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Renewable or Nuclear Energy? Jordan's Energy Strategy Options

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Abstract

The gap between energy supply and demand is widening in Jordan. Sound measures to overcome this gap are essential for sustainable energy development. In this paper conventional and non-conventional energy resources are discussed. These include crude oil and natural gas, wind, solar, biogas, geothermal, hydropower, and nuclear power. Using multi-criteria analysis, options were evaluated for the best component in the energy mix. It was concluded that solar energy is the most inexpensive source of energy while nuclear power is the most expensive; it seems likely that the Jordanian nuclear power program will prove not to be feasible.

Keywords: *Renewable energy, Nuclear energy, Jordan*

1. Introduction

Jordan does not have the natural resources of its neighbors and has traditionally imported nearly all of its energy and fuel requirements. Under its new National Energy Strategy, renewable and nuclear energy is set to transform the kingdom into a net exporter by 2030, despite a rapidly growing population. As the price of oil remains high, energy security has become even more of a priority to Jordan. The government is seeking an investment of US$18 billion in this sector by 2020. The most prominent proposals include developing civil nuclear power, oil shale and renewable energy resources. The plans aim to increase the renewable energy share in the energy mix from 2% to 7% by 2015 and to 20% by 2020 [1-8].

Wind will be one of the major sources of energy. Negotiations for the kingdom's first wind farm are in the final stages. The government aims to generate some 600MW by 2015 and to double this capacity by 2020. Other sources will be solar power with 600MW of generation by 2020 and 50MW through waste to energy technology [1].

With all of these projects in the works, the energy sector is one of the strongest prospects for investment in the Jordanian economy. Although challenges remain, most notably securing financing during the downturn and keeping up with the pace of demand, the sector should see major growth in the next two decades.

In this paper, a decision-support system through a multi-criteria analysis, an attempt is made to assist decision-makers to evaluate different options for Jordan to enhance its energy mix strategy, different factors, aspects and limitations for each option will be taken into account.

2. Energy Sources in Jordan

2.1 Crude oil and natural gas

Crude oil and natural gas resources in Jordan are very limited. Figure 1 depicts the contribution of the local production of crude oil and gas to the overall energy consumption in the whole consumed energy in the Kingdom during the period 2007-2011 [1].

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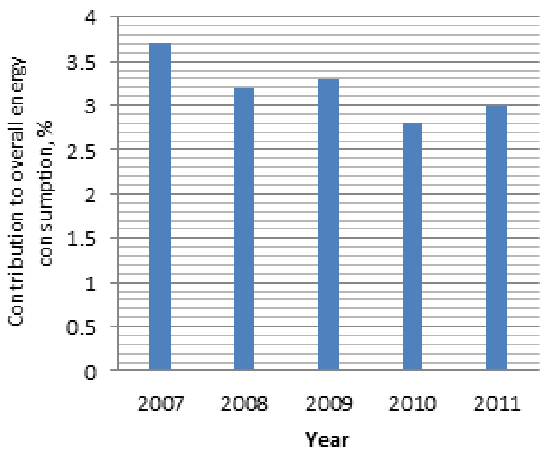

Figure 1: Jordan's production of crude oil and natural gas

The energy mix during the year 2011 is shown in figure 2, four energy resources are identified; oil products, natural gas, renewable energy and imported electricity. The renewable energy resources constitute of 2% of the total energy mix [4].

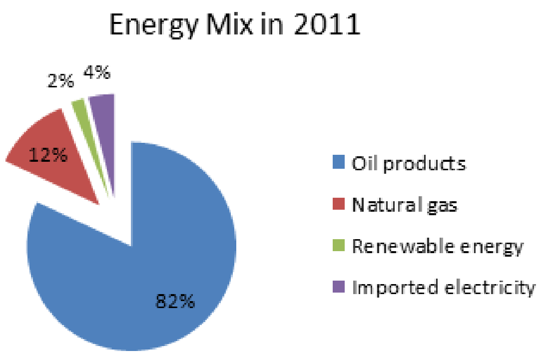

Figure 2: Jordan's energy mix in 2011

2.2 Wind

Jordan has significant wind energy resources that could be potentially exploited for power generation. The country's Wind Atlas indicates that some areas in the Northern and Western regions of the country have wind speeds that exceed 7 meters/second (M/S). Two wind pilot projects exist in the County with a capacity of 1.5 MW. They have been running since early 1990.
Currently, two wind projects are proceeding. The first one is "Al-Khamshah" for 30-40MW, a Greece company was selected to build the project but still negotiating with the Government the prices. The second one "Al-Fujeij" for 80-90MW, the Ministry of Energy and Mineral Resources (MEMR) is reviewing proposals from companies that showed interest in the project [4].

2.3 Solar Energy

Jordan is blessed with an abundance of solar energy, which is evident from the annual daily average solar irradiance on a horizontal surface ranges between 5-7 Kilowatts/hr (kWh)/m^2; one of the highest figures in the world. Several studies on solar energy projects are being carried out on decentralized solar PV systems to provide energy services to remote and rural villages. Presently in Jordan, with a total capacity of 1,000 kW peak are operating in the rural and remote villages providing electricity for lighting, water pumping and other social services. Moreover, they are interested in developing additional solar thermal for domestic utilization. About 15 percent of total households are equipped with solar water heating systems – with a goal to increase it to 30% by 2020. They contribute up to1 percent of the total energy consumption at present.
Two feasibility studies are presently under way for two solar power plants. The first one is 100MW plant done by Millennium for Energy Industries using Concentrated Solar Power (CSP) technology. The second one is also a 100MW plant conducted by Kawar Energy "Shams Ma'an Project" using PV technology.

2.4 Biogas

Biogas from municipal waste represents a viable resource for electricity generation in Jordan. A 1 MW pilot demonstration project using municipal solid waste (MSW) through landfill and biogas technology systems was constructed and commissioned in 2001. The project was expanded in 2008 to about 4 MW. Jordan plans to introduce about 40-50 MW waste energy power projects by 2020.

2.5 Geothermal

Recently, this resource was investigated by a consulting firm hired by MEMR to evaluate the techno-economic potential of geothermal energy for power generation. The results of the study showed that further deep drilling (up to 3,000 meters) is required in order to judge on the techno-economic feasibility of this resource, where a Road Map showing the required actions and costs was developed for this approach.

2.6 Hydropower

Hydropower resources are very limited in Jordan. The country's only hydropower plant is the King Talal Dam with 7 MW installed power capacity which generates 25 GWh of electricity annually. Hydropower turbines with total rated capacity of 6 MW were also installed at Aqaba Power Station using the available head of returning cooling sea water. Various studies show an additional hydro resource potential of 400-800 MW could be exploited from the 400-meter elevation difference between Red and Dead Seas through the proposed Red-Dead Sea Canal project.

3. Jordan's Energy Strategy

Since the launch of the first Energy Sector Strategy in 2007, Jordan's vision has been to integrate renewables into its energy mix, with targets of 7% and 10% by 2015 and 2020 respectively. Due to the country's dependence on subsidized and low cost natural gas imported from Egypt, Jordan's government had failed, as of 2011, to initiate any meaningful progress in renewable energy and energy efficiency despite the obvious strategic importance of the same in providing energy security and establishing the basis for economic development.

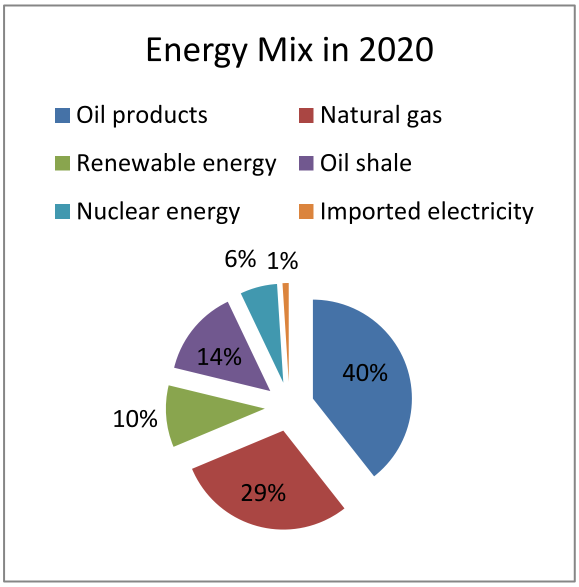

Figure 3: Projected energy mix in the year 2020

Jordan has not been in a strong financial position to support RE projects as a result of cheap natural gas supplies, while the nuclear industry - despite a lack of support from parliament - has received significant investment on the false promise of cheap and abundant energy. Exacerbated by the increasing cost of power generation as reported by the government, (up to 184 fils per kilowatt-hour that is equivalent to USD 0.26/kWh) due to the disruption of cheap Egyptian gas supplies, the urgency of developing RE has escalated dramatically.

The cost of power generation for the National Electricity Production Company has steadily increased from a low of approximately 5-7 USD cents/kWh (for base load gas generation) and a blended cost of generation of 10 USD cents/kWh in 2010, to today's high of 25 USD cents/kWh [4]. Very little of this increase has been passed on to the consumer due to socio-economic pressures. This has greatly affected Jordan's balance of payments, and has forced the kingdom to initiate plans for importing LNG, to fast-track energy efficiency programs, and to focus on RE on a more urgent basis.

One important component of the National Utilization Strategy is the formulation of renewable energy legislation. The Renewable Energy Law was approved in 2011 provides a legal mandate for the government to implement the following:

- New renewable energy regulatory frameworks related to electricity market and grid access
- Energy facilities
- Fiscal and non-fiscal incentives for renewable energy investors and local technology manufacturers
- Green power promotion and creation of Renewable Energy and Energy Efficiency Fund

Subsequent by-laws issued by the Electricity Regulatory Commission in early 2012, aimed to facilitate the development of RE at a pace much slower than the private sector would have liked. The new by-laws, that empower the law, provide for several important instructions pertaining to:

- Connecting distributed RE projects to the grid, thereby allowing for net-metering.
- Connecting utility scale RE projects to the grid.
- Benchmark pricing for accepting unsolicited proposals for utility scale RE projects.

While the by-laws are important, they have not been tested, and there is considerable room for their improvement. For example, net-metering is not economical for some segments of the economy, such as industry, that have very low electricity tariffs, and hence some additional form of support will be required in the form of Feed in Tariffs. The reallocation of subsidies from conventional to renewable energy has not yet taken place and will be a gradual process given that Jordan's future cost of conventional energy generation could decline with imported or domestic gas finds. The Ministry of Energy and Mineral Resources (MEMR) is progressing projects through an Expression of Interest (unsolicited proposals) framework that has attracted over 30 developers (proposing 1 GW of projects), and also through the planned tender of several projects supported by international lending organizations, including a 100MW CSP project and planned 200-300MW wind pooling project. The government had previously tendered several wind projects (such as Kamshah and 100 MW Fujeij) that failed to progress or were delayed due to inherent weaknesses in project planning.

• Several financing programs have also been launched to support renewables and energy efficiency including:

• The allocation of approximately $300 million from the Gulf Cooperation Council soft loan package to Jordan for supporting renewable energy projects.

• Launch of a public-sector energy efficiency fund together with German finance institution KfW to the tune of 30 million Euro to support efficiency measures on 700 public buildings.

• Mobilisation of the European Bank for Reconstruction and Development (EBRD) in Jordan with a partial focus on supporting renewables.

• The launch of micro-loans through the Development and Employment Funds for small scale systems.

• The placement of emphasis on renewables for projects supported by the Governorate Development Fund.

• The creation of the Renewable Energy and Efficiency Fund and its seeding with some$7 million in grant funding.

Due to the lack of Egyptian gas and the reliance on market-priced fossil fuels, the drive to kick-off renewable energy projects has not been stronger; however, it has been mired with bureaucracy and limited government capacity where quicker and more decisive action is needed. Today and for the coming two to three years, electricity costs can clearly be substituted by RE at no cost to the government. However, with the prospects of gas-based power generation whether from imported LNG (by 2013/2014) or from domestic supply of natural gas (by 2018) in the Risheh field, the burden of committing to a fixed-price 25 year RE power purchase agreement (PPA) seems daunting, yet necessary.

3. Jordan's Nuclear Energy Program

Jordan has been pursuing the option of nuclear power for several years. An agreement with France was announced in 2008 to supply a reactor to Jordan between the French reactor vendor, Areva, and the Jordan Atomic Energy Commission (JAEC), signed by President Nicholas Sarkozy. The reactor was expected on-line in 2015. By March 2009, four vendors had expressed an interest in supplying reactors to Jordan: Areva, offering the Atmea1 design (1000-1150MW) developed by a Mitsubishi/Areva joint venture, Atmea; the Korean Electric Power Corporation (KEPCO) offering either the 1400MW APR1400 PWR or the 1000MW OPR PWR; a Russian design not then specified; and a Canadian design also not then specified. It was expected that the vendor and technology would be selected by early 2011. By then, the target of completing the first reactor by 2015 had slipped to 2018. In 2009, Jordan had also signed a Memorandum of Understanding with Rio Tinto to develop its uranium reserves [9-10].

In May 2010, Jordan rejected the Korean options amongst others, shortlisting the Atmea1 design, a Candu design, Atomic Energy of Canada Limited's (AECL) 700-MW-class Enhanced Candu 6 Pressurised Heavy Water Reactor (PHWR) and the Russian Atomstroyexport (ASE) 1050MW AES92. A larger more modern design from Russia, AES2006, was rejected because the site proposed, near Aqaba and the Red Sea did not have a strong enough grid to accommodate larger units.

By 2011, the target completion date had slipped to 2020 and the site near Aqaba had been abandoned, on grounds of its high seismicity, in favour of Al Majdal, about 25 miles north of the capital Amman. JAEC said that vendors had to include innovations in reactor design to take account of the special needs of Jordan. These included enhanced ability to withstand earthquakes and the need to take account of Jordan's limited water resources, which had implications for the cooling method. JAEC also said the design would need to include the ability to withstand a large commercial aircraft crash and minimize the size of the exclusion zone around the plant.

In the wake of the Fukushima disaster, JAEC announced key new requirements for Jordan including: 'capability to shut down the reactor and maintain safe shutdown; continued operation of emergency core cooling and residual heat removal systems; structural integrity of containment, spent fuel pool and buildings housing important safety functions; exclusion of any fire or explosion hazard inside the containment, fuel pool or other safety-important buildings; and "respect of safe radiological limits" in case of any release of radioactive material to the environment.' Also, there would be a need for a 'core-catcher' and the cost of a reactor would be $4900/kW excluding finance costs.

In May 2012, the JAEC announced that it had eliminated the Candu option and that the Areva/Mitsubishi Atmea1 and ASE AES-92 were the best qualified options. Nucleonics Week reported that: its [the Jordanian nuclear project] financial viability depended on Jordan's attracting a strong strategic partner or partners, but that this process was proving difficult.'

In June 2012, the Jordanian Parliament voted to suspend the country's nuclear power and uranium mining program pending completion of economic feasibility and environmental surveys. In October 2012, the Jordanian government announced the termination of an agreement with Areva to develop Jordanian uranium resources.

3.1 Design

Neither of the two designs shortlisted has undergone a comprehensive safety review carried out by a credible, experienced international safety regulatory body. Areva's Atmea1 plant has not been designed in detail yet and, if as present, it has no other serious customers, Areva may decide not to incur the expense. The AES-92 has only been offered for sale in India and after a construction program of 10 years, the plant is still not on-line. It is not clear what regulatory reviews this design has undergone, nor what design changes would be needed to bring it up to current international standards.

3.2 Economics

In Europe and North America, it is now widely accepted that even for a very experience user, nuclear power does not represent a cheap source of electricity. None of the current generation of nuclear power plant designs is in service yet and so it is too early to determine how expensive they will be. Jordan's lack of experience and the special requirements of the Jordanian situation, for example, political insecurity, specific siting requirements such as cooling water, inadequate grid size etc., mean that a Jordanian reactor will inevitably be significantly more expensive than a similar reactor in Europe and North America.

3.3 Commercial Issues

Jordan does not have the capability or experience to operate a nuclear power plant so it is expected that a foreign partner, an electric utility with substantial experience of operating nuclear power plants, would be involved, at least for the first decade, in a 'Build Own Operate' (BOO) or 'Build Operate Transfer' mode and take an equity stake in the plant. There is no evidence that any such partners will be emerge for what would appear to be a financially risky venture with the scope to cause serious reputational damage.

Obtaining the finance needed to build the plant appears a major problem with Jordan unlikely to be able to obtain finance by itself because of its poor credit rating. There is speculation the French or Russian governments may be persuaded to offer loan guarantees that would mean financiers would have much greater certainty of having their loans repaid. However, in the current financial climate, government Treasuries will be very reluctant to increase their national debts and will be reluctant to allow them.

3.4 Design issues

The geographical and geopolitical position of the plant mean it will require additional features to protect it from the potential man-made and natural hazards it could come up against. At best, these will incur major extra costs in construction and operation, and at worst will result in a plant that is vulnerable to such hazards.

3.5 Cooling water

One of the particular issues for Jordan, particularly for the Al Majdal site, is the lack of availability of cooling water. Nuclear power plants require large quantities of cooling water, usually from a large river, the sea, or a large lake. For the Al Majdal site, it is proposed that 'grey water' is used following the Palo Verde model.

Palo Verde is a nuclear power station in New Mexico comprising three reactors each of about 1300MW. Palo Verde is the only large nuclear plant cooled using waste water, using the 91st Avenue Waste Water Treatment plant. One of its owners states : 'it uses treated effluent from several area municipalities to meet its cooling water needs, recycling approximately 20 billion gallons [75 billion litres] of wastewater each year.' For Al Majdal, it is proposed that the Khirbet Al Samra Wastewater Plant be used to provide the cooling water. A full evaluation of the issues raised by use of waste water as a coolant is beyond the scope of this paper but it would require use of: 'adding secondary filtration that may be required, the need to select materials capable of coping with gray water's higher corrosion potential, and special chemical treatment requirements'. How far use of water from the Khirbet Al Samra for cooling would compromise the use of the water for irrigation is not clear.

3.6 Security issues

Inevitably a particular concern for a plant sited in Jordan will be security and the potential for the reactor to be a target for sabotage. Issues that will need careful consideration include:

• The ability of the reactor shell to stand up to impact from a missile or an aircraft;

• The vulnerability to interruptions in the cooling water supply;

• Interruptions to the external power supply;

• Non-availability of the reactor's on-site back-up power sources.

In addition to these man-made hazards, the siting of the plant in an area of relatively high seismic activity will require additional measures to ensure the integrity of the plant in the event of an earthquake of the largest plausible magnitude. Also, there will be significant additional costs over and above those required for a reactor sited in a less sensitive position.

3.7 Grid strength

A nuclear power plant of 1000-1100MW would be by almost an order of magnitude be the largest unit on the

Jordanian power grid, where, in 2010, the largest unit was 130MW. The National Electric Power Company reported that in 2012, total generating capacity was 3186MW and demand was about 15.1TWh. It is assumed by the government that by 2020, capacity would have grown to about 5000MW and if demand were to grow at the same rate, demand would be about 24TWh. This would mean a nuclear unit of 1100MW would comprise about 22 per cent of capacity and, assuming a load factor of 85 per cent, would account for 34 per cent of demand. This degree of reliance on only one generator is far higher than would be considered prudent elsewhere. The IAEA's advice on grid stability states : 'A practical limit to the sudden loss, and hence of the maximum capacity of a single generating unit, is around 10% of the minimum system demand' [10].

The IAEA also states: If an NPP is too large for a given grid the operators of the NPP and the grid may face several problems:
• Off-peak electricity demand might be too low for a large NPP to be operated in baseload mode, i.e. at constant full power.

• There must be enough reserve generating capacity in the grid to ensure grid stability during the NPP's planned outages for refueling and maintenance.

• Any unexpected sudden disconnect of the NPP from an otherwise stable electric grid could trigger a severe imbalance between power generation and consumption causing a sudden reduction in grid frequency and voltage. This could even cascade into the collapse of the grid if additional power sources are not connected to the grid in time.

3.8 Overall evaluation

It seems likely that the issues raised above will mean that the Jordanian nuclear power program will prove not to be feasible. However, it remains to be seen how long it will take for the government to bow to the inevitable. It has already spent four years pursuing an option, nuclear power, that is likely to prove infeasible and this is time and resources that was not available to other resources more likely to meet Jordan's priorities of ensuring reliable, affordable and environmentally sound electricity supply.

There is also the issue of the diversion of valuable human resources, talented young Jordanian engineers and scientists, away from productive sectors to the nuclear project. These 'opportunity' costs may well be more significant than the actual financial costs.

4. Methodology of the Hierarchy Analysis

In order to model multi-objective energy resources alternatives in Jordan, Saaty's AHP was adopted [11]. The model can be applied by breaking down the complex unstructured scorecard problems into component parts. Value tree structures are formed in order to arrange these attributes into hierarchical orders. Numerical values are assigned to represent subjective judgments on the relative importance of each part. These judgments are then synthesized via the use of eigenvectors to determine which variables have the highest priority. A finite number of values to rank (scale) the importance is assigned. AHP scale ranges from 1 (to denote equal importance of two attributes) to 9 (to represent an absolute importance of one attribute over another). The ranking system used by AHP is presented in figure 4. After the problem is decomposed to a tree or "hierarchy" of components of various levels, a pairwise comparison is carried out from the top level to lower levels. Then after each comparison, a "consistency" check is made to enable the analyst to revise his/her weights so as to obtain a consistency value below 0.1.

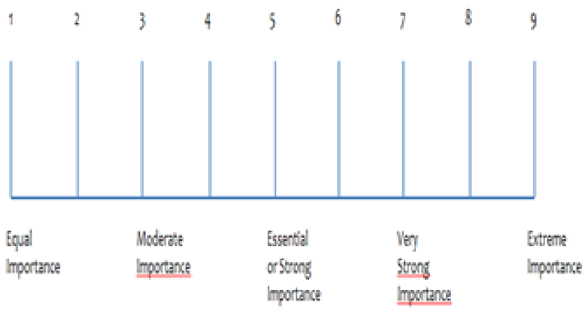

Figure 4: Ranking scale of the AHP adopted by Saaty [11]

There are five basic steps in applying the AHP in practice [11]:

1. Structuring the decision hierarchy.
2. Collecting data by pairwise comparisons.
3. Checking consistency of material judgments.
4. Applying the eigenvector method to compute weights.
5. Aggregating the weights to determine a ranking of decision alternatives.

Applying the AHP approach to cost-to-benefit analysis requires separating costs from benefits and constructing separate hierarchies for benefits and costs. The benefits hierarchy assigns decision criteria. The category weight is used to adjust the overall weight of each benefit criterion. After alternatives are evaluated with respect to all benefit and cost criteria, an overall benefit weight and a cost weight are determined for each alternative. Benefit cost ratios are formed to facilitate the final selection of alternatives. Using this approach to cost-to-benefit analysis can improve this type of decision-making tool by employing the pairwise comparison scale to quantify non-financial factors.

The primary advantage of the basic AHP approach is its simplicity; once the criteria are agreed upon, and supporting data are collected for each alternative, the AHP analysis can be processed. Sensitivity analysis can be used to test the solution, and examine how changes in criterion weights would alter the weights and rankings of the individual alternatives.

The decision regarding the selection of an optimum energy source in Jordan was evaluated according to its benefits and costs. The benefit and cost hierarchies were considered separately, and cost-to-benefit ratios were obtained. The benefit and cost hierarchies were constructed as shown in Figs 5 and 6, respectively. The overall objective for both hierarchies was to select an optimum energy source system. As shown in Fig. 5, the benefits hierarchy includes all possible benefits that may be derived from various energy sources. The benefit criteria at level 2 are efficiency, reliability, availability of fuel, national economy, national security, and safety.

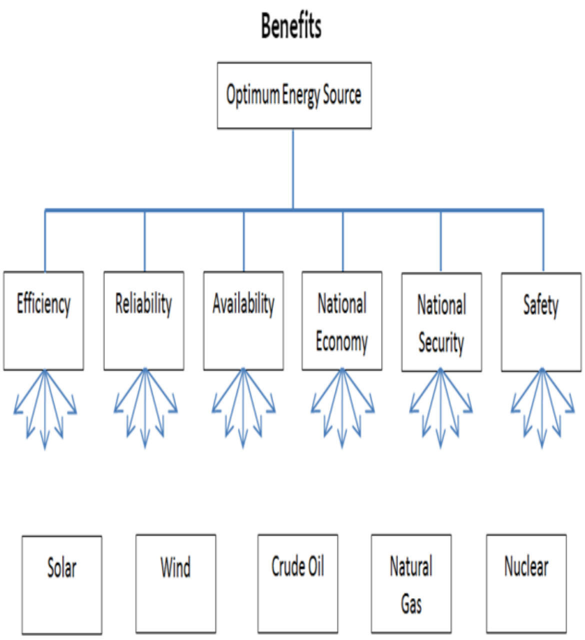

Figure 5: Benefits hierarchy diagram

Thus, the measurement of potential benefits from a particular energy source exceeds, in scope, the financial return on that system and encompasses its contribution to the overall benefit of the nation. These socio-economic gains are represented by the criteria of the national economy and social benefits.

Figure 6 shows the cost hierarchy. The cost criteria at level 2 are cost of fuel, hardware cost, maintenance and service, auxiliary system, and environmental constraints. All items in the cost criteria can be related in terms of cost or money-value, apart from one item which is very difficult to quantify in terms of money, namely, environmental constraints, which measures the effect of an energy source on the environment, directly or indirectly. The third level of the benefit and cost hierarchies represents the available energy resources as identified in the national strategic plan in Jordan. The selections of these alternatives were based on the data available in the annual report of the ministry of energy and mineral resources and its strategic plan. These resources are solar energy, wind energy, crude oil, natural gas, and nuclear power.

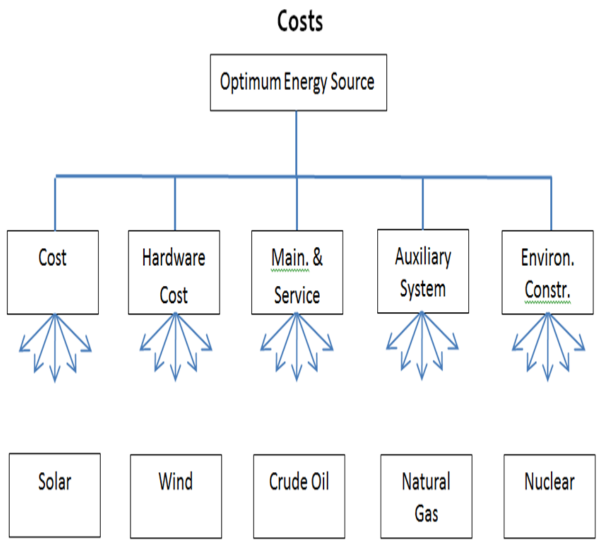

Figure 6: Costs hierarchy diagram

In order to establish the priorities (weights) of the alternatives in both the benefit and cost hierarchies, pairwise comparisons were necessary i.e. to compare the alternatives in pairs against a given criterion. Figure 4 shows the scale developed by Saaty [11] for a pairwise comparison. It defines values l-9 assigned to judgments in comparing pairs of level 3 against a criterion in the second level of both the benefit and cost hierarchies.

5. Results and Discussion

The benefit hierarchy results show that, based on efficiency and reliability, solar was the least efficient and reliable. However, in terms of availability of fuel, national economy, national security and safety, it was the most beneficial among all other resources.

The cost hierarchy shows that nuclear power would have the highest hardware cost, it has the highest need of an auxiliary system, and it has the highest environmental constraint. However, in terms of cost of fuel, maintenance and service, and environmental constraints, solar energy costs the least.

The overall cost priorities (weights) and the overall benefit weights are shown in Figure 7. Nuclear power has the highest cost; considering the cost of fuel, hardware cost, maintenance and services, auxiliary system such as cooling water and the environmental constraint, the relative overall cost weight for nuclear power is approximately 80% compared to 10% for solar energy. When we normalized these numbers, the cost to benefit ratio for nuclear power is 205% compared 19% for solar energy.

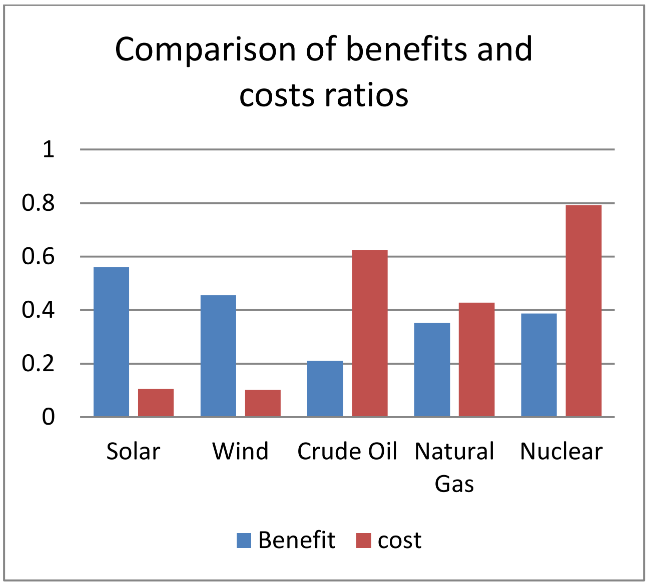

Figure 7: Comparison of befits and costs of different energy source

6. Conclusions

Based on the Analytic Hierarchy Process, the solar energy was the most inexpensive source of energy, while nuclear power is the most expensive. By considering cost-to-benefit hierarchies, the solar energy was still the most inexpensive and crude oil was the most expensive. In conclusion, we can say that the solar energy is the most desirable energy resource to be used in Jordan. As nuclear power has the highest cost among all other options, it seems likely that the Jordanian nuclear power program will prove not to be feasible.

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