Original Research

Renewable Energy Supply Chain Expansion Decisions-making Using AHP

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Abstract
In this study the challenges facing wider use of renewable energy are investigated. Robust supply chain is a necessity for better coverage of energy provision. Renewable energy industry faces several challenges in production, delivery, and distribution. Hence, a multi criteria decision-making model is formulated to inspect the effect of industry attributes on the decisions taken to achieve balanced and wider coverage of the renewable energy supply chain. AHP framework is developed and used to decide between three alternatives that cover the challenging areas of the supply chain in order to achieve the goal of the study. Additionally, a questionnaire is completed by three experts in the energy field in the state of Kuwait to assess the priorities of the three alternatives with respect to the study goal. Results of the study provide a sight into the nature of the problem and decisions to be taken to expand the use of renewable energy sources over fossil fuel.

Keywords - Analytical Hierarchy Process (AHP); Multi criteria decision making; Renewable energy factors; Renewable Energy Supply Chain (RESC); Supply chain expansion decisions

INTRODUCTION

Green energy is growing into a necessity not only for environmental considerations, but also to secure future energy provision to all areas of the world even those with scarce energy sources. The continuity and abundance of renewables, with proper research and development, can ensure that essential energy for survival is secured.

The focus on RESC development enhances the potential of providing energy economically. Efficient delivery of the generated energy whether through the electrical grid or other method, such as hydrogen, is a concern for robust supply chain, and wider use of renewable sources for energy generation. In [1], a review is introduced for many work in the literature that discuss the importance of replacing the use of fossil fuel by renewable energy sources to generate energy in several fields. Several reasons prevent from wider use of renewable energy. According to [2] the successful replacement of renewable energy to fossil fuel depends on its economic, environmental, and risk potential aspects. Moreover, the effective approaches to reach that goal is improving the production technology and developing a robust supply chain. As stated in [3], renewable energy generated from solar or wind is not highly reliable to fulfill electrical power demand that is needed extensively in State of Kuwait, Gulf area. Accordingly, use of renewable energy is restricted to industrial uses such as steam generation. [4] state that there are challenges to the use of renewables for energy generation in the Gulf area. These challenges are summarized as social barriers of community acceptance of the replacement of fossil fuel, and technological barriers of integration into the current grid and maturity of the technology. [5] discuss the obstacles that prevent wider use of renewables distributed networks. The study defines number of groups and their concerns to the issue, such as; technical and engineering community, financial and investment community, and policy and regulatory community. Additionally, they define a number of barriers to the widespread of using these renewables distributed networks summarized from recent literature and solutions to overcome these barriers. The dependence on renewable energy (RE) is becoming a must rather than only an approach of governments to fulfill power needs. Research in RE is highly focused on the development of the technology to obtain more economical production, application, and usage. However, the research on renewable energy supply chain (RESC) is scarce although it is extremely important. The value of the RESC (hydrogen supply chain) research in supporting decisions for the production, storage, and distribution of hydrogen is highlighted [6]. According to [7], the development of renewable energy technologies and economics of scale made RE competitive to fossil fuel. Additionally, smart grid leads to extreme expansion in the use of RE. The complexity and dynamics of RE generation network necessitated using supply chain management (SCM) to efficiently run the energy network from extraction to service points including all supply chain activates of design, management, and development. [8] highlight the importance for improving renewable energy supply chain (RESC) in order to widely use renewable energy over fossil fuel. The study summarizes challenges to use RE to internal challenges within the energy industry as RE industry profitability and rewards, large investment cost and infrastructure requirements, lack of knowledge and infrastructure, and resistance for change from firms and society. Additionally, external challenges are highlighted as proper governmental policies, integration with reliable suppliers, and community role to push for more RE installed systems and create a consuming market. The research on supply chain role in development of RE distribution and delivery continued in [9], as it studies rearrangement of the hydrogen supply chain using current technology to reduce the high costs of hydrogen pipelines. The new approach reduces the costs of energy transmission in the form of electricity. According to [10], transition to cleaner energy sources faces challenges, and hydrogen technologies have the potential to help overcome challenges and ease the transition. Thus, the study provides an oversight on the potential and role of hydrogen in energy storage and transfer. Hydrogen has the potential of balancing the supply and demand of power generated from renewables by providing a medium for transferring power or storing it for future use. [11] discuss the balance of energy generated and demand, and the case when renewable energy is generated in excess of demand. The study develops a delivery system that addresses the issue.

AHP (Analytical Hierarchy Process) developed by Saaty [12] is a powerful decision making tool, and can be used in several types of problems. The approach is used in the renewable energy research to decide on different industry attributes. In [13], using AHP prioritization for alternatives and sub criteria, the study was able to identify potential of improvements in RESC's certain aspects in each of the studied countries. The importance of supply chain study of renewable energy networks is due to its dependence on several factors through the supply chain from production to disposal. Renewable energy plants are large investments and should have governmental support, hence the necessity of good-based decisions. [14] introduce a framework for decision making for the suitable type of renewable using AHP. The study introduces criteria and subcriteria that are effective on that decision. The criteria that are set as effective on the study goal are technical, economic, social, environmental, and risk. A number of subcriteria are classified under these 5 criteria. [15] present as well an AHP framework to decide on the most suitable renewable source for three different locations. The study defines the effective criteria as cost, maximum capacity, environmental impact, job creation, and security, which can be classified also under the categories of economic, technical, environmental, social, and risk.

Many research in the literature develop models for replacement of use of fossil fuel by renewable energy source in certain application [1, 16]. However, the balanced supply chain between abundant supply and fulfilling demand, and accordingly expansion of the supply chain to areas of scarce resources of energy, is the motive of this study. The focus is on decisions regarding the production, distribution, and delivery of energy from renewables through efficient and robust supply chain. The drivers of the RESC are defined and formulated into goal, criteria, subcriteria, and alternatives. AHP is used to decide which of the presented alternatives will contribute the most in wider use of renewable energy over fossil fuel according to priorities of the criteria and subcriteria. The proposed framework is expected to contribute to developing efficient supply chain that addresses the challenges in specific areas to rely more on renewables as a dependable source of energy.

PROBLEM DEFINITION

I. Brief on Renewable Energy

Renewables are classified into six types; biomass, wind, solar, hydro, geothermal, and marine [17]. The most widely spread are wind and solar sources for generated energy. There are several challenges to the expansion of RE usage including technical and supply chain problems. Technical problems include finding better means of energy storage, to overcome the discontinuity of the supply and support more steady demand. With the hydrogen electrolysis as a good mean to transform produced energy into electricity for more feasible transfer medium, there are needs to improve its storage techniques. Improvement areas include finding better method to store large amounts of hydrogen without losses due to its light weight.

There are other several technical challenges for the wide use of RE, however the focus in this study is on supply chain problems. Naturally, supply chain problems are related to supply-demand balance and delivery of the energy [6].

The wider use of renewable energy is possible as the technology is advancing and the costs are lower. Additionally, RE is now more affordable. International organizations, such as the United Nations [18], are pushing toward expanding the use of RE to overcome climate change problems and help develop human lives [17]. Accordingly, authorities should exploit the advance in technology and regulations in RE to harness its potential benefits, and evaluate energy procurement strategy.

In the Arab region, power generation from renewable sources is still scarce with 1% of energy generation from renewables (mainly solar and wind) as opposed to almost 96% from fossil fuel [18]. Hence, a great potential is expected and extensive research is required to depend more on renewables for reliable energy generation.

II. Brief on Supply Chain

In a conventional products supply chain, supply chain network performance is affected by several factors. Suppliers, plants, distribution centers, and demand points are important attributes to determine locations of facilities. The number of supply chain layers and allocation of product flow to facilities affect the supply chain network and facility location decision as well. Additionally, transportation modes and availability impact supply chain decisions. All these decisions should be studied on a multi-period (dynamic) planning horizon to investigate the effect of demand variability along time. In addition, the effect of changes in the network parameters along the planning horizon on supply chain profit is a crucial concern [19].

In a conventional supply chain, the distribution of goods (raw materials, intermediate, and final products) forms about 25% of product cost [20]. This requires optimization of the decisions of facilities locations to move these goods to and from, along with the decisions about inventory levels and their costs compared to transportation costs. The tradeoff between holding inventory to fulfill future demand and transportation costs of fulfilling demand directly in same period is of the most important attributes in supply chain decision-making. All over, there are five areas that define supply chain capabilities; production, inventory, transportation, locations, and information. Moreover, supply chain efficiency is highly dependent on suitable means of transportation that can be assigned to several routes [19].

Figure 1 is an example of a conventional supply chain that can be compared to the unique structure of RE supply chain and how the production, storage and transportation attributes are similar. With electric grids, hydrogen pipelines, and large batteries as transfer and storage methods of the RE supply chain, the structure of conventional supply chain is approximately similar to RE supply chain. This can be detected in the work of [21], that define an energy supply chain net as a bundle of automated power grids that are connected via links, and this bundle interact with other bundles by link-bundles with suppliers that inject power to own grids.

Delivering RE is limited to few means, and their improvement is out of the scope of this work. Alternatively, with challenges in the supply chain of RE, the study can address them using an approach of decision making to determine which of the factors affect the RE supply chain significantly [23].

III. Factors Affecting RESC

From previous discussion, the following factors are found to be effective on the RESC [23]:

- Economical aspects of establishing the required infrastructure or improving the existing one.
- The efficiency of the RE technology to cope with increasing or special demand, including the degree of development in this technology [24].
- Factors regarding the extent to which RE is appealing for the community to be introduced to, and the degree of willingness to replace the fossil fuel with RE taking into consideration its challenges [24].
- How solid and integral is the supply chain network in terms of collaboration between its layers [24].
- The tradeoff between transporting hydrogen and utilizing the grid.
- How developed are the distribution, delivery and storage systems such as hydrogen supply chain, and smart grid.

Severity of the circumstances that can develop a risk to using the RE effectively as a reliable source of energy.

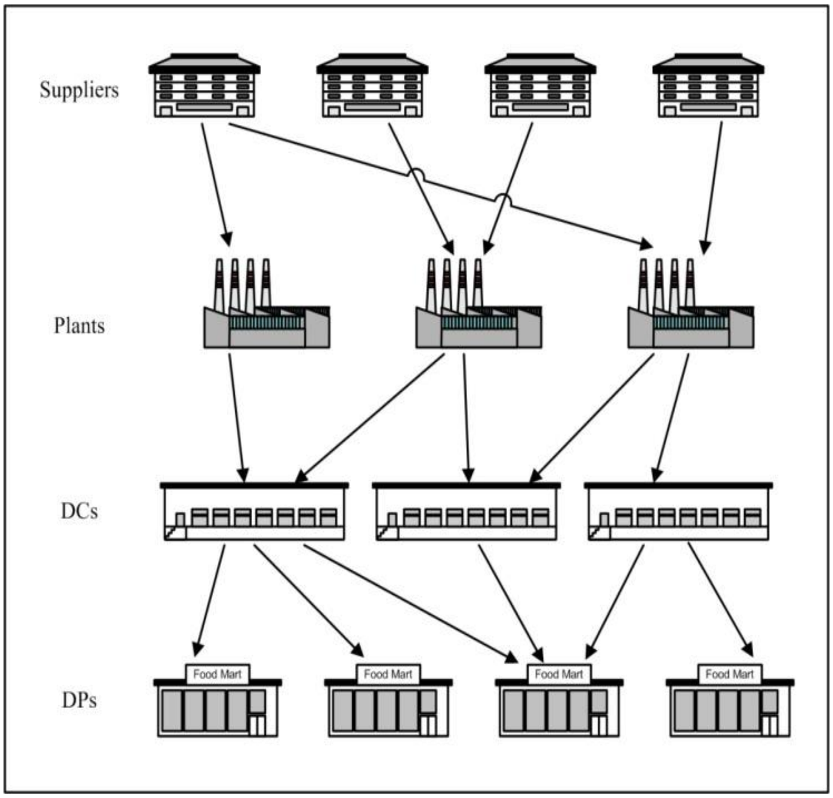

FIGURE 1
SUPPLY CHAIN WITH FOUR LAYERS; SUPPLIERS, PLANTS, DISTRIBUTION CENTERS, AND DEMAND POINTS [22]

This research goal is to investigate the challenges that hinder wider use of renewable energy and restricts the extension of its supply chain to cover more areas and include more supply and demand points. Accordingly, the proposed alternatives cover production, delivery, and distribution solutions to achieve more robust supply chain. Furthermore, the proposed criteria and subcriteria address a wide range of challenges faced by the energy industry and governments as they ramp up the development of green energy sources. The model also offers some preliminary solutions so that robust supply chains for renewable energy can be built. Table I shows the proposed model which is basically based on the presented model by [14].

TABLE I
AHP MODEL FOR WIDER USE OF RENEWABLE ENERGY

Goal	Wider coverage of renewable energy supply chain				
Criteria	Technical	Economic	Social	Environmental	Risk
Subcriteria	1. Efficiency of energy generation	1. Investment cost	1. Community acceptance	1. Gas emissions	1. Force majeure
	2. Technology maturity level	2. Operation and maintenance costs	2. Job opportunities created	2. Requirement of land and water resources	2. Investment conditions change risk
	3. Network maintenance	3. Payback period	3. Technology applicability in rural community	3. Visual impact	3. Outdated technology
	4. Infrastructure condition	4. Service life	4. Acceptance of system installation in special areas	4. Hazardous waste	
	5. Generation reliability	5. Integration with suppliers			
Alternatives	Investment in grid improvement	Use of advanced storage and delivery techniques		Develop capacity of production locations	

It is desired to decide on the suitable solution to achieve wider coverage of the supply chain network. The selection of the most effective solutions to achieve this goal is dependent on several attributes that drive and guide the supply chain. The nature of the renewable energy supply chain and its relation to several aspects makes the decision on the appropriate approach to be adopted to overcome wide spread challenges hard and multi-dimensional. Additionally, the technical, economic, social, environmental, and risk dimensions have several subcriteria that affects the decision. Accordingly, the multi-criteria decision making technique AHP (Analytical Hierarchy Process) is used to formulate a model with three solutions (alternatives) to select from:

1. Investment in grid improvement.
2. Use of advanced storage and delivery techniques.
3. Develop capacity of production locations.

Each alternative covers one of the development fields discussed in [6] to achieve a robust supply chain. Alternative 1 addresses the distribution, whereas alternative 2 covers storage and delivery, and alternative 3 covers production. Each of these supply chain practices affects its performance.

MODEL FORMULATION

I. AHP Assessment Procedure

The goal, 3 alternatives, 5 criteria, and 21 subcriteria are used to formulate the AHP model. AHP uses three levels of hierarchy; top level of the decision criteria, second level with the subcriteria for each criterion, and the bottom level for the alternatives. The assessment procedure is as follows [12]:

1. Define the problem alternatives and decision criteria and subcriteria.
2. Make a pairwise comparison between the subcriteria by assigning a number from 1 to 9, with 1 for equally important criteria and 9 for high importance for one criterion over another as in table 2, and assess consistency of the pairwise comparison matrix.
3. Use pairwise comparison matrices to assign priorities to criteria, subcriteria, and alternatives.
4. With priorities from pairwise consistent matrices, perform a top-down evaluation to calculate the weight of each alternative. The alternative with highest weight is selected as the most effective solution to achieve the goal.

TABLE II
RATING TABLE FOR PAIRWISE COMPARISON MATRIX

Rating table								
1	2	3	4	5	6	7	8	9
Equally important	Weak importance	Moderate importance	Moderate plus	Strong importance	Strong plus	Very strong importance	Very strong plus	Extreme importance

II. AHP Alternatives

A multi-criteria decision-making model is formulated with the goal of wider coverage of the supply chain network to include more supply and demand points. The AHP is used to evaluate the weight of the proposed alternatives under the criteria and sub criteria provided. The alternatives are designed to cover expansion solutions in the production, delivery, and distribution aspects of the supply chain.

Production challenges are the nature of renewable energy that is available in a certain time or certain location and not another. Delivery and storage challenges are that hydrogen electrolysis requires large batteries. However, transportation batteries are not large enough to accommodate the whole amount of generated energy, and that large batteries technologies need advancement in terms of ability to store 100% of feed energy into battery as large batteries lose energy faster. Distribution challenges are the ability of the current grid to transfer extra power generated from renewable resource beside the already flowing electricity [25]. Moreover, hydrogen pipelines high cost [9] is another distribution challenge and its development is a must.

III. AHP Criteria and Their Sub Criteria s

The RESC AHP model is developed with 5 criteria; technical, economic, social, environmental, and risk. For every criterion, several subcriteria are defined that are believed to affect the wider use of RE as a reliable source for power generation. The developed criteria and subcriteria are as follows:

Technical

1. Efficiency of energy generation: This attribute assesses how efficient is the network to exploit the available resources in energy generation.
2. Technology maturity level: The level at which energy generation technology is currently, defines how applicable and ready the process of generation to expand the reliability on that energy source.
3. Network maintenance: The ability to efficiently maintain the energy supply network and availability of required spare parts to continuously support the energy generation.
4. Infrastructure condition: The condition of the current grid and potential of accommodating additional power from the generated energy.
5. Generation reliability: How reliable is the energy generated from the renewable resource to support and fulfill the demand.

Economic

1. Investment cost: Initial cost of commencing the system.
2. Operation and maintenance costs: Costs required to keep the system running.
3. Payback period: The time duration required until revenue can be obtained.
4. Service life: The duration of equipment deterioration and depreciation rate.
5. Integration with suppliers: How economically efficient is the cooperation with the equipment suppliers for successful system operation.

Social

1. Community acceptance: The level of resistance to change from the community, and preference of conventional fossil fuel.
2. Job opportunities created: How appealing is the new investment to the community for promises of larger job market creation.
3. Technology applicability in rural community: As conventional deprivation of rural areas of advanced services, including power availability, is a concern. This attribute addresses the ability of renewable energy generation technology to support the needs of rural community.
4. Acceptance of system installation in special areas: Concerns regarding the installation of renewable energy generation system that requires wide areas and the ownership of these areas.

Environmental

1. Gas emissions: Readiness to handle gases generated from the process.
2. Requirement of land and water resources: Impact of using natural resources on the balance and continuity of life.
3. Visual impact: How effective is the size and shape of the generation equipment on natural sights.
4. Hazardous waste: The harmful potential of process waste and its impact on expanding the use of the technology.

Risk

1. Force majeure: Possibility of the effect of weather conditions on the continuity of energy generation.
2. Investment conditions change risk: Possible events that cause turmoil and its impact on the ongoing projects and investments.
3. Outdated technology: The risk of investing on a technology that does not stand long in time of fast paced developments.

RESEARCH METHODOLOGY

The proposed model in previous sections is assessed individually, to eliminate any bias [26], by 3 experts in the Ministry of Electricity and Water in Kuwait, with specialties in renewable energy and engineering fields. A definitions list of criteria and their sub criteria is accompanied with a questionnaire, and every expert assigned weights to pairwise comparison tables as in the example in Tables III & IV. Pairwise comparisons for criteria with respect to goal, sub criteria with respect to their criteria, and alternatives with respect to each sub criteria are performed.

TABLE III
PAIRWISE COMPARISON FOR TECHNICAL SUB CRITERIA

Technical	1. Efficiency of energy generation	2. Technology maturity level	3. Network maintenance	4. Infrastructure condition	5. Generation reliability

1. Efficiency of energy generation	1	5	1/6	4	1/3
2. Technology maturity level	1/5	1	1/4	5	4
3. Network maintenance	6	4	1	1/5	1/6
4. Infrastructure condition	1/4	1/5	5	1	4
5. Generation reliability	3	1/4	6	1/4	1

TABLE IV
PAIRWISE COMPARISON OF ALTERNATIVES W.R.T. TECHNICAL EFFICIENCY SUBCRITERIA

1. Efficiency of energy generation	Investment in grid improvement	Use of advanced storage and delivery techniques	Develop capacity of production locations
Investment in grid improvement	1	1/4	1/6
Use of advanced storage and delivery techniques	4	1	7
Develop capacity of production locations	6	1/7	1

Outcome of questionnaires is entered into AHP priority calculator excel sheet developed by Klaus D. Goepel [27]. The inconsistency for all pairwise comparison matrices is below 0.1, and priorities are obtained consequently. Example of pairwise comparison matrix and priorities matrix are given in Tables V & VI.

TABLE V
PAIRWISE COMPARISON MATRIX FOR EXPERT 1, CRITERIA W.R.T. GOAL

	1	2	3	4	5
1	**1**	1/5	6	1/2	3
2	5	**1**	9	3	4
3	1/6	1/9	**1**	1/5	1/3
4	2	1/3	5	**1**	4
5	1/3	1/4	3	1/4	**1**

TABLE VI
PRIORITIES MATRIX FOR CRITERIA W.R.T. GOAL

0.28	0.36	0.32	0.19	0.25	0.279806
0.21	0.27	0.32	0.34	0.27	0.279831
0.13	0.13	0.15	0.20	0.18	0.158928
0.31	0.17	0.16	0.21	0.23	0.216568
0.07	0.07	0.05	0.06	0.07	0.064867

RESULTS AND DISCUSSION

Results of priorities from the AHP excel calculator are recorded and analysed. Table VII shows priorities of criteria with respect to study goal to achieve wider coverage of RESC. According to experts assessment, it can be deduced that the technical challenges represent the most important criterion to achieve the goal with 37.7%. The least important criterion is the social aspect with priority of 8.7%, and rest

of criteria are shown in Table VII.

TABLE 7
CRITERIA PRIORITIES

Goal	Priorities
Technical	0.377
Economic	0.153
Social	0.087
Environmental	0.167
Risk	0.217

From Table VIII, the local and global priorities for technical sub criteria with respect to the criterion are illustrated. While local priorities are obtained from pairwise comparisons of the excel calculator, global priorities are calculated by multiplication of local priorities of a level in the hierarchy by global priority of its preceding level.

TABLE VIII
TECHNICAL SUB CRITERIA PRIORITIES

Technical	Local priorities	Global priorities
1. Efficiency of energy generation	0.280	0.11
2. Technology maturity level	0.280	0.11
3. Network maintenance	0.159	0.06
4. Infrastructure condition	0.217	0.08
5. Generation reliability	0.065	0.02

Economic, social, environmental, and risk subcriteria's priorities are shown in Tables IX-XII, and are calculated by the same rule for the technical criteria and its subcriteria.

TABLE IX
ECONOMIC SUBCRITERIA PRIORITIES

Economic	Local priorities	Global priorities
1. Investment cost	0.279	0.04
2. Operation and maintenance costs	0.198	0.03
3. Payback period	0.195	0.03
4. Service life	0.280	0.04
5. Integration with suppliers	0.048	0.01

TABLE X
SOCIAL SUBCRITERIA PRIORITIES

Social	Local priorities	Global priorities
1.Community acceptance	0.084	0.01
2. Job opportunities created	0.372	0.03
3. Technology applicability in rural community	0.355	0.03
4.Acceptance of system installation in special areas	0.188	0.02

TABLE XI
ENVIRONMENTAL SUBCRITERIA PRIORITIES

Environmental	Local priorities	Global priorities
1. Gas emissions	0.069	0.01
2. Requirement of land and water resources	0.163	0.03
3. Visual impact	0.153	0.03
4. Hazardous waste	0.615	0.10

TABLE XII
RISK SUBCRITERIA PRIORITIES

Risk	Local priorities	Global priorities
1. Force majeure	0.140	0.03

2. Investment conditions change risk	0.474	0.10
3.Outdated technology	0.386	0.08

Following the calculation of subcriteria priorities, alternatives priorities are obtained from pairwise comparisons of the alternatives reference to each subcriterion. Calculated global priorities for every alternative are then obtained as shown in Table XIII for each criterion by the summation of its subcriteria priorities. Table XIV shows final priorities of the three alternatives. Although approximately equal priorities of the alternatives show experts perspective of the importance of the all the three alternatives to develop and expand the coverage of the RESC, it can be seen that alternative 2 of using advanced storage and delivery techniques such as hydrogen electrolysis and storage is the most important with 35.2%. This result reflects the global trend in renewable energy to develop hydrogen technology as a good technique for storing and transferring generated power from renewable sources [28].

TABLE XIII
ALTERNATIVES PRIORITIES FOR EACH CRITERION

Alternatives	Technical	Economic	Social	Environmental	Risk
Investment in grid improvement	0.106	0.067	0.027	0.035	0.063
Use of advanced storage and delivery techniques	0.191	0.035	0.042	0.027	0.056
Develop capacity of production locations	0.080	0.051	0.018	0.105	0.098

TABLE XIV
FINAL ALTERNATIVES PRIORITIES

Alternatives	Priorities
Investment in grid improvement	29.8%
Use of advanced storage and delivery techniques	35.2%
Develop capacity of production locations	35.1%

CONCLUSIONS

As the global concern to environmental issues is growing, use of renewable energy instead of fossil fuel is becoming a necessity. In this study, the goal was to develop a decision-making model that addresses challenges of expansion of the use of renewable energy and consequently wider coverage of its robust supply chain. The challenges are defined by criteria and sub criteria, and proposed solutions to overcome the challenges are defined by the alternatives. Hence, five criteria with their sub criteria, and three alternatives are modeled into AHP decision making formulation. The AHP model of goal, criteria, sub criteria, and alternatives model was solved for priorities using Excel calculator. Three experts in the renewable energy and engineering fields, functioning in the area of the study, assigned weights to pairwise comparisons that was input to AHP excel calculator to obtain the priorities of the criteria, sub criteria, and alternatives. Results reveal that the alternative of using advanced storage and delivery techniques was the most important, with approximate priorities of the three alternatives. This result highlights the importance of the three proposed solutions to achieve wider use of the RE in State of Kuwait and the Gulf area where the study took place. It is worth mentioning that this model can be used in other geographical areas based on the background of the experts.

The developed model is proved useful in combining a number of the obstacles facing the renewable energy wider use and full replacement of fossil fuel by developing a robust RESC. Future work can attempt to design a whole RE supply chain network using similar techniques used to design conventional supply chains, taking into consideration problems and challenges discussed in the current work. Supply chain network design will be considered an extension and a result of the decision taken in current study regarding adopting one of the alternatives as a goal for supply chain wider coverage.

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