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Multi-criteria selection of electric power plants using analytical hierarchy process

Bilal A. Akash [a,*], Rustom Mamlook [b], Mousa S. Mohsen [a]

[a] *Department of Mechanical and Industrial Engineering, Applied Science University, College of Engineering, Amman 11931, Jordan*
[b] *Department of Electrical and Computer Engineering, Applied Science University, Amman 11931, Jordan*

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Abstract

This paper uses analytical hierarchy process (AHP) methodology to perform a comparison between the different electricity power production options in Jordan. The systems which were considered, in addition to fossil fuel power plants, are nuclear, solar, wind, and hydro-power. Results on cost-to-benefit ratios show that solar, wind, end hydro-power may be the best alternatives for electric power production. Nuclear electricity turns out to be the worst choice, followed by fossil fuel electric power. © 1999 Elsevier Science S.A. All rights reserved.

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1. Introduction

Jordan is a non-oil producing Middle-Eastern country. It relies heavily on importing oil from neighboring countries. Most of the electric power that is generated to serve different sectors of the country is produced from power plants that use fossil fuel. This fuel is either totally imported such as petroleum hydrocarbon fuel, or partially local (only with small percentage) such as natural gas. The 1996 electrical energy consumption in Jordan reached a value of 6000 GWh. About 93% of this amount was produced by the National Electric Power Company (NEPCO) which is the main electricity supplier in the country [1]. Other options or alternatives of energy sources for electric power generation must tee considered. These options may include nuclear, solar, wind, or hydro-electric energies. The Jordanian experience with electricity generation using solar and wind energy technology has been on the small and experimental scale. These renewable energy systems were utilized in mostly remote areas of Jordan. They are used to generate electric power for individual application such as clinics, lighting, and educational television sets. The remote village of Jurf Eldaraweesh located in the Jordan desert of a population of 600, is the best example [2]. The necessary electrical energy is totally supplied by solar and wind energy conversion systems.

In this paper, oil-fired power plants in addition to other alternatives are being evaluated. The other alternatives include nuclear, solar, wind and hydro-power. A brief description of various power plant technologies will be presented. Using a decision-support system through a multiple criteria analysis, such as AHP, an attempt will be made to assist decision makers to evaluate the use of the above technologies which can be most suitable for electrical power production in Jordan.

2. Fossil-fuel electrical power plants

In general, fossil fuels are non-renewable. They originate from the earth as a result of decomposition and chemical conversion of organic materials. They come in three organic forms: (1) solid, e.g. coal and oil shale; (2) liquid, e.g. most petroleum products, and (3) gas, e.g. natural gas. Coal represents the largest fossil-fuel energy resource in electric power generation [3,4]. Oil shale is a fossil fuel that exists in Jordan in abundance, but with unattractive physical properties. First, like all

* Corresponding author. Tel.: +962-6-5237181; fax: +962-6-5322899.

E-mail address: bakash@go.com.jo (B.A. Akash)

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Table 1
Jordan's electric power plants

Location	Maximum power rating (MW)	System	Fuel
Zarka	363	Steam turbine	Fuel oil
	32	Gas turbine	Gas oil
Aqaba	650	Steam turbine	Fuel oil
Central Aqaba	22	Internal combustion engine (I.C.E.)	Gas oil
Marka	72	Gas turbine	Gas oil
	30	I.C.E.	Gas oil
South Amman	60	Gas turbine	Gas oil
Risha	120	Gas turbine	Gas oil
Karak	18	Gas turbine	Gas oil
	4.5	I.C.E.	Gas oil
Rehab	160	Gas turbine	Gas oil
King Talal Dam	4	Hydro	Hydro
Jurf Eldaraweesh	0.3	Wind	Wind
Hofa	1.1	Wind	Wind
Other small power plants	73	Steam turbine	Fuel oil
	45.5	I.C.E.	Gas oil

oil shales, it has a low heating value due to the high ash content [5]. Secondly, the Jordanian oil shale has sulfur contents, ranging 4–6% [6]. Because of low prices of petroleum world wide the utilization of solid fossil fuels, such as oil shale, cannot be feasible at the time being. Therefore, oil shale power plants can not be considered to be competitive [3]. Petroleum and natural gas are the main fuels used for the electric power generation in Jordan in addition to small hydro-powered electricity generation plants. Table 1 represents the existing electrical power plants in Jordan [1].

3. Electricity power production using solar energy

Since the 1970s solar energy has received the greatest attention of all renewable energy sources all over the world. Many regard it as the solution for cleaner environment and may be the alternative to fossil and nuclear fuels. Thus, solar energy has been the object for production of electrical power. Many studies and experiences have shown that solar thermal power plants are one of the most economic forms of solar electricity generation. Solar energy can be converted into electricity by photovoltaic cells, but this process is mostly convenient and suitable for small applications only. Stand alone photovoltaic power systems were proposed for electrification of remote areas of which they are located outside the electricity grid-connection supply system [7]. On the other hand, solar energy can be converted into thermal energy by means of solar collectors or concentrators. A working fluid is used to convert the thermal energy into mechanical energy which is then converted into electricity. Unlike photovoltaics, large amounts of electrical power can be generated from such plants. The types of receivers that can be seriously considered are: (1) central receivers, (2) dispersed or distributed receivers and (3) solar ponds.

Like most countries of the Middle East, Jordan enjoys long periods of sunshine. The local weather has over 300 cloudless days per year. Future technology suggests that the Dead Sea itself can be used as 450 km^2 solar lake, operating a 2500 MW power plant [8]. In a recent study, the potential of using the Dead Sea as a large natural solar pond for generation of electricity in Jordan was explored [9]. Kribus et al. [10] have shown new solar power plant concept by incorporating new developments of solar power optics, high performance air receivers, and solar-to-gas turbine interface. In terms of economical point of view, Kolb [11] found hybrid power towers to be superior to solar-only plants with the same field size. There is a number of solar thermal power plants in operation around the world. They are found to be one of the most economical

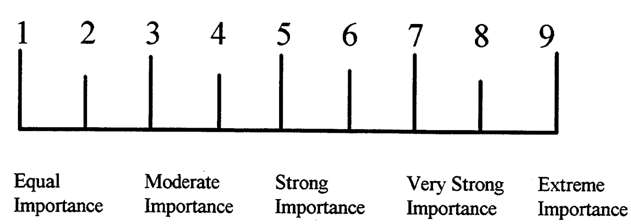

Fig. 1. Pairwise comparison scale.

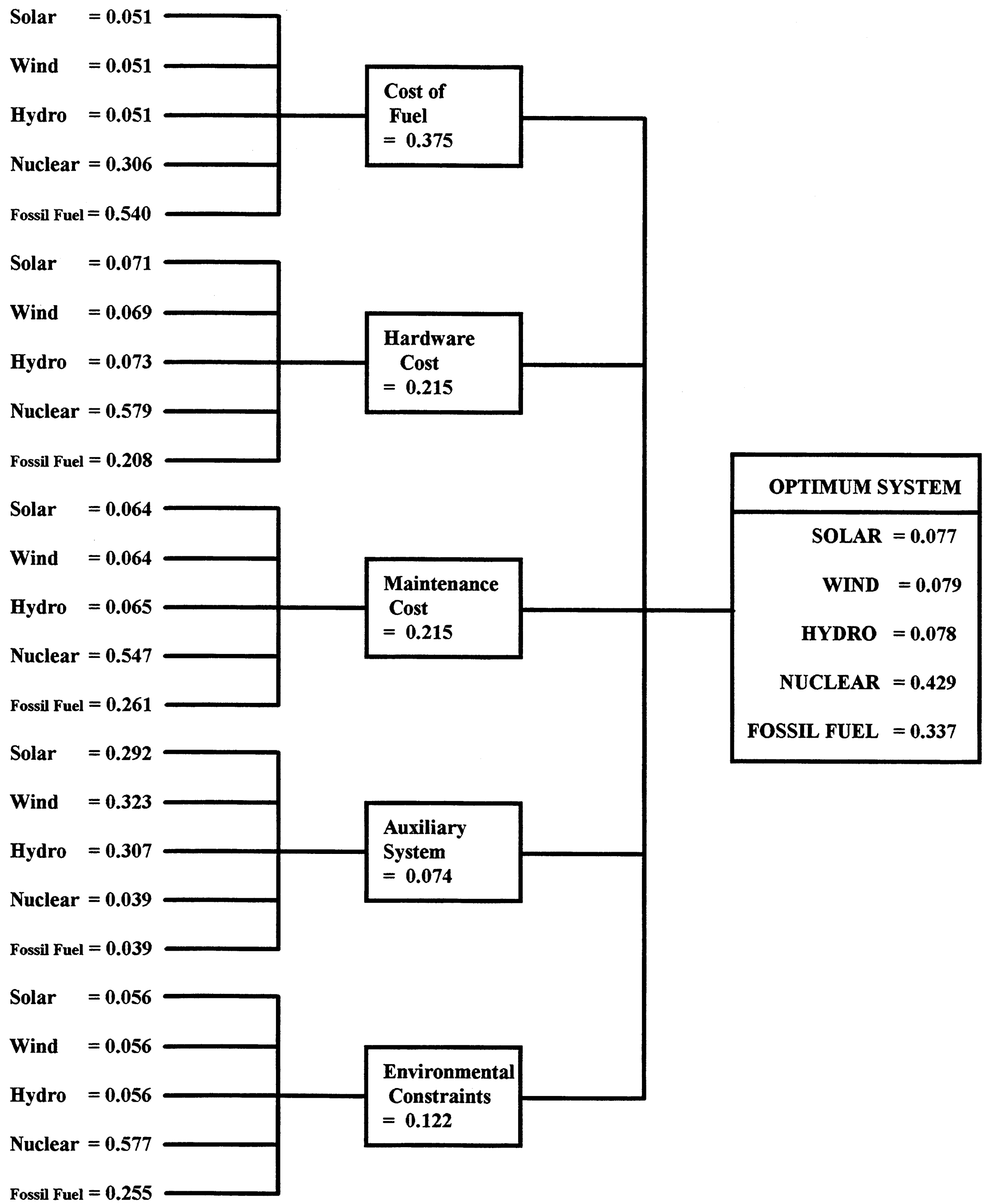

Fig. 2. Costs hierarchy diagram.

systems for generating electricity [12,13]. Recently, the co-generation of electricity and potable water by utilization of solar energy was carried out [14,15]. This kind of system looks attractive in remote areas where both water is scares and electricity grid is not available. The system is capable of producing 30 MWe or more.

4. Electrical power production using wind energy

It is very well established that wind energy resource is large and globally widespread. For different applications, it is clear that wind energy can be competitive in many locations [16–18]. Wind energy can be used in many applications such as water pumping [19], and water desalination [20]. It can also be used for the electrical power generation using wind energy conversion system [21]. Wind power is expected to be one of the least expensive forms of new electrical generation in the twenty-first century [22].

With global efforts to become tough on fossil fuel related energy systems and to reduce the emissions of

CO_2 significantly, this will most likely introduce lower cost wind systems. For example, large wind power plants at good wind sites using emerging technologies can deliver electricity into utility grid at low prices that are becoming competitive with those of conventional power generation. Wind power plants can use hundreds

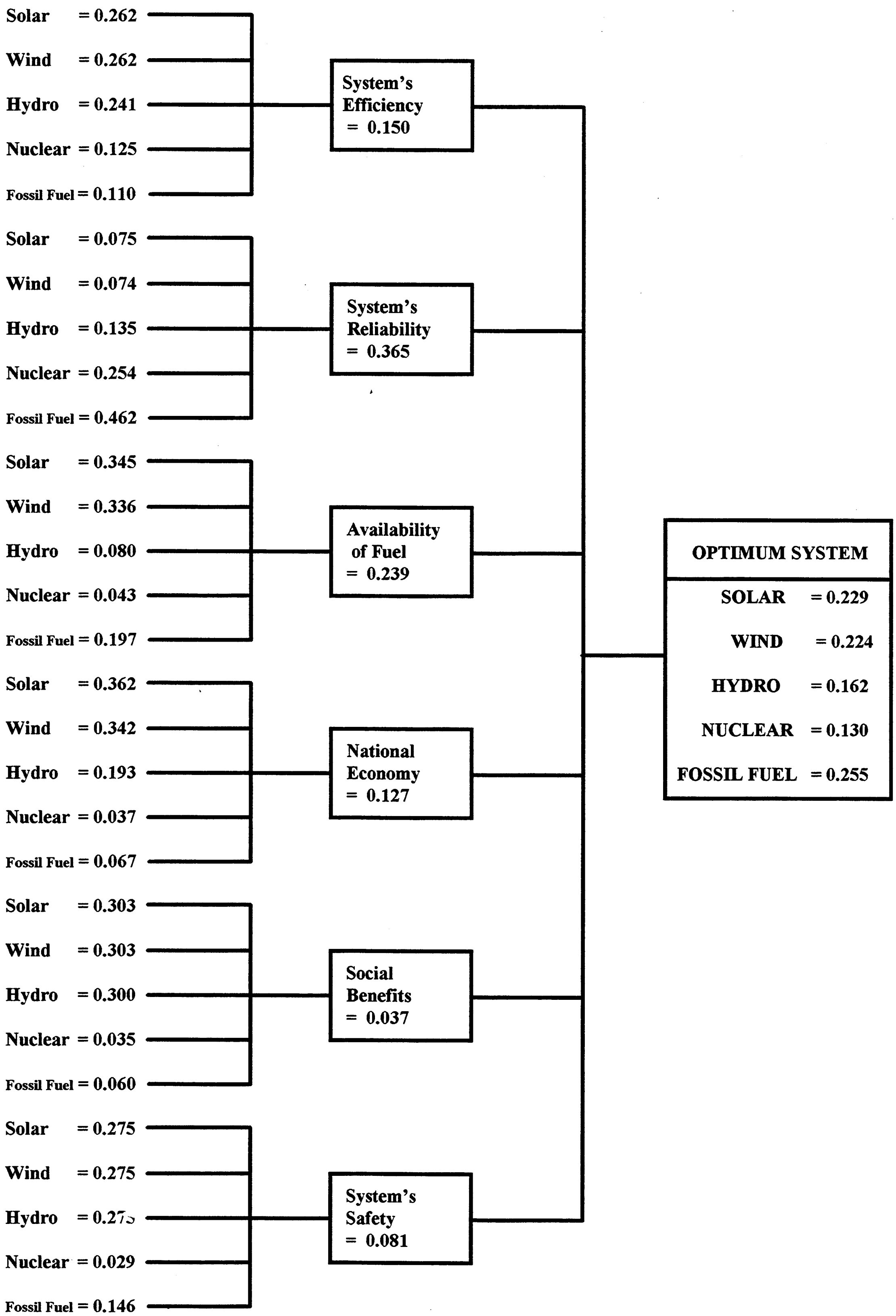

Fig. 3. Benefits hierarchy diagram.

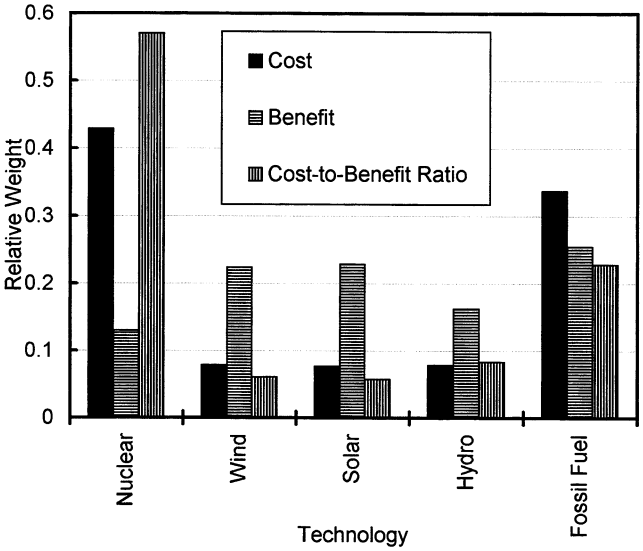

Fig. 4. Comparisons of costs, benefits, and cost-to-benefit ratios.

of wind turbines that range in size from 50 to 500 kW each located in some remote areas. The plant's computerized and control center operates similar to fossil fuel plants, except it does not have to be in sight of turbines. In a recent study a model of wind power plant for isolated location was presented [23]. Increases in the prices of fuel and cost of fossil fuel plants and in relying less on non-renewable energy resources, decrease the value and cost of wind power generation systems significantly [24,25].

There are number of sites in Jordan with potentially high wind speeds, that can be utilized for this purpose [26,27]. Habali et al. [27] have presented an evaluation of wind energy in Jordan and its application for electrical power generation. A total of 11 wind sites were considered covering the entire country. The three most potential sites in Jordan are found to be Ras Muneef, Mafraq, and Aqaba. They have wind speeds that range from 4 to 23 ms^{-1} throughout 80% of the whole year.

5. Hydro-electric power plants

Hydro-electric power plants can provide a basis for evaluating the potential of renewable sources of energy. When compared to other thermal power plants, they are found to be conventional and reliable. Some countries utilize this form of free natural energy into useful type of electrical power. For example, 11% of the electric power produced in the USA was provided by hydro-electric power [4]. Egypt and Turkey, countries of this region, also utilize this type of power for generating electricity at low costs.

A number of studies were involved in utilizing hydro-power in Jordan for the purpose of electricity production [28], water desalination [29,30], and both electricity production and water desalination [8,31]. These studies, mainly, considered the linkage of Red and Dead Seas with a canal to generate hydro-power. The Dead Sea is about 400 m below sea level (BSL), it is roughly 200 km to the north of the Gulf of Aqaba. It is an extension of the Red Sea. The Dead Sea has no outlet; its water level is a function of inflow and evaporation of water. For thousands of years the Dead Sea maintained an equilibrium with the annual inflow and evaporation of water. This resulted in a constant sea level. For example, in 1930 the surface of the Dead Sea was measured at its historical elevation of about 390 m BSL. The Jordan River is considered to be the main tributary of the Dead Sea. Over the years due to increase in population and agricultural development, water was diverted for irrigation in the Jordan Valley and neighboring countries. Therefore, its elevation was forced to drop, drastically; in 1993 it was 408 m BSL. To halt this trend, it will be necessary to introduce a substantial amount of new water to the sea. Sea water from the Red Sea can be used as a source of wafer needed for diversion into the Dead Sea. This diversion can be used to either maintain the sea at its current level and thus stop its dropping, or even to bring it back to its historical level. The power obtained from such process can be used to generate electricity and allow even more fresh water to be diverted from the Jordan River.

The annual amount of water that is evaporated from the surface of the Dead Sea is about 1600×10^6 m^3 [8]. This means that this amount of water can be used in such project to generate about 160 MWe.

6. Nuclear power plants

It is very well known fact that for those countries that rely on but do not have oil, nuclear power becomes a strategic as well as economic necessity [3]. Nuclear power plants can pay for their capital cost in a few short years. Thus, a less expensive electric power can be produced without relying on importing foreign oil, or at least the reduction in oil import. Some believe that one day oil will be depleted, and nuclear power becomes a must. Therefore, it is important to start this technology now in order to assure the country would not be left behind when the time comes to have to use nuclear technology.

Nuclear electricity offers an advantage from an environmental point of view and air pollution. It has less environmental problems that are associated with oil-fired power plants. Thus, nuclear power is bound to become the choice of power for the future. There are some difficulties that are associated with nuclear power, namely, waste disposal and safety. If this kind of energy becomes popular in most countries around the world, solutions to these problem become a must and thus be found.

7. The analytic hierarchy process

The analytic hierarchy process (AHP), which was developed by Saaty [32], has been an effective tool in structuring and modeling multi-objective problems. For example, it has been applied to business decisions [33], selection of areas of research and development programs [34], real estate investments [32], water policies [35], and water desalination technologies [29]. AHP can assist decision makers to evaluate a problem in the form of a hierarchy of references through a series of pairwise comparisons of relative criteria. Briefly, relative weights are determined through pairwise comparison. The method can be applied by breaking down the unstructured complex scorecard problems into component parts. Hierarchical orders are then arranged by forming value tree structures. Subjective judgments on the relative importance of each part are represented by assigning numerical values; the numerical values are selected in accordance to Fig. 1. These judgments are then synthesized in the use of eigenvectors to determine which variables have the highest priority.

The decision regarding the selection of an optimum system for electricity power generation in Jordan was evaluated according to benefits and costs. Cost-to-benefit analysis is obtained by separating costs from benefits and structuring separate hierarchies for benefits and costs. They were constructed as shown in Figs. 2 and 3. The overall objective (goal) for both hierarchies was to select an optimum system (i.e. level 1). Fig. 2 shows the cost hierarchy. The cost criteria at level 2 are cost of fuel, hardware cost, maintenance and service, auxiliary system, and environmental constraints.

Fig. 3 presents the benefit hierarchy, it includes all possible benefits that may be derived from the various electrical power generation power plants, as applied to Jordan. Level 1 of Fig. 3 is the selection of the optimum system in terms of benefits. The benefit criteria at level 2 are the efficiency of the system, its reliability, its safety, availability of the fuel used in the system, its effect on national economy, and social benefits.

The third level of the cost and benefit hierarchies represents the various technologies or alternatives which are going to be considered for electrical power production in Jordan. In addition to fossil fuel fired power plants these systems include nuclear, solar, wind, and hydro-power.

8. Results and discussion

Fig. 2 shows that nuclear and fossil fuel power plants have the highest cost, with relative weights of 0.429 and 0.337, respectively. On the other hand solar, wind, and hydro have much lower values of relative weights in the range of 0.077–0.079. It is based on the cost hierarchy which indicates that cost of fuel has the highest relative weight of 0.375 among all other costs considered. It is followed by hardware and maintenance costs; their relative weight is 0.215 each. Environmental constraints and the need of auxiliary system have the lowest relative weights with values of 0.122 and 0.074, respectively.

Benefits hierarchy (Fig. 3) shows that fossil fuel power plant has the most benefits having a relative weight of 0.255. It is followed by solar and wind power plants; their corresponding relative weights are 0.162 and 0.130, respectively. System's reliability has the highest relative weight of 0.365. It is followed by availability of fuel, system's efficiency, its effect on national economy, safety and then social benefits.

In order to give the complete picture the overall cost priorities (relative weights) were divided by the benefit priorities. An overall normalized cost-to-benefit ratio was obtained for each system. They are presented in Fig. 4. It is shown that nuclear electrical power plants have the highest overall cost-to-benefit ratio, with a relative weighs value of 0.57. Fossil fuel power plants have the second relative weight of about 0.23. The best systems with lowest cost-to-benefit ratios are solar, followed by wind and then hydro having relative weights of 0.058, 0.061, and 0.083, respectively.

9. Conclusions

Based on AHP, solar electrical power plants have the potential to be the best type of system for electricity production in Jordan. They are followed by wind and then hydro-power plants. One can argue that all three technologies or any of the two combined can be used since they have close relative weights. On the other hand nuclear power plants have the worst rating and fossil fuel power plants are some what little better than nuclear.

References

[1] National Electric Power Companys (NEPCO), Annual Report (in Arabic), Amman, 1996.

[2] R. Ta'ani, Renewable energy activities in Jordan, Proc. 4th Arab Inf. Solar Energy Conf. Amman, 1993, pp. 1077–1089.

[3] M. El-Wakil, Powerplant Technology, McGraw-Hill, New York, 1984.

[4] A. Fraas, Evaluation of Energy Systems, McGraw-Hill, New York, 1982.
[5] M. Hammad, Y. Zurigat, S. Khzai, Z. Hammad, O. Mobydeen, Energy Convers. Man. 39 (1998) 269–272.
[6] Y. Khraisha, Energy Convers. Man. 39 (1998) 157–165.
[7] F. Ariza-Lopez, R. Lopez, A. Lopez-Pinto, Solar Energy 61 (1997) 107–118.
[8] M. Murakami, A. Wolf, Int. J. Water Resour. Dev. 11 (1995) 163–183.
[9] R. Haj-Khalil, B. Jubran, N. Faqir, Energy Convers. Man. 38 (1997) 787–798.
[10] A. Kribus, R. Zaibel, D. Carey, A. Segal, J. Karni, Solar Energy 62 (1998) 121–129.
[11] G. Kolb, Solar Energy 62 (1998) 51–61.
[12] O.H. Al-Sakaf, Application possibilities of solar thermalpower-plantsin Arab countries, Proc. 6th Arab Int. Solar Energty Conf., Muscat, 1998, pp. 1–9.
[13] F. Trieb, J. Nitsch, Recommendation for the marketintroductionof solar thermal power stations, Proc. 6th Arab Int. Solar Energy Conf., Muscat, 1998, pp. 17–22.
[14] J. Rheinlander, F. Lippke, M. Schmitz-Goeb, L. Steinmuller, G. Tusel, Electricity and potable water from a solar tower power plant, Proc. 6th Arab Int. Solar Energy Conf., Muscat, 1998, pp. 23–28.
[15] F. Lippke, M. Schmitz-Goeb, A. Finker, PHOEBUS power tower processes with open volumetric air receiver, 8th Int. Symp. Solar Thermal Concentrating Technology, Cologne, 1996.
[16] L. Adell, R. Zubiaur, F. Marun, F. Ferrando, P. Moreno, L. Varona, A. Pantoja, Solar Energy 38 (1987) 281–295.
[17] P. Musgrove, Solar Wind Technol. 4 (1987) 37–49.
[18] M. Pandey, P. Chandra, Solar Wind Technol. 3 (1986) 135–149.
[19] M. Mohsen, B. Akash, Potentials of wind energy development for water pumping in Jordan, Proc. 6th Arab Int. Solar Energy Conf., Muscat, 1998, pp. 445–450.
[20] M.S. Mohsen, B. Akash, Int. J. Energy Res, 22 (1998) 683–690.
[21] W. Kleinkauf, Wind energy converters, control concepts and applications, Proc. 4th Arab Int. Solar Energy Conf., Amman, 1993, pp. 243–254.
[22] R. Thresher, S. Hock, Mech. Eng. 116/8 (1994) 68–72.
[23] B. Fortunato, G. Mummolo, G. Cavallera, Solar Energy 60 (1997) 347–358.
[24] S. Quraeshi, Solar Wind Technol. 4 (1987) 55–58.
[25] S. Quraeshi, B. Pederson, A. Sayigh, Solar Wind Technol. 1 (1984) 45–48.
[26] M. Amr, I. Saleh, R. Ta'ani, S. Habali, Wind as an alternative source of energy in Jordan, Proc. 4th Arab Int. Solar Energy Conf., Amman, 1993, pp. 151–163.
[27] S. Habali, M. Hamdan, B. Jubran, A. Zaid, Solar Energy 38 (1987) 59–70.
[28] Jordan Valley Authority (JVA), Potential for the Development of Hydropower between the Red Sea and Dead Sea, Main Report, Harza Overseas Engineering, Chicago, IL, 1982.
[29] B. Akash, O. Al-Jayyousi, M. Mohsen, Desalination 114 (1997) 1–12.
[30] B. Akash, M. Mohsen, Renewable Energy 14 (1998) 537–542.
[31] M. Murakami, Int. J. Water Resour. Dev. 11 (1995) 391–410.
[32] T. Saaty, The Analytic Hierarchy Process, McGraw-Hill, New York, 1980.
[33] M. Liberatore, T. Monahan, D. Stout, Engineer. Econom. 38 (1992) 31–42.
[34] F. Elkarmi, Instruments for policy formulation regarding new and renewable energy technologies (NRET'S) Proc. 4th Arab Int. Solar Energy Conf., Amman, 1993, pp. 1003–1014.
[35] O. Al-Jayyousi, M. Shatanawi, Int. J. Water Resour. Dev. 11 (1995) 315–330.