Assessment of sustainable renewable energy technologies using analytic hierarchy process

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Abstract. The investment of sustainable renewable energy has become an essential element in every modern country's survival and well-being. This study aims to establish a framework for the analytical hierarchy process (AHP) to select the best investment in sustainable renewable energy in Iraq. A survey was conducted with a panel of experts from different backgrounds and affiliations in the renewable energy field to assess seven criteria and four alternatives using the AHP technique. The findings showed that the results highlight the importance of power and environmental criteria and determine the best investment to achieve solar energy desired as the highest priority and can be carried out by organizations.

Keywords: Sustainable, Renewable energy, Environment criteria, Analytic hierarchy process

1. Introduction

There is a move towards investment in sustainable renewable energy projects in Iraq, and the government encourages renewable energy development, such as solar, wind, geothermal and hydropower. This study aims to establish an analytical framework to evaluate renewable energy technologies in Iraq (solar, wind, geothermal and hydropower), which will help to make decisions on the implementation of renewable energy technologies. Policy considerations include rising demand for energy, the government's need to minimize its carbon footprint to provide all people with affordable electricity [1].

Promoting renewable energy usage in the energy portfolio needs funding from private and public actors, but investors are far more likely to fund maturing technologies [2]. In developing countries, many renewable energy technologies are still considered emerging technologies and thus perceived to be linked to a certain degree of insecurity. Therefore, government funding is necessary to implement renewable successfully [3], [4]. It is essential to understand the different factors which influence investment decisions in renewable energy.

The selection of renewable energy projects is a type of multi-criteria problem. The multi-criteria decision-making (MCDM) is considered an important and active field of study and is commonly used in evaluating various criteria, comparing and rating various alternatives based on the evaluation criteria and, finally, prioritizing them[5], [6]. The range of stakeholders in the MCDM issue relates to providing quantitative and qualitative metrics for identifying each alternative's success in relation to criteria, and the relative importance of the evaluation criteria is calculated in relation to overall evaluations [7], [8]. The MCDM approaches have proven their ability to successfully deal with the energy issue as a problem-solving tool [9]. One of the MCDM's most common techniques is the analytical hierarchy process (AHP), which is primarily used in assessment and selection themes [10].

AHP is one of the methods for making decisions using a multi-criteria assessment to select the best alternative with respect to several factors [11]. Saaty in [12] proposes AHP, which is based on a hierarchical perception discovery process, where the main factor and lower-level factors are compared, arranged, and measured. It also divides complex problems into main factors and sub-factors by layers and measures the factors' weight by pairing them with comparisons. Other researchers used AHP to
analyse subjects such as evaluation renewable energy resources [13], an energy source policy assessment [14], an investigation on lean-green implementation [15], renewable energy source selection [16], the evaluation of the significant renewable energy resources [17]. Nevertheless, the use of the AHP approach in selecting the suitable investment of sustainable renewable energy technology is still scant in Iraq. For that, this work would support the literature in the renewable energy field.

An AHP analysis begins by defining problems and identifying hierarchical factors for problems. The comparison of attributes is made between two items that are adjacent to each other in the hierarchy [18]. The priorities are assessed by comparing them in pairs, then, these comparisons are added together to get the final priorities [19]. The final step involves what is called a "Consistency Analysis", where the predictors are put into a hierarchy, which in turn is placed into a formula that shows how much each is affecting the dependent variable. The AHP approach is essentially a systemic method for comparing factors in pairs.

At the end of this section, the rest of this paper is organized as follows: Section 2, Materials and Methods involved two stages; data collection and AHP formulation. Then the results and discussion in Section 3, that involved the application of the proposed methodology. Finally, in Section 4, necessary conclusions and further research directions are presented.

2. Materials and Methods

In this study, the methodology consists of two phases: data collection (survey) and application of the AHP technique. In the following subsections, further information will be given.

2.1. Data Collection

In this study, the selected organization worked in the engineering management field and was active in complex construction projects in Iraq. A recitation of the historical information regarding seven criteria related to the renewable energy objective of 'sustainability' was pulled from scientific literature [20], namely: power, investment ratio, implementation period, operating hours, useful life, operation and maintenance costs, and environment. Decisions of managers on such criteria are analysed and used to create a process structure. The definition of the AHP mechanism was taken as an input for the assessment process for seven evaluation criteria. This example could be broadened accordingly if more parameters are to be considered.

Twenty experts from a highly educated community on the specific energy case in Iraq were consulted for their judgements for each of the comparisons needed by the AHP. The experts came from both business and academia, including professors and energy company leaders. The data were collected from experts through questionnaires sent by mail or filled out during face-to-face sessions after consenting to participation. Firstly, the questionnaire focused on comparing the criteria to achieve a weight vector representing the priority given by each expert to each of them. The values of the comparisons were calculated by following the Saaty scale, as defined in Table 1.

| Definition                              | Relative Importance |
|-----------------------------------------|---------------------|
| Extremely preferred                     | 9                   |
| Very strongly preferred                 | 7                   |
| Essentially preferred                   | 5                   |
| Moderately preferred                    | 3                   |
| Equally preferred                       | 1                   |
| Intermediate importance between two     | 2, 4, 6, 8          |
| adjacent judgments                      |                     |

Secondly, experts input was used to determine the performance of decision alternatives for each criterion resulting from the normalized options matrix.
2.2. AHP formulation

The AHP is an effective method for dealing with such problems in decision-making [21]. AHP is used to assess, rank and select based on a wide variety of alternatives to the decisions, to make a decision making depends on a systematic and numerical process [22]. The AHP approach is distinguished by the collapse in a hierarchical tree of the decision problem and pairwise comparisons to assess parameters and alternatives [23]. Therefore, the hierarchical diagram of the multi-criteria problem was constructed in the AHP technique, as different levels (goal, criteria and alternatives), as shown in Figure 1.

Figure 1: Structuring a hierarchy of decision-making problem

Figure 1 shows the AHP hierarchy of decisions for selecting the optimum renewable energy technology for Iraq, demonstrating how the objective is to fulfil the seven factors (criteria) and four alternative decisions.

The AHP procedure can be summarized as follows [12]:

1- Decompose the problem into a hierarchy, as displayed in Figure 1.
2- Gather feedback on trade-off information by pairing comparison of the elements of the decision.
3- Comparing the criteria in pairwise and computing a normalized matrix using the following equations (1, and 2).
   \[ \bar{a}_{ij} = \frac{a_{ij}}{\sum_{i} a_{ij}} \]  
   \[ w_i = \left( \prod_{j=1}^{n} \frac{1}{\bar{a}_{ij}} \right)^{\frac{1}{n}} \]
4- Calculate the Lambda max (\(\lambda_{\text{max}}\)) value which should equal the number of factors in the comparison \(n\) for total consistency as given in Equation (3).
   \[ \lambda_{\text{max}} = \sum_{i=1}^{n} \left( \sum_{i=1}^{n} a_{ij} \right) w_j \]
5- Determining the relative weight of the criteria using Equation (4).
   \[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]
6- Checking the consistency ratio as given in Equation (5).

\[ CR = \frac{CI}{RI} < 0.1 \sim 10\% \] (5)

7- Ranking.

AHP technique typically has a range of significant advantages. For instance, for decision-makers, this is a reasonably easy way. Also, AHP requires no complex mathematical operations and functions on decomposition principles, collecting information for pair comparison, and generating and synthesizing priorities for vectors.

3. Results and discussion

The evaluation of the selected criteria for sustainable renewable energy was carried out through a questionnaire to 20 experts with more than ten years of experience in the field of renewable energy in Iraq. The decision-makers were asked to use Saaty’s nine-point scale of relative importance (Table 1) to compare the seven criteria (power, investment ratio, implementation period, operating hours, useful life, operation and maintenance costs, and the environment). After that, 20 matrices of comparisons in pairs for the criteria were defined based on each experts' judgments. The collected numbers would then be obtained by averaging the decisions of the seven experts for each criterion. The inconsistency ratio was calculated to achieve consistent weights among all participants. Accordingly, the outcomes of the criteria evaluation have been created as it is given in Table 2. The evaluation is done by calculating the weights and consistency ratio by AHP-OS software [24].

Table 2. Prioritization and ranking of criteria evaluation

| Criteria                        | Priority | Ratio | Rank |
|---------------------------------|----------|-------|------|
| Power                           | 30.7%    | 0.307 | 1    |
| Investment Ratio                | 5.2%     | 0.052 | 6    |
| Implementation Period           | 3.0%     | 0.030 | 7    |
| Operating Hours                 | 14.1%    | 0.141 | 4    |
| Useful Life                     | 16.2%    | 0.162 | 3    |
| Operation and Maintenance Costs | 7.1%     | 0.071 | 5    |
| Environment                     | 23.7%    | 0.237 | 2    |

The result processing's graphic illustration is obtained for all criteria using the AHP procedure, as shown in Figure 2.

![Figure 2. Prioritization of criteria weights](image)

The above graph verified that the power criterion has the largest impact index with a weight equal to 0.307, followed by the environment described as a second important criterion with the same weight as 0.237.
Accordingly, there are four decision alternatives for renewable energy projects, as mentioned earlier. The performance ratings of alternatives with respect to each criterion are given in Table 3. Thus, the result of decision hierarchy is depicted in Figure 3.

| Alternatives  | Score | Rank |
|---------------|-------|------|
| Solar         | 0.338 | 1    |
| Wind          | 0.262 | 2    |
| Hydropower    | 0.178 | 4    |
| Geothermal    | 0.221 | 3    |

Based on Table 3, the first-rate option is considered to optimize renewable energy projects’ expected benefits. The findings indicate that experts favour the solar industry and are best recommended for the company’s project management.

As a consequence of the AHP technique on sustainable renewable energy, Figure 3 indicates that solar is the best alternative for selecting renewable energy projects with a total weight of 0.338. The wind was the second-best alternative, with a total weight of 0.262 and the geothermal with a total weight of 0.221 and, ultimately, the hydropower with a total weight of 0.178. These individual outcomes then affirm solar and wind as critical tools for the future of renewable energy organizations in Iraq and provide greater trust in the proposed MCDM model and the overall preference for these energy options.

4. Conclusion
Research has shown that the selection of sustainable renewable energy is a technique for determining appropriate fundamental investment and selecting the best candidate using a multi-criteria approach. This paper has shown how the AHP approach can be used to select a renewable energy project that presents the multi-criteria ranking index. The implementation of AHP for the various criteria enables decision-makers to systematically relate the qualities of relative importance to the criteria and alternatives according to their preferences. The results demonstrate that the greater weight that the decision-makers have given to the criterion of power with appointed weight equal to 0.307, whereas, the second relative importance of criteria is the environment criterion with the weight’s score of 0.237.
Furthermore, this study found out that the best alternative was solar with a percentage of 33.8%, followed by wind, geothermal, and hydropower alternatives. This paper is intended to demonstrate and exemplify AHP's use in decision-making processes and should undoubtedly take many technical, energy and budget challenges and constraints into account. A broader survey of these sources could yield more accurate results as a future work for Iraq. Finally, the social dimension value must not be ignored, and policies must be established to ensure social recognition and acceptance of sustainable renewable energy, understand the need to include local people in the decision-making, and ensure an approach for sharing benefits projects. On account of the promising performance of the paper's findings, work on the remaining issues is ongoing. The new findings will be presented in forthcoming papers using another approach in MCDM models.

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