al. (2020)
	OC 28	Financial model development	Financial models are developed by state-owned companies	
	OC 29	Investment cost	The amount of initial investment cost	
	OC 30	Operating cost	Operating cost are dependent on the electricity price	
	OC 31	installation cost	Installation cost depends on the installation type such as open, closed, vertical, horizontal	
Economic analysis (A8)	OC 32	Initial capital	Initial capital affects RE diffusion rate	Asante et al. (2020); Shah et al. (2019)
	OC 33	Credit accessibility	Access to credits influences the project development	
	OC 34	Market size	Market size affects the renewable energy adoptions	
	OC 35	Pricing system	The pricing system influences the RE penetration	
Environmental performance (A9)	OC 36	environmental certification	The environmental certification is determined from green certificate based on low carbon emission	White et al. (2021); Mahalik et al. (2021); Kim et al. (2020)
	OC 37	geographical consideration	Location of installation and generation	
	OC 38	environmental awareness	Environmental awareness affects renewable energy consumption behaviors	
environmental impact (A10)	OC 39	carbon emission	Carbon emission reduction is determined by indicators set from policy makers and renewable energy source integrated with domestic factors	Liu et al. (2020); Razmjoo et al. (2021); Chavez-Rodriguez et al. (2018)
	OC 40	GHG emission	GHG emission is minimized as water level is considered	
	OC 41	fossil fuel saving	Fossil fuel saving is resulted from the substitution effects from non to renewable energy	Karytsas et al. (2017); Yang & Park (2020); Jacobson et al. (2018); Quirapas & Taeihagh (2020); Pan & Tang (2021)
	OC 42	Risks during transport storage and operation	Heating oil can be avoided during transport, storage, and operation	
	OC 43	Ground water pollution	renewable energy is promoted in all electrified energy sectors to reduce ground water pollution	
	OC 44	thermal radiation risk	Thermal radiation is reduced as heating technologies do not rely on fossil fuels	Yazawa & Shakouri (2021); Yang & Park (2020)

Appendix 2. Demographic profiles

Expert	Position	Year of Experience	Education Background
1	Director	20	Bachelor
2	Director	15	Bachelor
3	Main substation manager	32	Bachelor of Applied Science

4	Main substation manager	32	Bachelor of Applied Science
5	Main substation manager	29	Bachelor of Applied Science
6	Main substation manager	12	Bachelor
7	Senior Analyst	55	Bachelor of Applied Science
8	Senior Analyst	30	Bachelor of Applied Science
9	Senior Analyst	29	Bachelor
10	Senior Evaluator	8	Master
11	Junior Advisor	4	Bachelor of Applied Science
12	Junior Advisor	3	Bachelor
13	Engineer	4	Bachelor of Applied Science
14	Junior Analyst	3	Bachelor
15	Junior Analyst	1	Bachelor

Appendix 3. Initial direct relation matrix –Respondent 1 for RES adoption

				A1					A2					A3					A4					A5		
			$q\tilde{e}^k_{1ij}$	$q\tilde{e}^k_{2ij}$	$q\tilde{e}^k_{3ij}$			$q\tilde{e}^k_{1ij}$	$q\tilde{e}^k_{2ij}$	$q\tilde{e}^k_{3ij}$			$q\tilde{e}^k_{1ij}$	$q\tilde{e}^k_{2ij}$	$q\tilde{e}^k_{3ij}$			$q\tilde{e}^k_{1ij}$	$q\tilde{e}^k_{2ij}$	$q\tilde{e}^k_{3ij}$			$q\tilde{e}^k_{1ij}$	$q\tilde{e}^k_{2ij}$	$q\tilde{e}^k_{3ij}$	
A1			1.000	0.714	0.429			0.667	0.667	0.556			0.400	0.400	0.200			0.222	0.222	0.222			0.222	0.222	0.222	
A2			0.286	0.286	0.286			1.000	0.778	0.556			0.000	0.000	0.000			0.000	0.000	0.000			0.444	0.444	0.444	
A3			0.000	0.000	0.000			0.222	0.222	0.222			1.000	0.600	0.200			0.000	0.000	0.000			0.000	0.000	0.000	
A4			0.286	0.286	0.286			0.000	0.000	0.000			0.000	0.000	0.000			1.000	0.778	0.556			0.444	0.444	0.444	
A5			0.571	0.571	0.429			0.444	0.444	0.444			0.400	0.400	0.200			0.667	0.667	0.556			1.000	0.778	0.556	
			l^n_{ij}	r^n_{ij}				l^n_{ij}	r^n_{ij}				l^n_{ij}	r^n_{ij}				l^n_{ij}	r^n_{ij}				l^n_{ij}	r^n_{ij}		
A1			1.000	0.600				0.667	0.625				0.400	0.250				0.222	0.222				0.222	0.222		
A2			0.286	0.286				1.000	0.714				0.000	0.000				0.000	0.000				0.444	0.444		
A3			0.000	0.000				0.222	0.222				1.000	0.333				0.000	0.000				0.000	0.000		
A4			0.286	0.286				0.000	0.000				0.000	0.000				1.000	0.714				0.444	0.444		
A5			0.571	0.500				0.444	0.444				0.400	0.250				0.667	0.625				1.000	0.714		
			nc^k_{ij}					nc^k_{ij}					nc^k_{ij}					nc^k_{ij}					nc^k_{ij}			
A1			0.720					0.676					0.678					0.300					0.300			
A2			0.500					0.743					0.500					0.100					0.500			
A3			0.300					0.300					0.667					0.100					0.100			
A4			0.500					0.100					0.500					0.743					0.500			
A5			0.673					0.500					0.678					0.676					0.743			