Evaluation of Renewable Energy Projects Using Multi-Criteria Approach

Arif Malik*, Mohammed Al Badi, Abdullah Al Kahali, Younis Al Nabhani, Alwarith Al Bahri, Hamed Al Barhi
Department of Electrical & Computer Engineering
College of Engineering, Sultan Qaboos University
Al Khod-123, Oman
*asmalik@squ.edu.om

Abstract— **Many renewable energy (RE) projects cannot compete with conventional energy projects in terms of economics alone. However, if externality costs of competing technologies are carefully evaluated and taken into account the renewable energy projects are likely to be selected on economic basis. But the problem is the evaluation of externality costs which are not always easy to assess. One way to overcome this problem is to use multi-criteria approach instead of just economics as a single criterion. This paper presents the methodology and results of ranking RE alternatives based on several important criteria, for energy problems in an island in Oman where renewable resources can be used as supplementary energy supply.**

Keywords—renewable energy; analytic heirarchy process; multi-criteria decision making; energy policy; energy planning

I. INTRODUCTION

Renewable energy has become the focus of attention all over the world to generate electricity as it is considered a panacea for the health of our planet because renewable energy is sustainable resource and it is environmentally friendly. In Oman renewable energy (especially solar and wind energies) is likely to play an important role in the future energy generation in Oman and there is already an ample literature available on the subject, see for example [1-10]. Most of electricity in Oman is produced by non-renewable fossil fuel resources (mainly natural gas) and the peak electricity demand in Oman is projected to increase from 4293 MW in 2012 to 8106 MW in 2019 [11], also the load is expected to increase more in the near future because of continuous growth in population of Oman and quick development of industry. As a result of this if Oman continues to generate electricity using natural gas only it will have to import natural gas instead of exporting it [12].

In addition to rise in prices of fossil fuel (Oil and Gas) the use of it also causes pollution by releasing carbon dioxide (CO_2) which causes global warming. For these reasons the Omani government has shown interest in renewable energy resources. In 2010, six pilot projects of renewable energy has been confirmed by the Authority for Electricity Regulation Oman, (AERO) of which four of them are solar projects and 2 wind projects at some selected sites. Using renewable energy resource will offer 6.6 MW of renewable capacity, extend the life of oil and natural gas and reduce carbon dioxide emission [13]. The Authority published a study which confirmed renewable energy utilization of solar and wind energy resources to support the implementation of renewable energy pilot projects in rural areas in conjunction with RAECO (Rural Areas Electricity Company SAOC). Presently most of generation in rural areas is with diesel generation.

One of the major hurdles in utilization of renewable energy resources is that they cannot compete with conventional energy resources when only financial costs are considered. The problem is this that in financial analysis the externality costs are always ignored. In economic analysis, however, the environmental costs are sometime considered but the evaluation of such costs is not always easy and remains subject of criticism. However, if externality costs of competing technologies are carefully evaluated and taken into account the renewable energy resources are likely to be funded and may form a significant percentage of generation mix. But the problem is the evaluation of externality costs, as mentioned earlier, which are not always easy to assess, for example, consider the externality cost of one ton of CO_2 in terms of economic impact on climate change or the externality cost of nuclear waste. One way to deal with this problem is to use multi-criteria decision making instead of just economics as a single criterion. The flexibility of this approach is that several different criteria can be used to evaluate the alternatives. In this research five important criteria are identified to evaluate six alternative RE systems. The criteria selected are Economic, Technical, Environmental, Planning, and Government Policy and Regulations. In deciding about the alternatives wind and PV systems and their penetration levels in the overall generation system are considered. The objective of this study is to evaluate the economics of renewable energy (RE) projects at the selected site Masirah island in Oman. The study also evaluate RE projects at Masirah using multi-criteria decision making techniques called Analytic Hierarchy Process (AHP) using the five criteria mentioned above.

The paper is organized in six sections. After the introduction the second section discusses the site data at Masirah in Oman. The third section focuses on alternatives considered at the selected site. Section four includes system design for economic analysis at the selected site. Section five discusses application of AHP technique to find the best alternatives. Last section is conclusions and recommendations.

II. Site Data at Masirah

A. Wind and Solar Potential

Masirah is an island off the East coast of Oman with an area of about 650 km^2. Masirah is good area for using renewable energy resources especially for wind as some studies indicate that it has a significant potential as a rich site of wind power and high wind resources with very low variations [9,10,13]. The average annual wind speed is 5.8 m/s at 10 m height. The monthly average wind speed is shown in Fig. 1. The measured annual average daily sunshine hours at Masirah are about 9.5 hours with annual average daily insolation level is about 6.16 kWh/m^2/day [14].

B. Generation and Load Data

The power demand for the year 2011, at Masirah was met by ten diesel powered generators located at a central power station. The individual generator power rating ranged from 265 to 3,136 kW with a total site power capacity of 10,597 kW. The peak power demand was about 8,500 kW and of the minimum demand was 1400 kW [15]. Figure 2 shows monthly peak demand at Masirah. The fuel price at the site is taken as 0.49$/liter.

III. Renewable Alternatives at Masirah

Six alternatives of RE systems are short-listed for Masirah. In deciding about the alternatives wind and PV systems and their penetration levels are considered. Table 1 shows RE alternatives that are considered to be evaluated for economic evaluation.

TABLE I. RENEWABLE ALTERNATIVES

Alternative 1	0% Renewable Capacity (Business-as-usual)
Alternative 2	10% wind capacity of overall generation capacity
Alternative 3	25% wind capacity of overall generation capacity
Alternative 4	10% PV capacity of overall generation capacity
Alternative 5	25% PV capacity of overall generation capacity
Alternative 6	(15% wind +10% PV) Hybrid capacity of overall generation capacity

Alternative 1 is just "do nothing" or business-as-usual scenario. The other alternatives have different percentages of RE capacity. These RE percentages in the above table are chosen more or less arbitrarily. 25% RE capacity is the maximum limit that is considered for reliability point of view. 10% RE is just considered as relatively small contribution. At the moment there is no clear Government policy about RE targets and the timeframe in which these targets should be achieved. However, the Government has given general guidelines that for new projects in rural areas 10% capacity of RE should be considered beside conventional capacity [16].

A. Wind Turbine Selection

HOMER software [17] is used to do economic analysis at Masirah for the above alternatives. A possible option for the

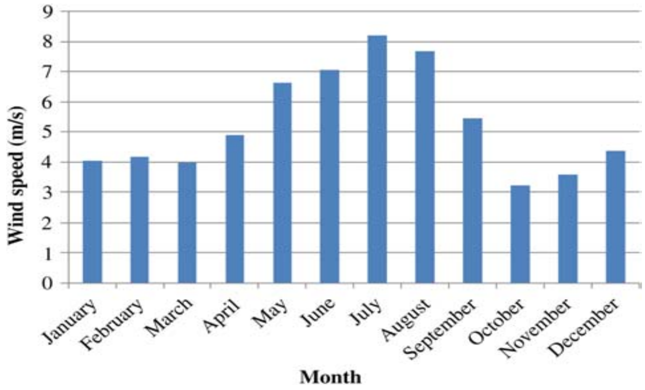


Fig. 1. Monthly average wind speed at Masirah

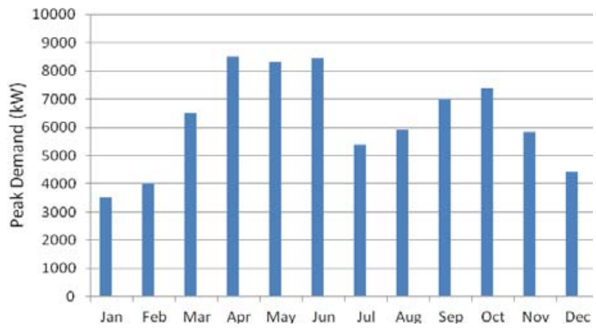


Fig. 2. Monthly peak demand at Masirah

wind turbine, used to generate system configurations that can meet the demand at minimum cost, is TeKvale [18]. TekVale WES 250kW wind turbine is considered with rated power of 250kW and wind average power is about 70.46kW (Pw=70.46kW). The characteristics of 250kW wind machine can be seen in [18].

B. PV System

The current cost of the PV arrays varies from manufacturer to manufacturer and country to country. An average cost for the arrays is assumed to be around US$2400/kW including installation and transportation and replacement cost is taken as 90% of the capital cost. The efficiency at standard test condition is considered as 13% and the derating factor of 90%. The temperature effects on efficiency are also considered in simulation.

C. Batteries

The battery capacity and type chosen from batteries specified in HOMER, Surrette Battery Engineering's Surrette 6CS25P models (6V, 1156Ah, lifetime throughput: 9645 kWh) are considered in the models.

D. Power Converter

The function of the power converter is to maintain the flow of energy between the AC and DC components. The initial cost for the converter is chosen to be US$900/kW and operation and maintenance of US$5/year, with a lifetime of 15 years and efficiency of 90%. The replacement cost is taken as US$750/kW. All these values are taken from [18].

IV. Economic Evaluation of Alternatives

The six alternatives mentioned in table 1 are simulated in HOMER for 20 years with the existing load and generation data at the site. The capital costs of existing diesel generators at the site are considered sunk whereas only their replacement costs are considered.

Fig. 3 shows system design using wind turbine and diesel generation. The system is simulated, with current diesel system and using 4 and 11 wind turbines corresponding to 10% and 25% renewable penetration in Masirah to satisfy the demand. Fig. 4 shows some simulation results of wind-diesel system configuration. Similarly other design configurations such as PV-diesel and wind-PV-diesel systems are simulated. For complete data and simulation results see [19]. The summary of results is shown in table 2. Economic analysis results shows that alternative 3 with 25% wind capacity of overall generation capacity is the most economical alternative.

TABLE II. Summary of Results

Alternatives	COE ($/kWh)	NPC ($)	Fuel cost ($)	Mean output RE (kW)	CO2 emission (kg/yr)
1	0.171	78,475,032	76,240,320	0	40,343,904
2	0.168	77,404,632	72,512,696	295	38,371,368
3	0.164	75,566,536	66,011,088	810	34,930,920
4	0.170	78,328,728	71,946,568	213	38,017,784
5	0.173	79,507,328	67,892,480	531	35,926,488
6	0.167	76,629,272	66,178,352	442 (Wind) + 213 (PV)	35,019,436

V. Analytic Hierarchy Process Analysis

Planning criteria, which cannot be expressed into a common perspective, are said to be non-homogeneous. The presence of several non-homogeneous criteria in a multi-criteria decision making process requires a tool which is able to compare each of the options intelligently. The Analytic Hierarchy Process (AHP) is a powerful and flexible decision making process to help people set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. The AHP engages decision makers in breaking down a decision into smaller parts, proceeding from the goal to criteria to subcriteria down to the alternative courses of action. Decision makers then make simple pairwise comparison judgments throughout the hierarchy to arrive at overall priorities for the alternatives [20-21]. The evaluation and final prioritization of RE alternatives

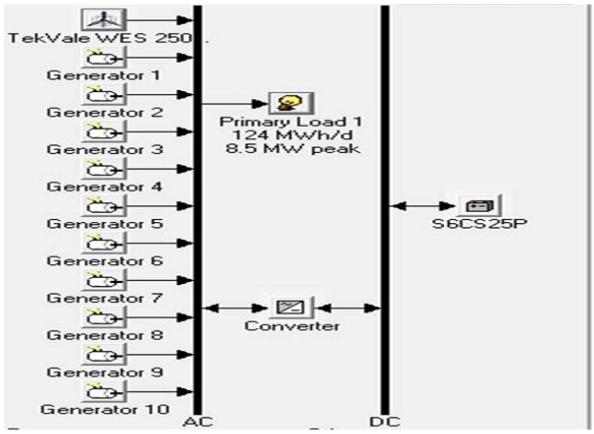


Fig. 3. System configuration using wind turbine and diesel generators.

G1	Gen1 (kW)	Gen2 (kW)	Gen3 (kW)	Gen 4 (kW)	Gen 5 (kW)	Gen 6 (kW)	Gen 7 (kW)	Gen 8 (kW)	Gen 9 (kW)	Ge 10 (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)
11	3136	3136	1000	1000	1000	265	265	265	265	500	20	25	$ 5,547,500	6,894,459	$ 75,566,536	0.164	0.16	13,264,...
11	3136	3136	1000	1000	1000	265	265	265	265	500	30	25	$ 5,560,000	6,894,927	$ 75,583,784	0.164	0.16	13,264,...
11	3136	3136	1000	1000	1000	265	265	265	265	500	10	25	$ 5,535,000	6,897,957	$ 75,589,552	0.165	0.16	13,271,...
4	3136	3136	1000	1000	1000	265	265	265	265	500	20	25	$ 2,047,500	7,420,079	$ 77,404,648	0.168	0.06	14,571,...
4	3136	3136	1000	1000	1000	265	265	265	265	500	30	25	$ 2,060,000	7,420,547	$ 77,421,896	0.168	0.06	14,571,...
4	3136	3136	1000	1000	1000	265	265	265	265	500	10	25	$ 2,035,000	7,423,685	$ 77,428,768	0.169	0.06	14,578,...
	3136	3136	1000	1000	1000	265	265	265	265	500	20	25	$ 47,500	7,722,407	$ 78,475,040	0.171	0.00	15,320,...
	3136	3136	1000	1000	1000	265	265	265	265	500	30	25	$ 60,000	7,722,874	$ 78,492,288	0.171	0.00	15,320,...
	3136	3136	1000	1000	1000	265	265	265	265	500	10	25	$ 35,000	7,726,604	$ 78,505,168	0.171	0.00	15,329,...

Fig. 4. Simulation results of using wind turbine and diesel generators.

is accomplished with the aid of AHP software, Expert Choice [22].

A. *AHP Criteria and Sub-Criteria to Evaluate RE Alternatives*

The alternatives mentioned above are evaluated under different criteria. The selected criteria are technology and sustainability, economic, environmental, planning, and Government policy and regulations. With the exception of economic criterion the other criteria are evaluated under each alternative using experts' opinion. The experts were chosen who are either policy makers or are concerned with actual operation. The alternatives evaluated under economic criterion are shown earlier in table 2. There are some subcriteria also considered under the main criteria. The criteria and sub-criteria are explained below.

1) Technology and Sustainability: Technology and sustainability factors are grouped together, because the more technically perfect a power plant the more is its contribution to sustainable development. The following sub-criteria are considered under this criterion.

a) Availability: The availability of a power plant is the amount of time that it is able to produce electricity over a certain period, divided by the amount of time in the period. The availability of power plant is affected by scheduled maintenance and unexpected forced outages. The type of fuel, the design of the plant, the quality of the equipment and its maintenance are the main factors that affect the availability.

b) Dispatchability of RE System: Because of the unavailability of resource the RE systems get disadvantaged and cannot be dispatched as the need arises. From plant operation point of view this subcriteria is important.

c) Power Quality of RE System: This could be a concern about the RE systems, for example, power fluctuations in wind energy systems.

d) Technical Problems in O&M: This could be another concern about the RE systems.

2) Economic: Several costs should be taken into account when trying to make a decision for the best power plant. The main costs are the capital costs, the O&M costs, and the fuel costs. In AHP analysis the alaternatives evalauted under economic criterion in table 2 are used for ranking the alternatives.

3) Environmental: All energy sources have some impact on the environment. Fossil fuels ,coal, oil, and natural gas do substantially more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions. The following subcriteria are considered under this criterion.

a) CO_2 emissions avoided: The importance of this subcriteria is considered under each alternative.

b) Visual impact: This reflects the visual nuisance that may be created by the development of a project in specific area. The landscape of the different sites, the distance from the nearest observer, the type and size of plants to be installed and the possibility to integrate them with their surroundings must all be considered when evaluating the various alternatives proposed.

c) Social acceptability of RE systems: This criterion is extremely important since the opinion of the population and of pressure groups may heavily influence the amount of time needed to go ahead with and complete an energy project.

d) Other emissions avoided: The other emissions that are avoided, for example, SO_2, NO_x, particulates etc.

e) Impact on ecosystem: There is some negative aspect of wind alternatives because of impact on bird life etc.

4) Planning: In generation planning the capacity credit of RE system is an important consideration. Another important criteria could be the realization time (time to realize and put into operation) of the technology under consideration.

5) Government Policy and Regulations: This criterion is also used to evaluate different alternatives discussed earlier. As Government policy and regulations can have significant affect on promotion of renewable technologies.

B. Survey Instruement

Considering the five criteria and six alternatives a survey instrument was designed to solicit the opinion of experts. The survey instrument was quite elaborate to do pairwise comparison of each alternative under each criterion. The experts were also asked to rank the criteria and subcriteria. The experts were chosen from Oman Power and Water Procurement (OPWP) Company, Rural Area Electricity Company (RAECO) and Authority for Electricity Regulation of Oman (AERO). No response was received from AERO. From OPWP two senior planning engineers responded and appreciated the research. From RAECO also two Junior engineers responded. Altogether four responses were received.

C. AHP Analysis

The AHP analysis was applied by using software called 'Expert Choice Comparison' [22] and the alternatives are evaluated using the quantitative (economic criteria) and qualitative analysis (experts opinion) found before. The ranking of criteria analyzed from experts' opinion in terms of importance is shown in Fig. 5. Fig. 6 shows ranking of alternatives in terms of economics. Fig. 7 shows the ranking of alternatives in terms of Government policy and regulations. Fig. 8 shows the ranking of alternatives with respect to technology. Fig. 9 shows the ranking of alternatives in terms of planning criteria. Fig. 10 shows ranking of alternatives in terms of environmental criteria. Fig. 11 shows the final overall ranking of alternatives with respect to all the criteria.

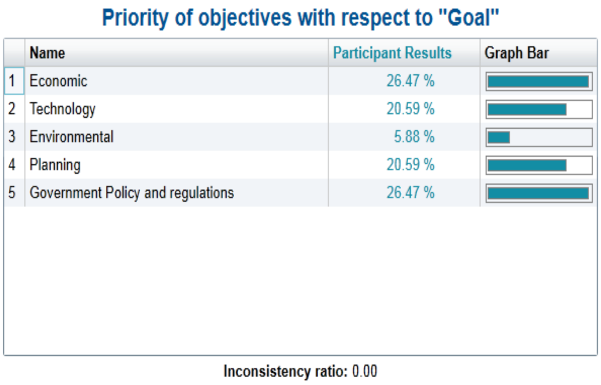
D. Discussion of Results

From quantitative analysis for economic it was found that the alternative 3 with 25% wind capacity of the total generation capacity has the highest ranking and the percentage of economic sub-criteria found from annualized cost as following: Capital cost of RE (39.88%) , fuel cost saving (54.05%) and O&M cost (6.06%) from economic criteria.

The AHP results show that the most important criteria are economic and government policy and regulations with the same percentage 26.47% (Fig. 5).The second ranked criteria in terms of importance are technology and planning with the same percentage 20.59%. The least important criteria is environmental 5.88%. And the final ranking of alternatives (Fig. 11) shows that the best is alternative 4 which is to install 10% PV capacity of overall generation capacity with the percentage of 22.73%. The second is alternative 1 which is to install 0% renewable capacity of overall generation capacity with the percentage of 20.31%. The third is alternative 2 which is to install 10% wind capacity of overall generation capacity with the percentage of 18.45%. The fourth is alternative 5 which is to install 25% PV capacity of overall generation capacity with the percentage of 13.82%. The fifth is alternative 6 which is to install (15% wind +10% PV) capacity of overall generation capacity with the percentage of 13.70%. The worst is alternative 3 which is to install 25% wind capacity of overall generation capacity with the percentage of 10.99%.

VI. Conclusions and Recommendations

In this paper, six alternatives using renewable energy have been studied to augment stand-alone diesel generators used in Masirah Island. There are a lot of options and configurations of hybrid power systems using local renewable resources to reduce the dependence on fossil fuels for rural electricity

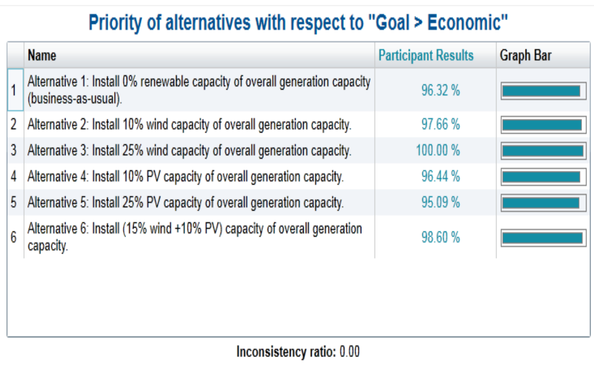


Priority of objectives with respect to "Goal"

	Name	Participant Results	Graph Bar
1	Economic	26.47 %	
2	Technology	20.59 %	
3	Environmental	5.88 %	
4	Planning	20.59 %	
5	Government Policy and regulations	26.47 %	

Inconsistency ratio: 0.00

Fig. 5. Ranking of the criteria.

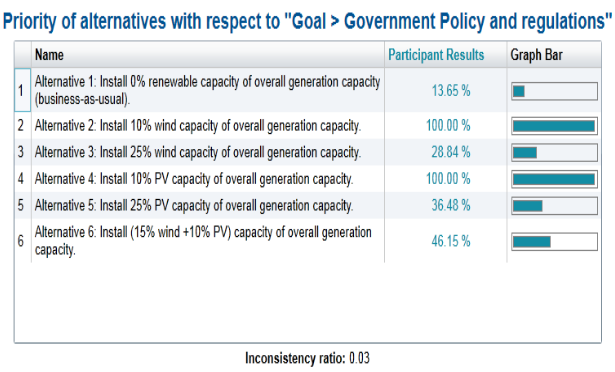


Priority of alternatives with respect to "Goal > Economic"

	Name	Participant Results	Graph Bar
1	Alternative 1: Install 0% renewable capacity of overall generation capacity (business-as-usual).	96.32 %	
2	Alternative 2: Install 10% wind capacity of overall generation capacity.	97.66 %	
3	Alternative 3: Install 25% wind capacity of overall generation capacity.	100.00 %	
4	Alternative 4: Install 10% PV capacity of overall generation capacity.	96.44 %	
5	Alternative 5: Install 25% PV capacity of overall generation capacity.	95.09 %	
6	Alternative 6: Install (15% wind +10% PV) capacity of overall generation capacity.	98.60 %	

Inconsistency ratio: 0.00

Fig. 6. Ranking of alternatives in terms of economics.

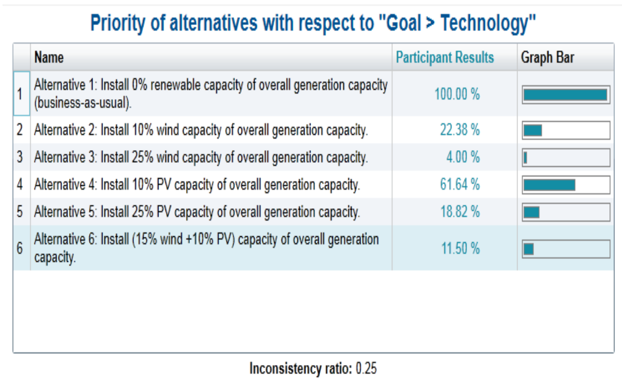


Priority of alternatives with respect to "Goal > Government Policy and regulations"

	Name	Participant Results	Graph Bar
1	Alternative 1: Install 0% renewable capacity of overall generation capacity (business-as-usual).	13.65 %	
2	Alternative 2: Install 10% wind capacity of overall generation capacity.	100.00 %	
3	Alternative 3: Install 25% wind capacity of overall generation capacity.	28.84 %	
4	Alternative 4: Install 10% PV capacity of overall generation capacity.	100.00 %	
5	Alternative 5: Install 25% PV capacity of overall generation capacity.	36.48 %	
6	Alternative 6: Install (15% wind +10% PV) capacity of overall generation capacity.	46.15 %	

Inconsistency ratio: 0.03

Fig. 7. Ranking of alternatives in terms of Government policy and regulations.

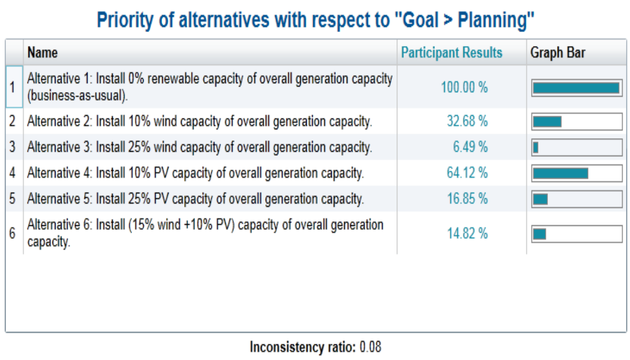


Priority of alternatives with respect to "Goal > Technology"

	Name	Participant Results	Graph Bar
1	Alternative 1: Install 0% renewable capacity of overall generation capacity (business-as-usual).	100.00 %	
2	Alternative 2: Install 10% wind capacity of overall generation capacity.	22.38 %	
3	Alternative 3: Install 25% wind capacity of overall generation capacity.	4.00 %	
4	Alternative 4: Install 10% PV capacity of overall generation capacity.	61.64 %	
5	Alternative 5: Install 25% PV capacity of overall generation capacity.	18.82 %	
6	Alternative 6: Install (15% wind +10% PV) capacity of overall generation capacity.	11.50 %	

Inconsistency ratio: 0.25

Fig. 8. Ranking of alternatives in terms of technology.

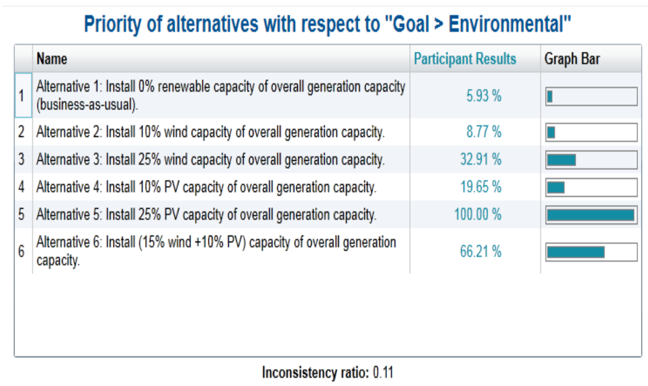


Priority of alternatives with respect to "Goal > Planning"

	Name	Participant Results	Graph Bar
1	Alternative 1: Install 0% renewable capacity of overall generation capacity (business-as-usual).	100.00 %	
2	Alternative 2: Install 10% wind capacity of overall generation capacity.	32.68 %	
3	Alternative 3: Install 25% wind capacity of overall generation capacity.	6.49 %	
4	Alternative 4: Install 10% PV capacity of overall generation capacity.	64.12 %	
5	Alternative 5: Install 25% PV capacity of overall generation capacity.	16.85 %	
6	Alternative 6: Install (15% wind +10% PV) capacity of overall generation capacity.	14.82 %	

Inconsistency ratio: 0.08

Fig. 9. Ranking of alternatives in terms of planning.



Priority of alternatives with respect to "Goal > Environmental"

	Name	Participant Results	Graph Bar
1	Alternative 1: Install 0% renewable capacity of overall generation capacity (business-as-usual).	5.93 %	
2	Alternative 2: Install 10% wind capacity of overall generation capacity.	8.77 %	
3	Alternative 3: Install 25% wind capacity of overall generation capacity.	32.91 %	
4	Alternative 4: Install 10% PV capacity of overall generation capacity.	19.65 %	
5	Alternative 5: Install 25% PV capacity of overall generation capacity.	100.00 %	
6	Alternative 6: Install (15% wind +10% PV) capacity of overall generation capacity.	66.21 %	

Inconsistency ratio: 0.11

Fig. 10. Ranking of alternatives in terms of environment.

generation. Wind-diesel hybrid system is an economically viable alternative to a traditional diesel generation system. The cost of fuel storage, transportation, and potential environmental impact should be considered. The electricity of Masirah Island is heavily subsidized by the State. The affordability of electricity in Masirah Island depends largely on the subsidy from the Government and the relatively low price of local diesel, which is much cheaper than the corresponding international fuel prices.

Taking into consideration of the load profile of Masirah different configuration of equipments were analyzed through HOMER and it was found that, least cost of energy ($ 0.164/kWh) with lowest NPC is about $75 million observed with wind-DG system. The highest cost of energy $ 0.173/kWh with highest NPC is about $80 million observed with solar-DG system.

Analytic Hierarchy Process (AHP) approach is used to evaluate RE alternatives at Masirah. Different criteria are identified and ranked. Alternatives are ranked based on economic criterion using HOMER. Alternatives are also ranked based on other criteria using experts' judgments. Experts' judgments are obtained using surveys. The final rankings of alternatives are done using AHP. The best alternative found is alternative 4, i.e., installing 10% of PV capacity.

For future recommendation it is suggested to simplify the survey form as it "deterred" many experts giving their opinion. The experts also showed concerns over the

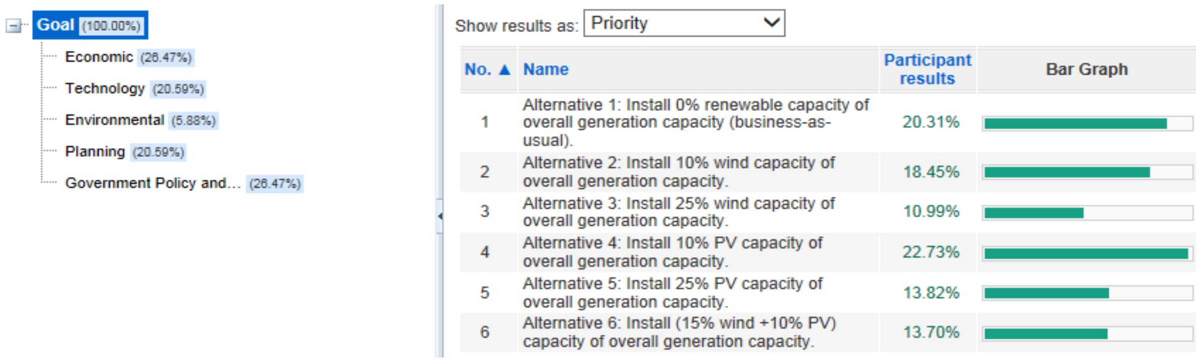


Fig. 11. Ranking of alternatives with respect to overall goal.

inconsistency that might occur during the pair-wise comparison of alternatives with respect to each criterion. This study was the first of its kind in Oman and the experts were not sure about the efficacy of AHP technique. To address some of the concerns raised by experts in Oman Power and Water Procurement Company (OPWP) a short presentation was made in front of them and their valuable input was taken in refining the survey instrument. However, the experts of other organizations were not briefed properly due to time constraints and were approached only through emails and hence there was reluctance in responding to the questionnaire. Had their enough time it would have been much more useful to visit Rural Area Electricity Company (RAECO), Authority for Electricity Regulation (AERO), and Public Authority for Electricity and Water in Oman (PAEW) to get their valuable feedback as they are the main stakeholders and responsible for planning and implementing renewable energy projects.

Acknowledgments

The authors are grateful to the Directorate General of Meteorology and Air Navigations for providing hourly wind speed data for the site and the Rural Area Electricity Company for providing load and generation data of the site. The authors are also grateful to the respondents of OPWP and RAECO who participated in AHP survey.

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