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The portfolio of renewable energy sources for achieving the three E policy goals

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ABSTRACT

Renewable energy is considered by many policy-makers to contribute to achieving at least three major policy goals: the energy goal, the environmental goal, and the economic goal (3E goals). As an innovation-oriented island country with scarce natural resources, Taiwan announced the Sustainable Energy Policy Principles in 2008 that stated that Taiwan's renewable energy policy should accomplish the 3E goals. Several studies point out that specific renewable energy policy goals lead to specific renewable energy sources and technologies because each type of renewable energy has different features. In order to achieve the renewable energy policy goals, this research aims to examine how different policy goals lead to corresponding renewable energy sources. The relative importance of each goal is evaluated by using analytic hierarchy process (AHP). The weight of each policy goal is adjusted separately to construct policy scenarios by the sensitivity analysis. According to the results, non-pumped storage hydropower, wind energy, and solar energy are three sources that could meet the three policy goals at the same time.

1. Introduction

The exhaustion of fossil fuels and the climate change mitigation have become major challenges for governments all over the world in recent years. To engage this challenge, many countries are pursuing the research, development, and demonstration of renewable energy sources. In general, the primary goal of governments' renewable energy policy is to get more renewable energy in place. However, a closer look reveals that there are, in fact, multiple goals that renewable energy policy intends to achieve. Take Ireland as an example, Komor and Bazilian [1] have argued that the numerous drivers and motivators for Irish renewable energy policy can be sorted into the energy goal, the environmental goal, and the economic/industrial goal. The International Energy Agency (IEA) also indicates that many policy-makers consider that renewable energy in IEA member countries contributes to improving energy security, environmental protection, and economic development (the three Es) [2].

As an innovation-oriented island country with limited natural resources, Taiwan imports over 99% of its energy supply. Thus, Taiwan also seeks renewable energy to engage the challenge of high carbon emissions and the exhaustion of fossil fuel. The Sustainable Energy Policy Principles announced in 2008 stated that the renewable energy policy should achieve each of the 3E goals as noted above [3].

Several studies point out that specific renewable energy policy goals lead to specific renewable energy sources and technologies because each type of renewable energy has different features [1,4,5]. This research aims to assess various renewable energy sources regulated in Taiwan's "Renewable Energy Development Bill" in order to meet different policy goals. There are many sophisticated analytical methods that look for optimal solutions to the multi-goal problem [6]. The analytic hierarchy process (AHP) introduced by Saaty [7] is one of the most widely used techniques for assessing each alternative against a set of identified criteria. In this study, AHP is adopted to construct a renewable energy source assessment model in order to identify and weigh the criteria that are critical in the renewable energy assessment.

Moreover, AHP provides quantitative output that can be used with sensitivity analysis to explore how changes in criteria or weights affect strategic scenarios [8]. Sensitivity analysis can improve the credibility of AHP by providing appropriate answers to "what if" questions, and is particularly valuable for multi-objective decision-making problems [9]. By performing sensitivity analysis, the value of AHP can be extended by including scenario building and analysis into the AHP process. Analysts can build scenarios to depict possible circumstances that affect the criteria weights or attributes for each alternative [8]. In this study, the sensitivity analysis is employed to change the weights of each policy goals in order to draw possible policy scenarios. Using these policy scenarios as a guideline, policy-makers can apply AHP to examine the impacts of each policy goal on the determination of renewable energy sources.

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The organization, for the remainder of this research, is as follows: Section 2 briefly illustrates the current renewable energy policy in Taiwan. Section 3 introduces six renewable energy sources regulated by Taiwan's Renewable Energy Development Bill. A multi-objective framework is constructed in Section 4 for assessing the renewable energy sources according to Taiwan's policy background and related literature. Section 5 describes the AHP method and the sensitivity analysis applied in this study. The empirical analysis conducted by AHP and sensitivity analysis is presented in Section 6. Finally, Section 7 presents the conclusions and policy implications based on the results of Section 6.

2. Renewable energy policy background

In Taiwan, the development of renewable energy is in its initial stage; related green market mechanisms such as Tradable Green Certificates have not been introduced [10]. Although Taiwan is not a member country of the United Nations, the government is now expecting to increase its use of renewable energy for electricity generation. It must therefore address the pressures that Taiwan encounters and recognize the background and requirements of Taiwan's energy policy.

Taiwan is a densely populated island with scarce natural resources. The energy supply has rapidly increased during the past two decades along with the dramatic economic growth [11]. The total energy supply has increased from 51.64 million kiloliters of oil equivalent (KLOE) in 1988 to 142.47 million KLOE in 2008, at average annual growth rate of 5.21% [12]. In addition to high dependence on imported energy, Taiwan is particularly dependent on fossil fuels in its energy mix, as shown in Table 1. Consequently, Taiwan ranks 17th in the world on CO_2/population emission [13].

To engage the challenge of rapidly increasing global greenhouse gases (GHGs), the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992, followed by the Kyoto Protocol in 1997. The European Union has legislated the Directive 2005/32/EC [14], namely Directive of Eco-design Requirements of Energy-using Products (EuP), in response to the Kyoto Protocol. Under the EuP directive, the products will be restricted from importation if the CO_2 emission within production exceeds the regulated standard. Due to its high dependence on export, Taiwan has to support renewable energy in order to cope with the global trend of green procurement [15].

On the other hand, the indigenous energy price easily fluctuates owing to high dependence on imported fossil fuels. Supplies of traditional fossil fuel are gradually being depleted. In addition, the increasing demand of developing countries with rapidly economic growth, unstable geopolitics, and natural disasters also make the price of crude oil rise and fluctuate. The development of indigenous renewable energy sources can decrease dependence on imported fossil fuels [16].

Table 1
Energy supply by resources.

	1988		2008		1988–2008
	KLOE	%	KLOE	%	Average Growth rate (%)
Coal	13,683.4	26.50	46,186.7	32.42	6.27
Petroleum	27,225.9	52.72	70,466.7	49.46	4.87
Natural gas	1394.7	2.70	13,420.0	9.42	11.99
Nuclear	8876.6	20.81	11,823.5	8.30	1.44
Hydropower	446.8	1.14	411.6	0.29	−0.41
Solar photovoltaic and wind power	3.0	0.01	56.7	0.04	15.90
Solar thermal	9.8	0.02	109.5	0.08	12.82

Moreover, the Sustainable Energy Policy Principles stated that the renewable energy policy should take economic development into account [3]. According to the National Energy Conference in 2009, the research and development (R&D) of renewable energy technologies and the development of the renewable energy industry should be addressed in the renewable energy policy. In particular, the development of the renewable energy industry is now regarded as a strategy to create jobs and improve national competitiveness [17].

3. The development of renewable energy in Taiwan

According to the Renewable Energy Development Bill approved in 2009, renewable energy sources mainly include solar energy, biomass, geothermal, wind energy, ocean energy, and non-pumped storage hydropower. The current generation capacity and the potential of each renewable energy source in Taiwan are discussed below.

3.1. Solar energy

In Taiwan, the use of solar energy comprises solar thermal energy and photovoltaics. Based on an estimate of the area of solar collections, the potential of solar energy for heat supply is around 1.8 millions square meters [18]. The solar water heater (SWH) is the major application of solar thermal energy in Taiwan [11]. The current installation rate by household in the domestic sector is about 3.5% [19]. For electricity, the potential is around 12 thousand MW generation capacity, based on an estimate of the solar photovoltaic settings for residences, commerce, public facilities, and others [18]. Over 385 subsidized systems have been established in Taiwan as a result of the government's incentive program, the total capacity of which had reached 4080 kWp by 2008 [20].

3.2. Biomass energy

Biomass energy is widely used in Taiwan, including biogas from animal waste and fuel energy from the burial, gasification, breaking-down, and fermentation of household, industrial, and agricultural garbage [11]. The potential is around 2000 MW generation capacity based on the biomass investigation in Taiwan including municipal solid waste (MSW), refuse derived fuel (RDF), petroleum cokes, sugar cane, rice husks, black liquor, scrap tires, paper rejects, and biogas [18]. According to statistics from the Bureau of Energy, the installed capacity of biomass energy and MSW were 116.8 MW and 622.5 MW until 2008, respectively [12].

3.3. Geothermal energy

Taiwan is an island extruded by the Eurasian Plate and the Philippine Sea Plate; consequently, the nation has abundant geothermal resources. The potential is around 1000 MW generation capacity, according to the investigation of over 26 major geothermal sites in Taiwan [18]. However, most of the geothermal resources in Taiwan are in remote areas, so exploitation is difficult. The economically and technically feasible exploitation is only about 150 MW [11]. In Taiwan, the main application of geothermal energy is electricity generation. The most promising site is the Chin-Suei geothermal energy project located at Yi-Lan County, which is developed by the local government using a build, operate, and transfer method (BOT) for multiple uses of geothermal resources [16].

3.4. Wind energy

Wind energy is one of the fastest growing renewable energy resources, and its share in power system is increasing worldwide

[21]. The potential of wind energy is at least 1000 MW generation capacity in inshore wind power systems, and 2000 MW generation capacity in offshore wind power systems, based on the investigation of many sites in Taiwan, having a wind speed of more than 5 m/s [18,22]. To promote wind power generation, Ministry of Economic Affairs initiated a wind demonstration project in 2000. The total capacity reached 252.1 MW, with more than 190 established wind power generators by 2008 [20].

3.5. Ocean energy

The oceans represent a vast and largely untapped source of energy in the form of fluid flow. Several approaches to extracting energy from oceans include tidal energy, marine currents, wave energy, and ocean thermal energy conversion (OTEC). The Kuroshio Current in the northwestern Pacific Ocean, flowing along the east coast of Taiwan, has an average speed of 0.9 m/s that might have 60 GW potential generation capacity. In addition, the northeast coast of Taiwan and offshore islands have the potential of wave energy generation. Based on an investigation, the potential of OTEC is around 30 GW generation capacity. The current development of ocean energy comprises a more detailed investigation of ocean energy distribution, the introduction of ocean energy technologies, and the demonstration of ocean energy generation [16].

3.6. Non-pumped storage hydropower

According to an investigation of over 129 rivers in Taiwan, their potential is around 5110 MW generation capacity [18]. By 2009, the total installed capacity of hydropower in Taiwan had reached 1937.9 MW, excluding pumped storage hydropower of 2602 MW [12].

4. The assessment framework

As argued by IEA [2] and Komor and Bazilian [1], the numerous policy goals for a country's renewable energy policy can at least be sorted into broader policy goals of three types: the energy goal, the environmental goal, and the economic and industrial development goal. This study constructs a renewable energy source assessment framework for Taiwan (Fig. 1) with the renewable energy policy, technologies, and end-user markets in Taiwanese context as well as the framework proposed by Komor and Bazilian [1]. This study, moreover, conducts in-depth interviews with three government officials and academic researchers as key experts, including Director General of Bureau of Energy, Legislator, and Director of

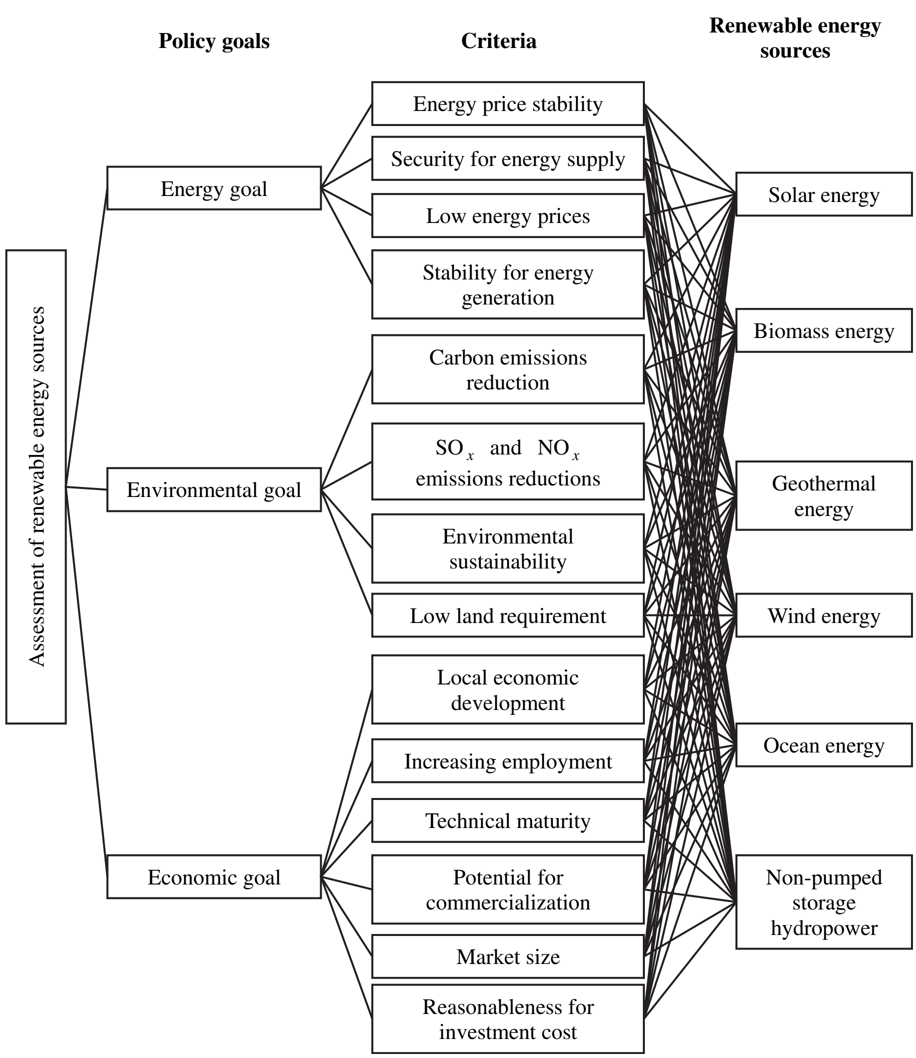

Fig. 1. The assessment model for renewable energy sources in Taiwan.

Taiwan Institute of Economics Research, to ensure the validity of the proposed framework.

4.1. Energy goal

Taiwan is looking to renewable energy to help it accomplish the energy goal of low and stable energy price, secure energy supply, stable energy generation for family, industrial and national needs. In order to meet the energy goal, the assessment of renewable energy sources must consider insulation from energy price volatility, security for the energy supply, low energy prices, and stability for the energy supply.

4.1.1. Energy price stability

Influenced by many factors including the increasing demand of rapidly growing developing countries, unstable geopolitics, and nature disasters, fossil fuel prices are increasingly volatile [1, 16]. Since Taiwan obtains 38.5%, 28.6%, and 9.8% of its electricity from coal, natural gas, and oil respectively [12], the electricity sector is particularly vulnerable to these price fluctuations. According to Taiwan Power Company's annual budget plan, it could have lost 900 million US dollars in 2010 [23]. The proposed electrical power price adjustments have caused both industrial and household customers' grievances against the government. Although Taiwan has an indigenous supply of crude oil and natural gas, the low degree of self-sufficiency does not necessarily eliminate price fluctuations. The development of indigenous renewable energy can help protect Taiwan from energy prices fluctuations in international markets.

4.1.2. Security for energy supply

Energy security means consistent availability of sufficient dependent on secure supplies of energy [24]. The IEA suggests that the development of renewable energy should take energy security into consideration [2]. According to statistic of the Bureau of Energy, most of Taiwan's electricity is generated from imported fuels, including coal, natural gas, oil, and nuclear power [12]. Such high dependence on imported resources shows that Taiwan is highly exposed to international economic and political changes in terms of price fluctuations. Moreover, such risks could also be possibly expressed as an energy supply shortage [1]. Among Taiwan's imported fuels, the supply of natural gas and crude oil is especially affected by changes in international markets. The exploitation of local renewable energy sources increases the security of the energy supply.

4.1.3. Low energy prices

Energy is a fundamental economic input for transportation, industry, agriculture, resident, services, and other sectors. Low energy prices reduce production costs to facilitate economic growth. In addition, energy is a basic need for heating, cooking, and transportation [1]. Maintaining low energy prices is necessary to maintain residents' living standard. However, renewable energy density is so low that energy prices are usually higher than those for fossil fuels. To maintain residents' basic living standards and national competitiveness, the utilization of renewable energy sources should take renewable energy prices into account.

4.1.4. Stability for energy generation

A common drawback existing in renewable energy is the unpredictable and intermittent output of electrical power, especially for wind energy and solar energy, so that renewable energy is incapable of providing the all-renewable electricity production nowadays [25,26]. In order to realize the future of all-renewable electricity production, many researches on renewable energy technologies focus on resolving this drawback [27–29]. Owing to the intermittent nature of renewable energy, some studies imply that the stability of electricity output is critical for the development of renewable energy [30–32]. Hence, this study suggests that the stability for energy generation is necessary to be considered in the assessment.

4.2. Environmental goal

Environmental issues have attracted more attention in recent years due to climatic problems associated with the increased levels of carbon emissions and pollutions [33]. Renewable energy also helps Taiwanese government accomplish the environmental goal. The assessment of renewable energy sources should consider carbon emissions reduction, SO_x and NO_x emissions reductions, environmental sustainability, and low land requirement in respect to the environmental goal.

4.2.1. Carbon emissions reduction

According to the investigation of the International Energy Agency, Taiwan ranks 17th in the world on the CO_2/population emission scale and ranks 20th in terms of the total CO_2 emissions, producing 276.18 million tons in 2007 [13]. Aggressive action in the energy sector will be necessary if the Taiwanese government is eager to clear its bad reputation. Thus, the capability to reduce carbon emissions should be emphasized in assessments of renewable energy [1,34,35].

4.2.2. SO_x and NO_x emissions reductions

In addition to CO_2, burning fossil fuels emits various compounds that lead to air pollution. One of the expectations for exploitation of renewable energy is that it will reduce air pollutants such as SO_x and NO_x which is also harmful to human health [1,4,36]. Due to the immaturity of technology, the reduction of SO_x and NO_x emissions will go a long way toward achieving the environmental goal.

4.2.3. Environmental sustainability

Sustainability is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [37]. Although renewable energy is considered as the substitution of fossil fuels toward the environmental sustainability, the environmental impacts caused by the exploitation of renewable energy is worth being evaluated according to the following factors: landscape impact, acoustic emissions, electromagnetic interferences, unpleasant odors, and microclimatic changes [4].

4.2.4. Low land requirement

It is worth noting that the amount of energy per unit of land area is small due to the low energy density of renewable energy [25]. To obtain capacity that approximates that of fossil fuels, renewable energy sites need very large areas of converters to capture energy. However, human activities are regarded as relevant factors in environmental pressure. A strong demand for land can also probably cause economic losses, which are proportional to the specific value of site and the possible attendant alternative needs [4]. Land requirement is a critical factor for assessing renewable energy sources because Taiwan is an island country with limited territory.

4.3. Economic goal

The Taiwanese government also expects that renewable energy policy can accomplish the economic goal, notably stimulating Taiwan's economic growth and increasing employment [17].

4.3.1. Local economic development

Taiwan's economic development has relied on high-tech industry in the past. Nowadays, the Taiwanese government expects that the industrial structure can be adjusted to facilitate economic growth by developing renewable energy [17]. Several Taiwanese semiconductor and TFT-LCD manufacturers have invested heavily on solar panel manufacturing plants, and these companies are counted on renewable energy technologies for their future growth. The benefits created by the development of renewable energy should be evaluated in the assessment.

4.3.2. Increasing employment

Due to the low economic growth in Taiwan in recent years, the unemployment rate has been a major concern there. Creating job opportunities is an important consideration in renewable energy policy, and sustainable energy development should promote creativity, higher employment, and higher job satisfaction [38]. In order to achieve the economic goal, increasing employment is crucial for the assessment of renewable energy [1,39,40].

4.3.3. Technical maturity

Technical maturity is essential for evaluating an applied technology [4]. The more mature an emerging technology is, the more successful the opportunities will be [41]. It is necessary to evaluate the technical maturity of renewable energy technologies for meeting the economic goal in Taiwan's renewable energy policy.

4.3.4. Potential for commercialization

Although there are numerous types of renewable energy, many of them are technically immature and only performed in pilot plants and, thus, cannot be utilized in large-scale. Many countries have deployed policy measures to facilitate the commercialization of renewable energy technologies to capture competitive position in the global market for domestic renewable energy industry [42–44]. These studies, therefore, suggest that superior commercialization of technology will be crucial to accomplish the economic goal. The potential and the possibility of commercialization of successful renewable energy utilization are significant to evaluate for reaching such goal [35].

4.3.5. Market size

In order to accomplish the economic goal of stimulating economic growth and increasing employment, the potential market size of renewable energy and its related technologies should be carefully evaluated, including domestic and oversea markets [35]. As an emerging industry, the potential market size of renewable energy technologies plays an important role to establish the industrial competitiveness [35,44,45]. Larger market size attracts more companies that are willing to invest in the technologies, which is helpful to facilitating development of related industries.

4.3.6. Reasonableness for investment cost

Presently, the investment costs along with the risks of renewable energy are still high and not recommended from an economic point of view [46]. At the national level, however, the environmental and energy goals have to be evaluated against investment costs to determine whether renewable energy sources are more efficient [35,47]. Several studies, thus, suggest taking the investment costs into consideration in a utilization of renewable energy [48–52].

5. Research methods

The major purpose of this study is to explore the corresponding renewable energy alternatives under different renewable energy policy goals. This research primarily uses the AHP to determine the feasibility of renewable energy sources to meet the 3E policy goals. For policy making purposes, it is important that policy succeeds not only in evaluating the priority of different policy goals, but also in estimating whether the alternatives meet the policy goals. Renewable energy policy should be better planned to allow the resources and efforts to be allocated to assess the importance of the policy goals. In such a context, the AHP proposed by Saaty [7] appears to be an extremely useful mechanism that allows decision makers to express their qualitative and subjective judgments. Furthermore, the results derived by AHP can test the priority of alternatives under different presumed scenarios with sensitivity analysis. In this section, the AHP and the sensitivity analysis are illustrated.

5.1. Analytic hierarchy process

The AHP method is a popular multi-objective decision-making and planning tool that is analysis based on an additive weighting process, in which several relevant attributes are represented according to their relative importance [9]. AHP has been extensively applied by academics and professionals in the field of renewable energy research [34,35,40,47,53–56]. In the specific case of renewable energy policy analysis, the AHP allows the "hierarchization" of different policy goals and their affiliated criteria, making possible a quantitative treatment that leads to a numerical estimate of the relative importance of each criterion and alternative.

Literature review, brainstorming, and the Delphi method can be used to search for criteria when establishing a hierarchical structure. After that, the criteria are mutually compared for $n \times (n-1)/2$ times if there are n criteria. A nine-point scale recommended by Saaty [7] is adopted to obtain experts' opinions, with preferences between options given as equally, moderately, strongly, very strongly, or extremely preferred (with pairwise weight of 1, 3, 5, 7, and 9, respectively), and values of 2, 4, 6, and 8 as the intermediate values for the preference scale. Matrix A can be formed to represent the pairwise comparisons as Eq. (1):

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

where a_{ij} represents the geometric mean that the expert panel compares the criterion i with criterion j.

To estimate the relative weights of the criteria in this matrix, the priority of the criteria is compared by computing the eigenvalues and eigenvectors with Eq. (2):

$$A \cdot w = \lambda_{\max} \cdot w \quad (2)$$

where w is the eigenvector of the matrix A, and $\lambda_{\max}$ is the largest eigenvalue of the matrix A. The eigenvector w can be obtained by Eq. (3):

$$w = \left(\prod_{j=1}^{n} a_{ij} \right)^{1/n} \Big/ \sum_{i=1}^{n} \left(\prod_{j=1}^{n} a_{ij} \right)^{1/n} \quad (3)$$

where n is the number of criteria being compared in this matrix. The largest eigenvalue $\lambda_{\max}$ of A can be estimated by using Eq. (4):

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i} \quad (4)$$

The consistency of the matrix is done by examining the reliability of judgments in the pairwise comparison. The consistency index (CI) and the consistency ratio (CR) are defined as Eqs. (5) and (6):

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \quad (5)$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (6)$$

where n is the number of criteria being compared in this matrix, and RI is the random index. The average consistency index of a randomly generated pairwise comparison matrix of similar size is shown in Table 2.

5.2. Sensitivity analysis

Sensitivity analysis generally involves the manipulation of model criteria in an attempt to determine the degree of influence that the criterion has on the overall model output. This type of analysis is useful in that it allows for an understanding of the different outcomes that could arise given a certain amount of variation in the model assumptions [8]. In the AHP process, the results are dependent on the decision makers' subjective perceptions of the relative importance of those elements [9]. By using sensitivity analysis, AHP can build assumed scenarios that provide more information for decision makers to realize how different circumstances affect their decision-making without forcing them to change their original considerations. Many studies regarding related renewable energy issues have applied sensitivity analysis to consider the output effect that criteria weight changes lead to [5,40,47,57]. This research employs the sensitivity analysis to explore how specific policy goals affect the determination of corresponding renewable energy sources.

The idea of sensitivity analysis is illustrated below [9]. Eq. (5) of final scores denoted by c is:

$$c_k = \sum_{i=1}^{n} w_i b_{ik} \tag{7}$$

where w_i denotes the weight corresponding to criterion i, and the vector b_i represents the principal eigenvector of the comparison matrix under criterion i. The vector b_i identifies the relative values of the K alternatives with respect to the criterion i.

Assuming the pairwise comparisons entered by the researcher imply the original weights (w_1,w_2,w_3) of three criteria, the score of alternative k is given by Eq. (8):

$$c_k = b_{k1}w_1 + b_{k2}w_2 + b_{k3}w_3 \tag{8}$$

Suppose the researcher is interested in varying w_1. Defining $p = w_2/w_3$, Eq. (9) can be derived as:

$$w_1 + w_2 + w_3 = w_1 + pw_3 + w_3 = 1 \tag{9}$$

which implies:

$$w_3 = (1 - w_1)/(p + 1) \tag{10}$$

$$w_2 = pw_3 = (1 - w_1)p/(p + 1) \tag{11}$$

By substituting Eq. (10) and (11) into (8), Eq. (12) is derived as:

$$c_k = b_{k1}w_1 + b_{k2}(1 - w_1)p/(p+1) + b_{k3}(1 - w_1)/(p+1) \tag{12}$$

This procedure allows for graphically displaying the scores for c_k because the weight of the first criterion is varied from zero to one [9].

6. Empirical analysis

In this section, the constructed assessment model is used to assess the renewable energy sources regulated in the Renewable Energy Development Bill to select suitable renewable energy technologies for Taiwan. The weights of each criterion are obtained by using AHP and are presented below. Moreover, a renewable energy source portfolio is assembled by applying sensitivity analysis to achieve a set of policy goals. Four policy scenarios built by sensitivity analysis are the likely policy condition, the energy scenario, the environmental scenario, and the economic scenario. The results are elaborated below.

Table 2
Random index (RI).

n	1	2	3	4	5	6	7	8
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41
n	9	10	11	12	13	14	15	
R.I.	1.45	1.49	1.51	1.48	1.56	1.57	1.59	

6.1. The analysis of AHP

Before engaging in discussing this result, it is instructive to take a closer look at Table 3. To accomplish the research purpose, this study has surveyed experts in Taiwan (Appendix 1) who are familiar with the status quo development of renewable energy technologies, the market conditions, and the renewable energy policy to assess the six major renewable energies defined in the Renewable Energy Development Bill. The consistency of 15 expert questionnaires which have been collected is verified through using CI and CR suggested by Saaty [7]. As a result, 14 valid questionnaires with values of CI and CR smaller than 0.1 are employed in obtaining the final criteria weights of the assessment framework by adopting the AHP illustrated in the previous section.

As presented in Table 3, the environmental goal (0.409) is the most emphasized policy goal at the present time, with the economic goal (0.324) and the energy goal (0.266) rank second and third, respectively. Within the environmental goal, environmental sustainability (0.395) is identified as the most critical criteria to evaluate renewable energy sources. According to the Renewable Energy Development Bill approved in 2009, the major purpose of renewable energy development and popularization is to enhance sustainable development in Taiwan. By complying with the first item of the Renewable Energy Development Bill, environmental sustainability ranks first within the environmental goal to further accentuate the challenge of heavy reliance on fossil fuel in Taiwan.

Market size (0.231) is identified as the first priority factor within the economic goal. The first item of the Renewable Energy Development Bill declares that facilitating the development of related industries is one of the main purposes on renewable energy exploitation. Lewis and Wiser [45] indicate that many countries are seeking to expand their domestic use of renewable energy to develop the indigenous renewable energy industries. It is implied that a larger market size is helpful to facilitate the development of related industries.

Security for energy supply (0.393) is the dominant factor within the energy goal to evaluate the renewable energy sources. It is necessary to evaluate the possibility of electricity generation to decrease reliance on imported fossil fuels. By utilizing indigenous renewable energy sources to reduce such dependency, the security for the nation's energy supply will be enhanced to achieve the energy goal further.

6.2. Scenario 1: likely policy condition

This scenario represents experts' perspectives regarding the status quo of renewable energy policy associated with the corresponding renewable energy sources. The synthesized result in this scenario indicates how to achieve all three policy goals at the same time. After completing the renewable energy source assessment model, the six renewable energy sources are evaluated by our chosen experts who are familiar with the status quo development of renewable energy technologies, the market conditions, and the renewable energy policy, to determine the most suitable renewable energy sources. The performance of each renewable energy source is pairwise compared by our experts. As presented in Table 3, non-

Table 3
Results of likely policy condition.

Criteria	Local weights	Global weights	Solar energy	Biomass energy	Geothermal energy	Ocean energy	Wind energy	Non-pumped storage hydropower
Energy goal	**0.266**		**0.167**	**0.157**	**0.164**	**0.156**	**0.165**	**0.190**
Energy price stability	0.157	0.042	0.153	0.158	0.176	0.144	0.167	0.203
Security for energy	0.393	0.105	0.185	0.150	0.154	0.169	0.157	0.185
Low energy prices	0.131	0.035	0.110	0.153	0.182	0.158	0.172	0.225
Stability for energy generation	0.319	0.085	0.171	0.167	0.167	0.145	0.171	0.180
Environmental goal	**0.409**		**0.164**	**0.136**	**0.171**	**0.169**	**0.178**	**0.182**
Carbon emission reduction	0.311	0.127	0.155	0.143	0.160	0.166	0.186	0.190
SO_x and NO_x emissions reductions	0.220	0.090	0.160	0.129	0.156	0.167	0.190	0.198
Environmental sustainability	0.395	0.162	0.179	0.134	0.183	0.163	0.171	0.171
Low land requirement	0.074	0.030	0.128	0.133	0.194	0.242	0.142	0.161
Economic goal	**0.324**		**0.197**	**0.176**	**0.141**	**0.141**	**0.171**	**0.173**
Local economic development	0.179	0.058	0.216	0.163	0.137	0.154	0.181	0.149
Increasing employment	0.124	0.040	0.216	0.183	0.136	0.155	0.174	0.136
Technical maturity	0.148	0.048	0.214	0.182	0.132	0.123	0.136	0.214
Potential for commercialization	0.173	0.056	0.198	0.170	0.150	0.126	0.182	0.174
Market size	0.231	0.075	0.207	0.171	0.122	0.159	0.183	0.159
Reasonableness for investment cost	0.145	0.047	0.125	0.196	0.179	0.125	0.161	0.214
Final scores			**0.175**	**0.154**	**0.160**	**0.157**	**0.172**	**0.181**
Rank			**2**	**6**	**4**	**5**	**3**	**1**

pumped storage hydropower (0.181) is the most preferred renewable energy source among all six sources, followed by solar energy (0.175), ocean energy (0.172), geothermal energy (0.160), wind energy (0.157), and biomass energy (0.154).

Furthermore, each cell in Table 3 identifies scores for each alternative by criterion. These scores represent the performance distribution of a specific criterion across alternatives. Several important explanations can be made regarding the results of the likely policy condition based on Table 3. Non-pumped storage hydropower performs best overall among the six renewable energy sources regulated in the Renewable Energy Development Bill due to its potential of achieving energy and environmental goals. Solar energy and wind energy also perform well according to Fig. 2. In addition to generating electricity without GHGs emissions, the use of hydropower, solar energy, and wind power can enhance Taiwan's energy independence. Moreover, the development of solar photovoltaic industry and wind power industry is regarded an opportunity to stimulate economic growth, as stated by the 2009 National Energy Conference [17].

6.3. Scenario 2: energy scenario

By adjusting the weights given to the three policy goals, one can test the preference of alternatives corresponding to a particular condition. In this scenario, the energy goal is assumed to be the dominant policy goal. As shown in Fig. 3, the weight of energy goal is increased to 0.850, while the weights of other two policy goals are reduced proportionately under this scenario.

According to Fig. 3, non-pumped storage hydropower has the highest score (0.190), followed by solar energy (0.168), wind energy (0.165), geothermal energy (0.164), biomass (0.157), and ocean energy (0.156). According to the investigation of hydropower in Taiwan, the technologically feasible capacity is 5110 MW, and is within the theoretical capacity of 11,727.32 MW [58]. At the end of 2008, the total installed capacity of hydropower in Taiwan had reached approximately 1937.9 MW, excluding the pumped storage hydropower of 2602 MW. Thus, there are about 3000 MW retained for use to enhance the security of the energy supply. In addition to the abundant hydropower resources in Taiwan, the more mature technology also leads to a competitive cost for electricity generation. Under the energy scenario, therefore, non-pumped storage hydropower is the most preferred renewable energy source to reach the energy goal.

6.4. Scenario 3: environmental scenario

In the environmental scenario, the weight of environmental goal is increased to 0.900 to be the dominant policy goal. As presented in Fig. 4, non-pumped storage hydropower (0.182) and wind energy (0.178) are two more important renewable energy sources for achieving the environmental goal. This result reveals the fact that the advantage of utilizing non-pumped storage hydropower and

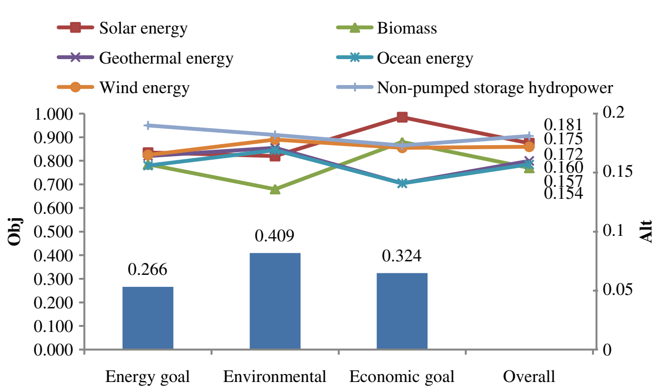

Fig. 2. Likely policy condition.

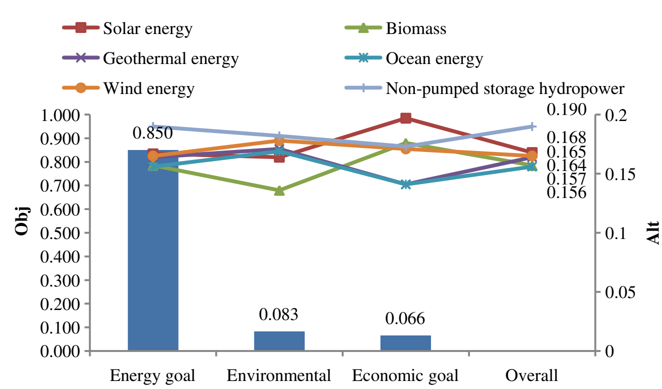

Fig. 3. Energy scenario.

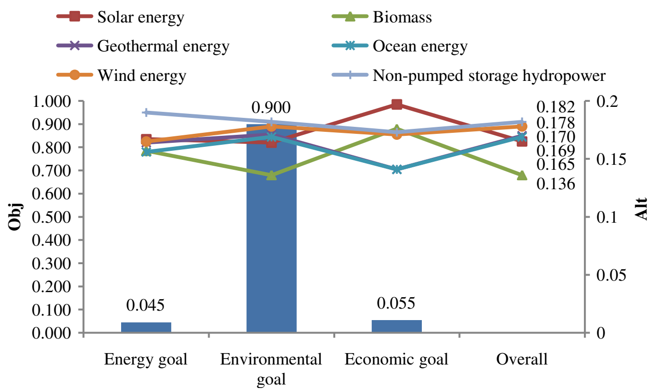

Fig. 4. Environmental scenario.

wind energy is to generate electricity without air pollutant and CO_2 emissions due to the high performance on "carbon emission reduction" and "SO_x and NO_x emissions reductions", as presented in Table 3. According to this result, it is believed that the development of non-pumped storage hydropower and wind energy facilitates to achieve the environmental goal.

6.5. Scenario 4: economic scenario

The relative importance of the economic goal is more emphasized in this scenario as the dominant policy goal (0.975). According to Fig. 5, solar energy becomes the most preferred alternative with the highest score (0.197), followed by non-pumped storage hydropower (0.178), biomass (0.175), wind energy (0.171), ocean energy (0.142), and geothermal energy (0.141). As noted before, the utilization of solar energy in Taiwan consists of solar thermal energy and solar photovoltaics. The SWH is the major application of solar thermal energy in Taiwan. With the Promotion Measures for Solar Water Heater Installment and the Facilitating Industry Upgrade Act, Taiwan has the third highest installation density of 42 m^2/km^2 in the world [16]. As for solar photovoltaics, the 2009 National Energy Conference has declared and encouraged solar photovoltaics industry as one of the renewable energy industries to develop owing to its recent fast growth [17]. The total production value reached 17.2 billion U.S. dollars in 2008, and by 2010, it is estimated that will have more than doubled to 41.0 billion dollars in the global market [59]. The Council for Economic Planning and Development documents reveals that the output value of Taiwan's solar photovoltaic industry reached around 3.1 billion U.S. dollars in 2008, with an 89% growth rate compared with 2007 [60]. The photovoltaics industry is suggested to be another emerging industry in Taiwan to spur the economic growth based on the above industrial analysis.

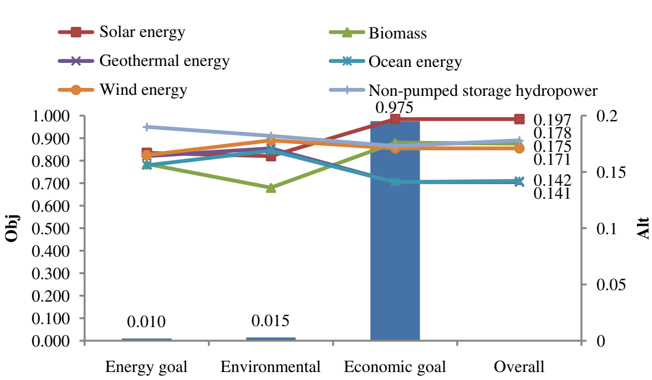

Fig. 5. Economic scenario.

7. Concluding remarks

The Sustainable Energy Policy Principles announced in 2009 stated that the development of renewable energy in Taiwan should simultaneously accommodate energy, environmental, and economic goals [3]. To meet various policy goals, every renewable energy source and technology should be carefully reviewed, since each has distinct features. This study aims at clarifying how different policy goals determine corresponding renewable energy sources. In this research, the AHP is employed to evaluate the relative importance of each policy goal. Moreover, the results of AHP can be applied to gather the corresponding renewable energy sources under different policy goals with sensitivity analysis. Based on this empirical study, some policy implications are delivered in the following subsection.

7.1. Policy implications

As presented in the previous analysis, there are four policy scenarios derived by changing the weights of the three policy goals separately. The policy implications are elaborated as follows.

(1) The results indicate that in the likely policy scenario, non-pumped storage hydropower scores highest, closely followed by solar and wind energy. In the energy scenario, non-pumped storage hydropower performs best. Non-pumped storage hydropower is the most preferred renewable energy source in the environmental scenario as well, closely followed by wind energy. In the economic scenario, solar energy is regarded as the best source to achieve the economic goal. Based on these scenarios, a renewable energy portfolio comprised of non-pumped storage hydropower, wind energy, and solar energy will achieve the three policy goals simultaneously.
(2) In all scenarios, non-pumped storage hydropower performs well. However, the promotion measures are deficient in non-pumped storage hydropower compared with existing promotion measures for solar energy and wind energy in Taiwan. This result suggests that the government provides policy incentives, such as higher guaranteed prices and funding, to stimulate the development of hydropower. Considering the drastic environmental impacts of building large hydroelectric plants, the small hydropower (SHP) system is deserved to be emphasized because this SHP system's impact to ecological environment is smaller than large-scale hydropower system.
(3) According to the previous analysis, wind energy has the second highest score behind only non-pumped storage hydropower in the environmental scenario. After the passage of Renewable Energy Development Bill, Taipower, the only state-owned power company in Taiwan, should raise the guaranteed price to encourage other private enterprises to invest in the establishment of wind turbine continually. Moreover, one may argue the low performance of "low land requirement" (0.142) within the environmental goal, as shown in Table 3. The offshore wind power system, hence, could be the future direction of research, development and demonstration in order to prevent large land requirement as a defect of onshore system.
(4) Solar energy is considered the most preferred renewable energy source to meet the economic goal. Thanks to the rapid growth of photovoltaics industry in recent years, the development of solar energy is regarded as an industrial policy to stimulate Taiwan's economic development. Although Taiwan is not suitable for large-scale renewable energy exploitation due to its limited land resource, becoming one of major providers of solar energy equipment is a feasible strategy that Taiwan could

adopt. To enhance the competitiveness of Taiwan's photovaltics industry, it is suggested that future industrial policy could provide tax exemption, capital grants, or other effective measures toward a complete up- and downstream supply chain and peripherally related industries. As to the demand side, the installment subsidies and guaranteed prices can serve as incentives to increase the domestic demand for household solar panels.

(5) Policy-makers in a democratic society are faced with the challenge of determining which policy goals to pursue and what type of renewable energy source to utilize [1]. This study applies AHP and sensitivity analysis to simulate how different policy goals lead to corresponding renewable energy sources, which enables policy-makers to recognize the suitable renewable energy sources under different policy goals and could serve as a reference for renewable energy policy making.

7.2. Suggestions for future studies

This study only determines the corresponding renewable energy sources under different policy goals to form a renewable energy portfolio. In future works, it is suggested to identify the feasible renewable energy technologies and systems exploiting the proposed renewable energy portfolio in this study.

Although some possible policy suggestions are proposed as above, it is necessary to deeply explore the effective policy measures in regard to the promotion of renewable energy portfolio consisting of non-pumped storage hydropower, wind energy, and solar energy in future studies.

Appendix 1. Surveyed objects and their backgrounds

Objects	Title	Affiliation
A	Professor	Graduate Institute of Bioresources, National Pingtung University of Science and Technology
B	Professor	Graduate Institute of Management of Technology, National Chiao Tung University
C	Professor	Department of Bioenvironmental Systems Engineering, National Taiwan University
D	Professor	Department of Civil Engineering, National Central University
E	Professor	Department of Aeronautics and Astronautics, National Cheng Kung University
F	Associate Professor	Department of Resources Engineering, National Cheng Kung University
G	Director	Energy Research Center, National Taiwan University
H	Director	Research Division I, Taiwan Institute of Economic Research
I	Associate Researcher	The Center for Energy and Environmental Research, Chung-Hua Institution for Economic Research
J	Associate Researcher	Science & Technology Policy Research and Information Center, National Applied Research Laboratories
K	Director General	Bureau of Energy of Ministry of Economic Affairs
L	Researcher	Industrial Economics and Knowledge Center, Industrial Technology Research Institute
M	Researcher	Advanced Technology Research Division, Energy & Environment Laboratories, Industrial Technology Research Institute
N	Legislator	Social Welfare and Environmental Hygiene Committee of the Legislative Yuan of Republic of China

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