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CSP ASSESSMENT IN COMPARISON TO OTHER ELECTRICITY GENERATION OPTIONS USING MULTI CRITERIA DECISION ANALYSIS (THE LIBYAN CASE)

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Abstract* - Life cycle cost analysis provides an economic comparison among different alternatives, whilst not including non-monetary aspects. To accomplish this, Multi Criteria Analysis (MCA) has been introduced. Here, MCA is applied to Libya in the context of electricity generation technology, where demand is forecast to double over the next 20 years. Four options are compared; new CCGT plants, wind turbines, PV technology, and Concentrating Solar Power (CSP). The value tree of the objectives was constructed with six high level factors that each option is evaluated against. These factors are then broken down into 23 performance criteria, including those related to political and social upheaval. Two scenarios are proposed. The first is to compare conventional as well as renewable technologies to meet both base and peak electricity loads. The second scenario is to continue using CCGT plants for base load generation and supplement the sector with renewable technologies to meet peak loads. Three regions of Libya are examined separately. Results show that solar technologies outperform CCGT and wind options for both scenarios. Our conclusion is that power supply systems based on solar technologies, especially CSP, will play a greater role in generating peak and base load electricity in Libya.

***Index Terms* - solar engineering, renewable energy deployment, MCDA.**

I. INTRODUCTION

In practice the most common form of analysis in government is cost-effectiveness analysis (CEA), where the costs of alternative ways of providing similar kinds of output are compared. Less common, although widely used in transport and health and safety, is cost benefit analysis (CBA), in which some important non-marketed outputs are explicitly valued in money terms. Both CEA and CBA are analytical ways of comparing different forms of input or output, in these cases by giving them monetary values [1]. However this paper presents the application of Multi Criteria Analysis techniques (MCA), for comparing impacts of different options in ways which do not involve giving all of them explicit monetary values.

MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. Discussions of the different types of MCA techniques which can be practically applied can be found in the literature [2-6].

A standard feature of the MCA technique is the construction of a performance matrix as shown in Table 1. In this matrix each row describes one of the options to achieve the project goals and each column describes the performance of these options against specific criteria. The performance of the options in the matrix against each criterion can be expressed as numbers, in binary, or in qualitative terms. MCA methods are distinguished from each other mainly in terms of how they process the basic information and data presented in the performance matrix and convert all these data and information into consistent numerical values.

Table 1. The performance matrix

	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Option 1				
Option 2				
Option 3				

II. OUTLINE OF THE APPROACH USED IN THIS RESEARCH

Among the MCA methods, the technique known as multi criteria decision analysis (MCDA) was chosen. This is because:

- It is good at analyzing complex tasks.
- It is easy to use and apply.
- It allows realistic time and manpower for the analysis process.

If the multi criteria decision analysis is to be applied fully for the appraisal of any options of a project, then eight steps are normally involved [2-6]. The sequence of these steps is summarized in Fig. 1.

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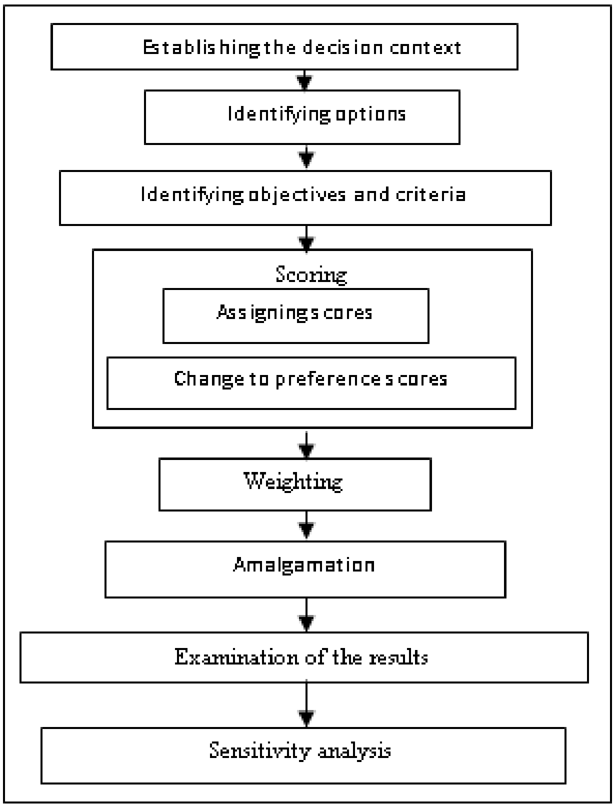

Fig.1 Steps in Multi Criteria Decision Analysis

Step one: Establishing the decision context

This step includes three sub-steps. These are firstly establishing the aim of the MCDA and identifying the main stakeholders. The second sub-step is designing the socio-technical system for conducting the MCDA. The last sub- step is considering the context of the appraisal.

Step two: Identifying options

In this step the options that will achieve the end goals of the project under review have to be identified. In some cases these options are pre-specified, in other cases they have to be developed.

Step three: Identifying objectives and criteria

Here, we first need to identify the criteria by which the consequences of each option are to be assessed. Then, one needs to organize these criteria by clustering them under both high level and lower level objectives in a hierarchy. This is known as constructing the value tree.

Step four: Scoring

This step involves two sub-steps. In the first, the performance of each option against the criteria is assessed using monetary, quantitative, or qualitative measurements. In the second, the scores are changed into preference scores. This is necessary because it is not possible to combine monetary, quantified measurements, and quality terms all together directly. They first need to be normalized so that an overall evaluation of the options can be achieved. The key idea of converting into preference scores allows the use of a relative preference scale, as shown in Fig. 2. This is simply a scale that ranges from 0 to 100 where the most preferred option with the best score is assigned a preference score of 100, and the least preferred option having the worst score is given a preference score of 0. The remaining options are assigned scores so that differences in the scale numbers represent differences in strength of preference.

Step five: Weighting

Here, weights are assigned to each of the criteria to reflect their importance to the decision. The direct weighting method was used; whereby100 points are allocated among the criteria according to their importance. The points are allocated by the person doing the analysis, by a board of experts, or by persons affected by the outcome of the analysis; and preferably by a combination of all of these.

Step six: Amalgamation

Amalgamation is a combination of Steps four and five; namely preference scores and weights. The aim is to calculate an overall weighted score for each of the options. Mathematically, if the preference score for option i on criterion j is given by s_{ij} and the weight for each criterion is given by w_j then if the number of criteria is n, the overall score for each option S_i is given by the expression:

$$S_i = w_1 s_{i1} + w_2 s_{i2} + \ldots + w_n s_{in} = \sum_{j=1}^{n} w_j s_{ij}$$

Step seven: Examination of results

After step six, the options are ordered according to the overall weights of the preference scores. This can be helpful in indicating how much better one option is over another. Another way of examining the results is by plotting two-dimensional graphs between one of the criteria and the overall weighted scores.

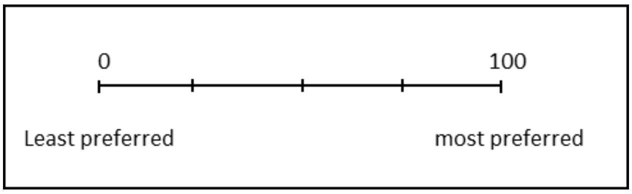

Fig.2 Relative strength of preference

Step eight: Sensitivity analysis

The sensitivity analysis of the results can be carried out in four sub-steps:

- Conduct a sensitivity analysis of the results to changes in scores or weights. This is achieved by answering the question of “Will the overall options order be affected if scores or weights are changed?” This is important because the participants often differ in their views of the relative importance of the criteria and of some scores.
- Looking at the advantages and disadvantages of selected options. A high score on a heavily weighted criterion is an advantage while a high score on a relatively unimportant criterion cannot be considered as an advantage. This is because it will not contribute much to the overall weighted

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score. Also a low score on an important criterion is a disadvantage, while a low score on an unimportant criterion is not, because it does not reduce the overall preference significantly.

- If new options can be created that might be better than those originally considered then they are introduced into the performance matrix, scored and weighted. The steps are then repeated.
- Repeat the above steps until the required model is obtained keeping in mind the amount of time and resources available.

It is to be noted that it is not necessary to go through all the stages of the MCDA process for all projects, as these vary from simple problems that could be solved just by analyzing the performance matrix and the evaluation ends there. However for more complex projects a full analysis has to be applied.

III. APPLYING MCDA TO THE LIBYAN FUTURE ELECTRICITY GENERATION TECHNOLOGY

A. *Establishing the decision context*

Aside from being poorly managed, Libya's energy sector is largely unsustainable. Libya is an oil and gas exporting country and most of the oil and gas that is produced is exported. Electricity is generated mainly by burning oil and natural gas — both finite fossil fuel sources. The Libyan oil reserves are expected to last for the next 30 to 50 years while natural gas may be produced for slightly longer.

Libya also has current and severe issues of a socio-political nature. The country was divided by the fall of Gaddafi in 2011, and is now essentially divided into three regions. A map of Libya is shown in Fig. 3, where the size of the circle indicates the population of a town. The three regions, which form the geographical boundaries for this paper, are taken as follows. Firstly, there is the north-west of the country, surrounding the official capital of Libya, Tripoli. This region has its own government (one of two competing governments which lay claim to be the official government of Libya) and has its own military arms, tribal alliances and regional benefactors. It is eager to claim a larger share of the country's massive oil wealth and access to ports and airports, thus running its own economy. In the north-east of the country, principally surrounding Tobruk and Bayda, is the second competing government of Libya, with similar aims and resources to that existing in the north-west. The third region is the south, although for practical purposes one may take this to mean the south-west of Libya located around the cities of Sabha and Hun – since there are few major settlements in the south-east of the country. The situation in the north is further complicated by so-called Islamic State or ISL strongholds between (and sometimes including) the large cities of Benghazi and Sirte. The socio-political situation in this coastal region is extremely fluid, and we have omitted this north-central region from this current analysis. However, we have assumed that it will be possible for decision makers to make decisions regarding power generation on a national basis, despite the difficulties described above.

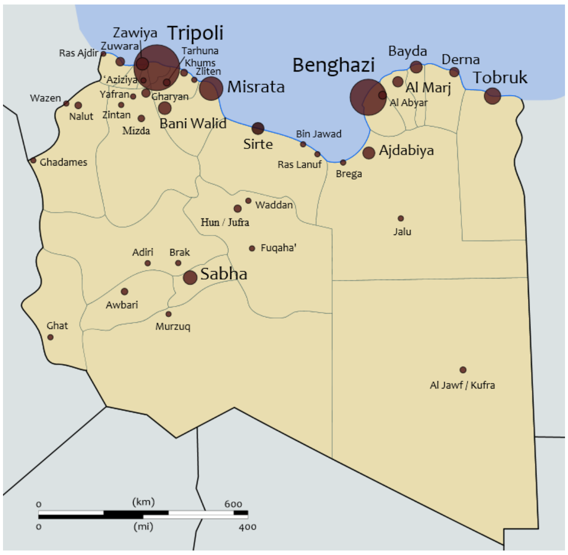

Fig.3 Map of Libya showing major settlements

If decision makers do take up the challenge, they need to supplement the country's energy sector by introducing renewable energies alongside the prime energy sources. One of the most important alternative energy sources to consider for the future is solar power. Recent research has indicated that the solar potential in Libya is even greater than the petroleum productivity [7]. What makes solar power so attractive in Libya is the high intensity of daily solar radiation and the long daily sun duration of up to 11 hours. A number of solar energy technologies for large scale electricity generation do exist, with a varying level of maturity. These include photovoltaic (PV), concentrated photovoltaic (CPV), and concentrated solar thermal power plants (CSP) with its variants of parabolic trough, linear Fresnel, central (tower) receiver, and parabolic dish. CSP can also provide thermal energy storage.

Bearing all this in mind, studies and research should be focused on implementing these technologies in order to limit the dependence of the Libyan economy on conventional (fossil fuel based) energy resources. Reasons for this include:

- Good solar resource.
- Land availability.
- Financial resources of Libyan government.
- Maturity of the technology.

The benefits to be obtained by adopting these technologies are:

- Fulfilling the need of the people regarding job creation in these areas.
- Ensuring the settlement of people in their local cities and reducing the migration to the big cities.
- It will be a good step towards the implementation of the renewable energy technologies in the country.

- It will play a part in reducing the impact of global warming as the Libyan CO_2 emissions exceed the African average and it is ranked No. 1 in the African continent regarding CO_2/capita.
- Saving national oil resources.
- Helping to prolong the life of existing conventional power plants.

As renewable energy technologies do exist in many varieties, choosing one that is suitable for the Libyan situation could be a challenging task. This paper uses the Multi Criteria Decision Analysis (MCDA) technique to compare and rank these technologies in terms of their suitability for Libya.

B. *Identifying the options to be appraised*

The following are the options to be appraised by the MCDA method:

1. Continue building new CCGT plants.
2. Using Wind energy.
3. Using PV systems.
4. Implementing the technology of CSP (specifically parabolic trough technology).

These alternatives were chosen based on their maturity and their advanced stage of development for large scale electricity generation.

C. *Identifying objectives and criteria*

The value tree was constructed by developing a hierarchical model of the objectives and criteria. The higher-level objectives were categorized into six main groups. Each, when appropriate, was broken down into a number of performance criteria. Altogether, twenty-three criteria were included in the model. These are listed below and are shown in Fig. 4.

1. Environmental impacts:

- Harmful emissions.
- Noise.
- Visual impact
- External costs
- Public acceptance

2. Economic aspect:

- Capital cost
- O & M costs
- Fuel cost
- Electricity cost.

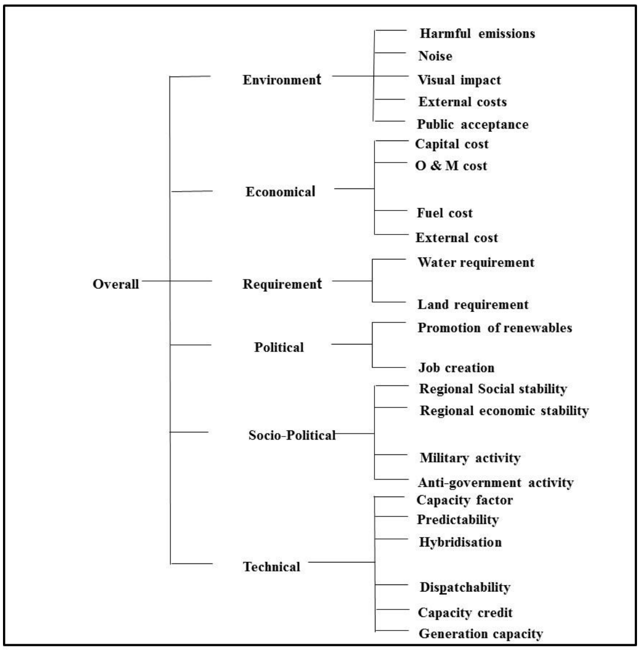

Fig.4 Hierarchical representation of objectives and criteria

3. Economic aspect:

- Capital cost
- O & M costs
- Fuel cost
- Electricity cost.

4. Technology requirements:

- Water requirement.
- Land requirement.

5. Political aspect

- Promotion of renewable energy
- Job creation

6. Socio-Political aspect

- Regional Social stability
- Regional economic stability
- Military activity
- Anti-government activity

7. Technical aspect:

- Capacity factor
- Predictability
- Hybridization
- Dispatchability
- Capacity credit
- Generation capacity

IV. SCORING THE OPTIONS

This was done by means of the performance matrix, Table 2. In this matrix each column represents an option while each row represents one of the criteria to be used for the evaluation. Three methods were used to score the options against the different criteria:

- When monetized values are available, then they were used.
- Some criteria were evaluated with the aid of quantitative measures.

- The rest of the criteria were judged by means of a rating (qualitative measures).

A. Environmental impacts

- ***Harmful emissions.***

Harmful emissions are one of the most important side effects for electricity generation technologies. This led to extensive studies that deal with the amount of these emissions during different stages of the power production chain [9-14]. This criterion was evaluated on the basis of the amount of harmful emissions emitted by each option during electricity production. As carbon dioxide is the most significant of these emissions, then this was judged according to the amount of CO_2 in grams emitted for each kWh of electricity generated [8].

Table 2. The performance matrix of the options being appraised

Objectives	Criteria	Alternatives			
		CCGT Plant	Wind Energy	PV Plant	CSP Plant
Environmental	CO2 emissions	469	12	46	22
	Noise	No	Yes	No	No
	Visual impact	3	5	1	2
	External Costs	3.6	0.18	1.02	0.22
	Public Acceptance	3.2	8.2	56.4	56.4
Economic	Capital Cost	750	900	700	2000
	O & M Cost	11.1	30	19	45
	Fuel Cost	37.5	0	0	0
	Electricity Cost	7.25	11.1	34	25.5
Requirement	Water Requirement	205	0	1	906
	Land Requirement	435	8650	2500	1850
Political	Promote renewables	X	√	√	√
	Job Creation	0.1	0.24	0.49	0.53
Socio-political	Regional social stability	5	3	1	2
	Regional economic stability	4	3	2	4
	Military activity	5	3	2	2
	Anti-government activity	5	4	3	3
Technical	Capacity Factor	80	30	18	38.5
	Predictability	***	*	*	**
	Hybridisation	X	X	X	√
	Dispatchibility	√	X	X	√
	Capacity Credit	90	22.5	50	90
	Generation Capacity	7008	2000	1790	4050

- ***Noise impacts.***

People will not accept high levels of noise. In addition, it can have a negative impact on animal life. Some technologies introduce the effect of this impact in more ways than others. In particular it is related to wind turbines, and a number of publications have addressed this issue [15-20]. This criterion was assessed qualitatively on the basis of sound produced by each option during electricity generation and its effect on the local environment.

- ***Visual impact.***

Most if not all of the considered options will have some visual impact on the environment, as plant and equipment will be clearly visible to local people. This, in particular is more important if the generating plant is located near to an urban area. The analysis will depend of whether the options will be regarded as attractive or not. This will mainly depend on aesthetic tastes, though most of the people will regard PV arrays as more attractive than the highly visible wind turbines with their shadowing and flicker effect [21-30]. As there is no quantitative measure for this criterion, it was assessed using a scale from 1 to 5, where 1 will represent the option with the least negative visual impact while 5 will represent the option with the worst negative visual impact.

- **External cost.**

External costs of electricity refer to the costs of damage imposed on society and the environment by an electricity generation chain, but not accounted for in the market price of electricity. Electricity generation impacts include effects of air pollution on health, buildings, crops, forests and global warming; occupational disease and accidents. A number of publications exist in the literature discussing this issue in detail [31-34]. The equivalent monetary value of the external costs used in this work was adopted from [8] in US cents/kWh.

- **Public Acceptance**

In the energy sector, there is a growing consensus that the integration of renewable energies into the energy system cannot be reached with the opposition of the citizens. This makes public acceptance of renewable energies a fundamental to further increasing their share in the overall energy supply. This has led to a large number of investigations to address this issue in different areas of the world [35-39]. In general most renewable energy technologies were more acceptable by the public in comparison to the conventional energy technologies. The performance of the alternatives against this criterion was adapted from [40] in terms of the percentage of community support for the preferred type of energy supply technology to be implemented for their electricity generation.

B. Economic Objective

This objective, as shown in the value tree, was divided into four criteria. These are the capital cost, operation and maintenance cost, fuel cost, and electricity cost. Capital cost is very important for the investor, whereas operation, maintenance and fuel costs are more critical for the plant operators, while electricity cost is a significant parameter for the end users. All of these are negative criteria. This means that the higher the score of the option, the worse the option is. Extensive studies are available in the literature evaluating and discussing these parameters [43-47]. The capital costs and operation and maintenance costs were evaluated in €/kW of installed capacity [41]. Fuel cost was judged in US dollars/MWh [42]. Electricity cost was evaluated by the price of electricity delivered to the customer in US cents/kWh [8].

C. Requirements Objective

Two of the most important requirements for electricity generation are land and water. All of the four alternatives considered for evaluation in this work will need an area of land to build on and most of them will need water for their operation. A number of studies do exist in the literature investigating the land requirements for electricity generation [48-50]. The figures used in this work were adopted from [51] and it expresses this criterion in terms of km^2/exajoul. Note that land requirement is a negative criterion.

For the water requirement, the alternatives vary in the amount they need for operation. Wind energy requires none, PV plants need minimal water for PV panel cleaning if it all, CCGT plants need a larger amount than PV mostly for power block cooling purposes, while a CSP plant will need a significant amount of water for both mirror cleaning and power block cooling. The amount of water for CCGT and CSP plants will be reduced significantly if dry cooling is used instead of wet cooling for the power generation process. This criterion was assessed in terms of amount of water in gallons required per MWh [52]. The water requirement is also a negative criterion.

It is worth emphasizing that the importance of these two criteria will be different according to the location of the proposed plant. While land value is more important than water in the north region of Libya, it is the water that is more critical than the land in the southern part. This is reflected in the weight of these criteria.

D. Political Objective

All governments are under international pressure to adopt more environmentally benign technologies for energy production. This objective was broken down into two criteria; the first is the promotion of renewables which was assessed in qualitative terms where the option falling in the renewable energy category will be highly welcomed by the government and will receive a “tick” (✓), while the option falling in the conventional energy technologies category will be least welcomed and will receive a “cross” (X).

The second criterion is the number of jobs to be created by each of the options being appraised. Jobs considered were the operation and maintenance jobs only as these will be more critical to the government as they are normally filled by local workers and engineers. Jobs related to manufacturing, construction and commissioning were excluded as they are more likely to be performed by foreign companies. Many studies have looked at how different technologies affect the jobs market [53-55]. The criterion in this work was assessed in terms of number of jobs to be created for each MW installed [56].

E. Socio-political Objective

This objective refers to the specific conditions that exist in Libya currently, a consequence of the overthrow of Gaddafi in 2011. The difficulties in providing a stable environment within which to generate energy have to be considered in our analysis. The four criteria in this section all have a negative impact and are ranked on a 1 to 5 scale, with 5 having the highest negative impact.

- ***Regional social stability***

During and following the political events of 2011 there was movement of groups of people throughout the regions of Libya, mainly dependent on the political allegiances of people. This social instability is still continuing, and tends to de-stabilize the workforce and create turbulence to energy requirements. It is region dependent.

- ***Regional economic stability***

The economic situation also varies by region, and is also a product of recent political upheaval. In the north of the country, both the north-west and north-east regimes have created short-term economic stability. However the long-term economic situation is unpredictable, and has an influence on any power generation investment decision. In the south of Libya the economic situation is more stable, but wealth is centred on the large settlements.

- ***Military* activity**

This refers to both internal military presence and external interventions. Power generation plants are potential military targets, and must be secured. This criterion needs to consider the degree to which a plant can be secured and its potential for repair, replacement, and removal.

- ***Anti-government activity***

With regional governments currently holding sway, anti-government activity is considered to include any action from within or outside that region to the effect that local power generation conditions are altered. Uprisings from within, or interventions from outside, are likely to have similar impacts to those of the military activities that were discussed in the previous section.

F. Technical Objective

This is one of the most important high level objectives as it involves evaluating the engineering aspect for the operation of the proposed alternatives. Six criteria will be used to compare the power supply options within this objective. These are the capacity factor, predictability, hybridization, dispatchability, capacity credit, and generation capacity.

- ***Capacity factor***

The capacity factor of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity indefinitely. Values for this criterion were obtained from [8]. This criterion is a positive one; the higher it is the better the option.

- ***Predictability.***

This refers to the accuracy to which plant output power can be predicted at relevant time scales to assist power system operation. This criterion was assessed qualitatively with a scaling system of 3 stars. The less predictable option will have just one star, the most predictable one will have 3 stars, while the one with moderate predictability will be scored with two stars. This was adapted from [8].

- ***Hybridisation.***

Hybridization is becoming increasingly an important issue in the field of electricity generation in general and in renewable energy technologies in particular [57-60]. Hybridization adds the benefits of backup reliability and faster start-up to the plants that are implementing it, in addition to other benefits [61]. This led to the fact that the option which can be hybridized will be more preferred and will have a “tick” (✓) while the one that cannot be hybridized will be least preferred and will be scored with a “cross” (X).

- ***Dispatchability.***

Dispatchable generation refers to sources of electricity that can be dispatched at the request of power grid operators; that is, generating plants that can be turned on or off, or can adjust their power output on demand [62, 63]. This is important because of many factors such as load matching, peak matching, and overcoming intermittency in the nature of power sources [64]. This criterion also has been assessed in qualitative terms.

- ***Capacity credit.***

Capacity credit is widely used to quantify the ability of different generating technologies to support demand. The capacity credit of any power plant may be defined as a measure of the ability of the plant to contribute to the peak demands of a power system [65-67], i.e. the amount of output from a power source that may be statistically relied upon, expressed as a percentage. The capacity credits of the different technologies being appraised were taken from the literature [8].

Table 3. The preference scores of the options being appraised

Objectives	Criteria	Alternatives			
		CCGT Plant	Wind Energy	PV Plant	CSP Plant
Environmental	CO2 emissions	0	100	92.56	97.81
	Noise	100	0	100	100
	Visual impact	50	0	100	75
	External Costs	0	100	75.44	98.83
	Public Acceptance	0	9.4	100	100
Economic	Capital Cost	96.15	84.61	100	0
	O & M Cost	100	44.24	76.7	0
	Fuel Cost	0	100	100	100
	Electricity Cost	100	85.6	0	31.78
Requirement	Water Requirement	77.37	100	99.88	0
	Land Requirement	100	0	74.86	82.78
Political	Promote renewables	0	100	100	100
	Job Creation	0	32.5	90.7	100
Socio-political	Regional social stability	0	50	100	75
	Regional economic stability	25	50	75	25
	Military activity	0	50	75	75
	Anti-government activity	0	25	50	50
Technical	Capacity Factor	100	19.35	0	33.06
	Predictability	100	0	0	50
	Hybridisation	0	0	0	100
	Dispatchibility	100	0	0	100
	Capacity Credit	100	0	40.74	100
	Generation Capacity	100	4	0	43.3

- ***Generation Capacity***

As the technologies are different in both their way of generating electricity as well as the nature of the source they are relying on, this makes the energy yield per installed capacity different for each of them. This criterion was evaluated by the amount of electricity generated in kWh in a year per kW of installed plant capacity. Values of this criterion were adapted from [68].

Table 2 presents the performance of the four options against the twenty-three criteria of the six high level objectives while Table 3 gives the same information after changing the criteria scores into preference scores.

V. CRITERIA WEIGHTING AND AMALGAMATION

The weights for each criterion were assigned by using the direct weighing method. The Economic, Political, Socio-political and Technical high level objectives were given the highest weight of 20 points each. Environmental as well as the Requirements high level objectives were weighted lower and allocated 10 points each.

In order to get an overall weighted score for the options, the linear additive model was applied where the products of weights by the scores of each criterion are summed (amalgamation).

VI. RESULTS AND DISCUSSION

As shown in Fig. 5, the study was conducted for two scenarios; the first is to compare conventional as well as renewable technologies to meet both base and peak electricity loads. The second scenario will assume that country's decision makers will not take the risk and will continue relying on CCGT plants to meet base electricity loads, but will supplement the sector with renewable technologies to meet peak loads. As illustrated in Figure 5, Libya was divided into three regions; north-east, north-west, and the south region, and the study was performed for all three regions separately.

The regions differ in the water and land requirements criteria, and in the renewable energy potential (solar and wind). In the northern regions (the coastal area) it is the land that was considered as more important than the water requirement, while in the southern (desert) area much land is available, but water is scarce.

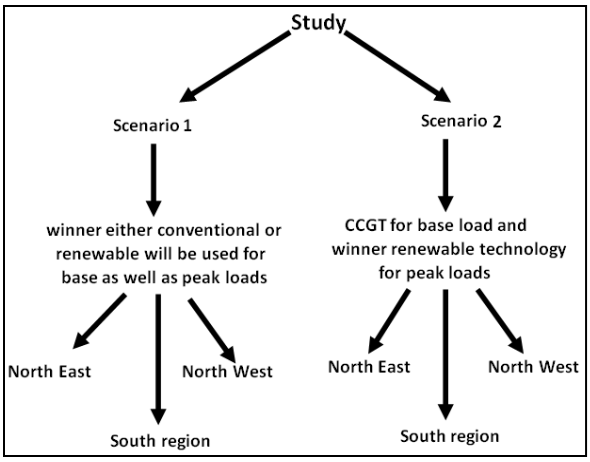

Fig.5 Outline of the MCDA study

Regarding the renewables potential; wind was considered in the study only in the north-east region in the two scenarios. In the other two regions, solar technologies were the only competitors to the CCGT plants. The socio-political weightings are varied between locations to reflect the greater risk of upheaval in the coastal north-east compared to Tripoli and the north-west, with the southern regions being the least at risk in this respect.

Table 4 presents the preference scores matrix with weights and overall weighted scores for the first scenario Case 1 (north east region). Tables 5 and 6 give the same information for Case 2 (north-west region) and Case 3 (south region) respectively. The study results for the second scenario in the three regions of the country are presented in Tables 7 to 9.

Table 4. Preference scores with weights and overall weighted scores - Scenario 1 – North-east

Objectives	Criteria	Alternatives				Weights
		CCGT Plant	Wind Energy	PV Plant	CSP Plant	
Environmental	CO2 emissions	0	100	92.56	97.81	4
	Noise	100	0	100	100	2
	Visual impact	50	0	100	75	2
	External Costs	0	100	75.44	98.83	1
	Public Acceptance	0	9.4	100	100	1
Economic	Capital Cost	96.15	84.61	100	0	7
	O & M Cost	100	44.24	76.7	0	3
	Fuel Cost	0	100	100	100	3
	Electricity Cost	100	85.6	0	31.78	7
Requirement	Water Requirement	77.37	100	99.88	0	3
	Land Requirement	100	0	74.86	82.78	7
Political	Promote renewables	0	100	100	100	10
	Job Creation	0	32.5	90.7	100	10
Socio-political	Regional social stability	0	50	100	75	3
	Regional economic stability	25	50	75	25	3
	Military activity	0	50	75	75	7
	Anti-government activity	0	25	50	50	7
Technical	Capacity Factor	100	19.35	0	33.06	5
	Predictability	100	0	0	50	3
	Hybridisation	0	0	0	100	2
	Dispatchibility	100	0	0	100	5
	Capacity Credit	100	0	40.74	100	3

	Generation Capacity	100	4	0	43.3	2
Over all weighted score		47.8	46.9	64.3	66.2	100

Table 5. Preference scores with weights and overall weighted scores - Scenario 1 – North-west

Objectives	Criteria	Alternatives			Weights
		CCGT Plant	PV Plant	CSP Plant	
Environmental	CO2 emissions	0	92.56	97.81	4
	Noise	100	100	100	2
	Visual impact	50	100	75	2
	External Costs	0	75.44	98.83	1
	Public Acceptance	0	100	100	1
Economic	Capital Cost	96.15	100	0	7
	O & M Cost	100	76.7	0	3
	Fuel Cost	0	100	100	3
	Electricity Cost	100	0	31.78	7
Requirement	Water Requirement	77.37	99.88	0	3
	Land Requirement	100	74.86	82.78	7
Political	Promote renewables	0	100	100	10
	Job Creation	0	90.7	100	10
Socio-political	Regional social stability	0	100	75	5
	Regional economic stability	25	75	25	5
	Military activity	0	75	75	7
	Anti-government activity	0	50	50	3
Technical	Capacity Factor	100	0	33.06	5
	Predictability	100	0	50	3
	Hybridisation	0	0	100	2
	Dispatchibility	100	0	100	5
	Capacity Credit	100	40.74	100	3
	Generation Capacity	100	0	43.3	2
Over all weighted score		48.3	65.8	66.2	100

By looking at the results obtained in Tables 4 to 6 regarding the first scenario, it is clear that solar energy technologies rank above conventional methods and wind energy for electricity generation for the case in hand. In the north-east region, CSP technology received an overall score of 66.2. This was similar to PV systems with an overall score of 64.3. CCGT and Wind plants received overall scores of 47.8 and 46.9 respectively. For the south region case the situation was very similar to the north-east region. The overall performance of CSP and PV were superior compared to the third alternative, i.e. the CCGT plant. CSP and PV received an overall score of 65.2 and 66.3 respectively while the score for the CCGT was only 48.8. In the north-west region CSP and PV were again superior compared to the CCGT plant. CSP and PV received an overall score of 66.2 and 65.8 respectively while the score for the CCGT was only 48.3.

Table 6. Preference scores with weights and overall weighted scores - Scenario 1 – South

Objectives	Criteria	Alternatives			Weights
		CCGT Plant	PV Plant	CSP Plant	
Environmental	CO2 emissions	0	92.56	97.81	4
	Noise	100	100	100	2
	Visual impact	50	100	75	2
	External Costs	0	75.44	98.83	1
	Public Acceptance	0	100	100	1
Economic	Capital Cost	96.15	100	0	7
	O & M Cost	100	76.7	0	3
	Fuel Cost	0	100	100	3
	Electricity Cost	100	0	31.78	7
Requirement	Water Requirement	77.37	99.88	0	3
	Land Requirement	100	74.86	82.78	7
Political	Promote renewables	0	100	100	10
	Job Creation	0	90.7	100	10
Socio-political	Regional social stability	0	100	75	7
	Regional economic stability	25	75	25	7
	Military activity	0	75	75	3
	Anti-government activity	0	50	50	3
Technical	Capacity Factor	100	0	33.06	5
	Predictability	100	0	50	3
	Hybridisation	0	0	100	2
	Dispatchibility	100	0	100	5
	Capacity Credit	100	40.74	100	3
	Generation Capacity	100	0	43.3	2
Over all weighted score		48.8	66.3	65.2	100

Looking to the results for the second scenario presented in Tables 7 to 9, the superiority of CSP technology was very clear. In the north-west, as well as in the south regions, CSP led with overall scores of 76.8 and 86.8 compared with that for PV plants of only 46.5 and 63.0. In the case of the north-east where three alternatives were competing, CSP ranked highest with an overall score of 72.6 followed by the option of PV systems with a score of 61.2, with the option of wind energy having the lowest score of 39.5.

VII. CONCLUSIONS AND POLICY IMPLICATIONS

One of the main issues in electrical generation planning is to find an optimized combination of power plants to supply a secure and sustainable load for the future. Generally in generation planning, the analysis of alternative decisions demands a quantitative and qualitative evaluation of the alternatives and their performance. The methods based on multiple criteria analysis can be very helpful in such cases as these methods have advantages over the traditional analysis methods based only on economic data. MDCA considers the full set of environmental factors of the object, and integrates significant economic indicators in addition to any other important objectives such as political and technical. The approach also eliminates the bias of analysts as they normally come from different backgrounds. In addition to this, the MCDA tool provides a helpful means that can easily deal with large data sets ranging from numerical, qualitative, linguistic, or missing values from a group of experts whose views may not agree with each other.

Table 7. Preference scores with weights and overall weighted scores - Scenario 2 – North-east

Objectives	Criteria	Alternatives			Weights
		Wind Energy	PV Plant	CSP Plant	
Environmental	CO2 emissions	100	0	70.58	4
	Noise	0	100	100	2
	Visual impact	0	100	75	2
	External Costs	100	0	95.23	1
	Public Acceptance	0	100	100	1
Economic	Capital Cost	84.61	100	0	7
	O & M Cost	57.69	100	0	3
	Fuel Cost	100	100	100	3
	Electricity Cost	100	0	37.11	7
Requirement	Water Requirement	100	99.88	0	3
	Land Requirement	0	90.44	100	7
Political	Promote renewables	100	100	100	10
	Job Creation	0	86.29	100	10
Socio-political	Regional social stability	0	100	75	3
	Regional economic stability	25	75	25	3
	Military activity	0	75	75	7
	Anti-government activity	0	50	50	7
Technical	Capacity Factor	58.53	0	100	5
	Predictability	0	0	100	3
	Hybridisation	0	0	100	2
	Dispatchibility	0	0	100	5
	Capacity Credit	0	40.74	100	3
	Generation Capacity	9.29	0	100	2
Over all weighted score		39.5	61.2	72.6	100

Table 8. Preference scores with weights and overall weighted scores - Scenario 2 - North west

Objectives	Criteria	Alternatives		Weights
		PV Plant	CSP Plant	
Environmental	CO2 emissions	0	100	4
	Noise	100	100	2
	Visual impact	100	0	2
	External Costs	0	100	1
	Public Acceptance	100	100	1
Economic	Capital Cost	100	0	7
	O & M Cost	100	0	3
	Fuel Cost	100	100	3
	Electricity Cost	0	100	7
Requirement	Water Requirement	100	0	3
	Land Requirement	0	100	7
Political	Promote renewables	100	100	10
	Job Creation	0	100	10
Socio-political	Regional social stability	100	75	5
	Regional economic stability	75	25	5
	Military activity	75	75	7
	Anti-government activity	50	50	3
Technical	Capacity Factor	0	100	5
	Predictability	0	100	3
	Hybridisation	0	100	2
	Dispatchibility	0	100	5
	Capacity Credit	0	100	3
	Generation Capacity	0	100	2
Over all weighted score		46.5	76.8	100

	Capacity			
Over all weighted score		63.0	86.8	100

In this paper, the Multi Criteria Decision Analysis technique was successfully applied to support the analysis for long-term scenarios for the future of Libyan energy policy.

The Multi criteria decision analysis technique was used to conduct an inclusive comparison between four power supply options that were proposed to meet the expected electricity demand increase in Libya. In addition to the economic aspect, the aim was to evaluate the options environmentally, technically, politically, socio-politically and from a technology requirements point of view. These high level objectives were broken down into a number of performance criteria. Altogether, twenty-three criteria were included in the model; harmful emissions, noise, visual impact, external costs, public acceptance, capital cost, O & M costs, fuel cost, electricity cost, water requirement, land requirement, promotion of renewable energy, job creation, regional social stability, regional economic stability, military activity, anti-government activity, capacity factor, predictability, hybridization, dispatch ability, capacity credit, and generation capacity. After scoring, weighing, and amalgamation, the results showed that solar technologies (CSP plants & PV systems) outperformed CCGT and wind options in the north-east and south regions of the country. However CSP technology was superior to all other alternatives in the north-west region. In the second scenario; it was the CSP option that received the highest overall weighted score in all three regions of the country.

Table 9. Preference scores with weights and overall weighted scores - Scenario 2 – South

Objectives	Criteria	Alternatives		Weights
		PV Plant	CSP Plant	
Environmental	CO2 emissions	0	100	4
	Noise	100	100	2
	Visual impact	100	0	2
	External Costs	0	100	1
	Public Acceptance	100	100	1
Economic	Capital Cost	100	0	10
	O & M Cost	100	0	5
	Fuel Cost	100	100	5
	Electricity Cost	0	100	10
Requirement	Water Requirement	100	0	7
	Land Requirement	0	100	3
Political	Promote renewables	100	100	15
	Job Creation	0	100	15
Socio-political	Regional social stability	100	75	7
	Regional economic stability	75	25	7
	Military activity	75	75	3
	Anti-government activity	50	50	3
Technical	Capacity Factor	0	100	5
	Predictability	0	100	3
	Hybridisation	0	100	2
	Dispatchibility	0	100	5
	Capacity Credit	0	100	3
	Generation	0	100	2

In conclusion, based on the analysis used in this work, it is the power supply systems based on solar technologies; especially CSP, that present the most attractive option to Libya going forward. However the authors acknowledge the current political and social conditions that prevail in the country, and it is imperative that a national consensus is achieved before a Libyan national energy generation policy can be successfully developed and implemented.

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