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Evaluation of Solar Electric Power Technologies in Jordan

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Abstract

Jordan is considered one of the sun-belt countries, which possesses high solar radiation on its horizontal surface. The present study will be concerned on the uses of fuzzy sets methodology to perform evaluation between the most suitable solar technologies for power generation in Jordan, namely, solar ponds and photovoltaic (PV) technologies. The criterion of the evaluation were based on different parameters, i.e., power capacity, efficiency, availability, capacity factor, storage capability, cost, maturity, land usage and safety, they are planned as the technologies for the near foreseen term.
Based on benefit to cost ratios, the results showed that photovoltaic technology found to be the better choice in terms of generating electricity, research and development and more effective programs of support and installation.

Keywords: Fuzzy Sets Methodology; Solar Electric Power; Control Technology; Benefit to Cost Ratios; Power Plants; Renewable Energy.

1. Introduction

Jordan relies, almost completely, on imported oil from neighboring countries, which causes a financial burden on the national economy (Jaber et al, 2008). Domestic energy resources, including oil and gas, cover only 3–4% of the country's energy needs. Jordan spends more than 7.5% of its national income on the purchase of energy. The levels of energy and electricity consumption will probably double in 15 years, and it is probable that annual primary energy demand will reach $8x10^6$ ton of oil equivalent (toe) by 2010. Jordan accounts an average of $15.85x10^3$ ton of emissions, of which CO_2 constitutes around 97%; fossil-fuel combustion almost producing 85% by mass of the total GHG emissions (Jaber, 2002).

The solar energy flux reaching the Earth's surface represents a few thousand times the current use of primary energy by humans, earth receives 174 peta-Watt of incoming solar radiation at any given time, unfortunately, this huge amount of energy is not well utilized till now.

Electricity production using solar energy is one of the main research areas at present in the field of renewable energies, the significant price fluctuations are seen for the fossil fuel in one hand, and the trend toward privatization that dominates the power markets these days in the other hand, will drive the demand for solar technologies in the near term.

The great importance of electricity from solar technologies is due to the considerable associated benefits (Schott, 2006) (Haas, 2001) (NEPCO, 2006) (Badran, 2001) (Alrobaei, 2008), namely:

- Maximum power generation at peak load hours in hot climate countries like Jordan.
- The modular character of the solar field makes it possible to start at any power level.
- The off grid solar power production for remote locations maybe competitive to fossil fuel power due to the high cost of rural power since it requires to be distributed along far distance.
- Reduction of greenhouse gas emissions;
- Increases in local employment and income;
- enhanced local tax revenues;
- A more diversified resource base,
- Avoided risks of disruption in fossil fuel supply and association price instability
- Provision of infrastructure and economic flexibility by modular, dispersed and smaller scale technologies;
- The potential to greatly reduce, and perhaps eliminate, pollution associated with electricity services
- Contribution towards sustainability.
- Some solar technologies provides other benefits beside power generation i.e., fresh water.

Different types of solar power technologies need further improvements and cost reduction to be competitive with fossil fuel power plants in future power markets. The

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National Renewable Energy Laboratory (NREL) evaluated the potential for the emerging photovoltaic (PV) technologies to meet the solar program's technical and economic targets; they discussed the current structure, capabilities, assumptions and made a linear programming model of capacity expansion plans (Braun and Skinner, 2007) (Blair et al, 2006).

Solar power has the advantage of electricity generation at peak load hours. Hot climate countries, like Jordan, have the highest electricity peak load consumption in demands during the hot summer days as shown in Figure1, (NEPCO, 2006).

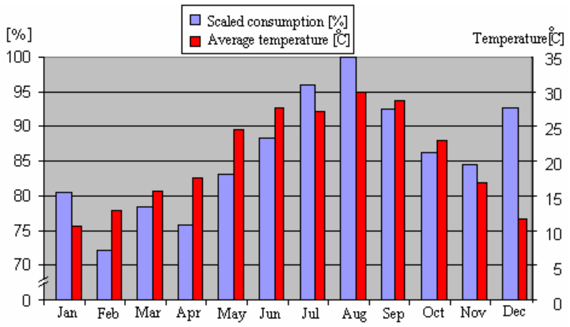

Figure 1. Monthly variations of electricity consumption in Jordan (NEPCO 2006**).**

Solar power plants play an important role in decreasing the environmental pollution; they contribute directly to the CO_2 reduction that caused by the conventional fossil fuel power plants. According to the Greenpeace study, the use of solar power plants can avoid 362 million tons of CO_2 emissions worldwide from 2002 to 2025. (Brakmann et al, 2005).

An evaluation study for different power production systems using fuzzy set methodology was prepared by Mamlook (2006). It shows that the solar power production is the best preferable option under the Jordanian climate in the basis of cost to benefit ratio. He also used the same mechanism under the same Jordanian climate for solar utilization applications; he showed that the solar power production is the second best choice that comes after the solar distillation (Mamlook et al, 2001).

Badran (2001) has studied different solar power technologies. He suggested that the Jordanian government needs to do more serious steps towards the utilization of industrial solar energy for power generation applications in arid regions.

Dead Sea is considered a perfect place for solar pond power plants due to its high salinity. The largest solar pond built so far is in Israel, and used to generate electricity, (Sukhatme, 1996). Other studies by (Khalil et al (1997) presented a theoretical study on the evaluation of electric solar pond power plant under Jordanian climate. Tahat et al (2000) built a mini solar pond in Jordan and studied its thermal performance to show its merits under Jordanian climate.

PV systems have wide range utilization in Jordan. They are used for water-pumping systems, powering radio–telephone stations, as well as supplying electricity to clinics and schools of very small communities in the remote regions (Hrayshat, 2007) (Jaber et al, 2004) (Badran 2001) (Abu-Khader et al, 2008). There are future plans consisting of installation of 1036 PV panels in remote villages (houses, schools, and other public buildings) each panel having an average generating capacity of 1050Wh/day (Hrayshat, 2007). Durisch et al (2007) performed calculations for five commercial PV modules for Al Qawairah site in Jordan and developed efficiency model for them.

In the present study, a fuzzy logic methodology is used to compare between photovoltaic (PV) and solar ponds in terms of their benefits (merits) and costs (barriers). The effect of different parameters on the power production of these technologies was taken from previous studies proposed for Jordanian climate, (Hrayshat, 2007) (Jaber et al, 2004) (Khalil et al, 1997) (Tahat et al, 2000) (Abu-Khader et al, 2008) (Badran 2001) (Durisch et al, 2007).

2. Solar Electric Power Technologies

Solar power technologies can be classified into direct (PV) and indirect electricity conversion, the indirect electricity conversion consists of concentrating and non-concentrating solar power systems (Quaschning, 2003).

2.1. Solar pond

A solar pond does not concentrate solar radiation, but collects solar energy in the pond's water by absorbing both the direct and diffuse components of sunlight; this is good for countries where the sky is frequently overcast. Solar ponds contain salt in high concentrations near the bottom, with decreasing concentrations closer to the surface (Figure 2).

This variation in concentration, known as a salt-density gradient, suppresses the natural tendency of hot water to rise, thus allowing the heated water to remain in the bottom layers of the pond while the surface layers stay relatively cool. Temperature differences between the bottom and top layers are sufficient to drive an organic Rankine-cycle engine that uses a volatile organic substance as the working fluid instead of steam. Temperatures of 90°C are routinely achieved in the pond bottom, and solar ponds are sufficiently large to provide some degree of energy storage. The potential of solar ponds to provide fresh water, heat and electricity, especially for island communities and coastal desert regions, appears promising, but has not been fully investigated (Zumerchik, 2001). Dead Sea is considered largest solar pond on earth, due to its high salinity. The largest solar pond built so far is the 250000 m^2 pond at Bet Ha Arava in Israel. The heat collected in this pond has been used to generate 5 MW of electrical power using an organic fluid Rankine cycle (Sukhatme, 1996). The principle of the collection and storage of solar energy in salt ponds where the salinity increases with depth is introduced, and the six polar ponds constructed by Israel since 1960 to test the theory of solar pond energy conversion are indicated. They examined the electric power, with attention given to the water layers, pumps, evaporator, organic vapor turbogenerator and condenser. The performance characteristics of solar pond power plants, which can be started up in a few minutes and deliver up to ten times or more of their rated output power, are pointed out as the basis for the suggestion that they can be used initially as peaking plants in the power grid. Respect to the Israeli plans, the accumulated generated

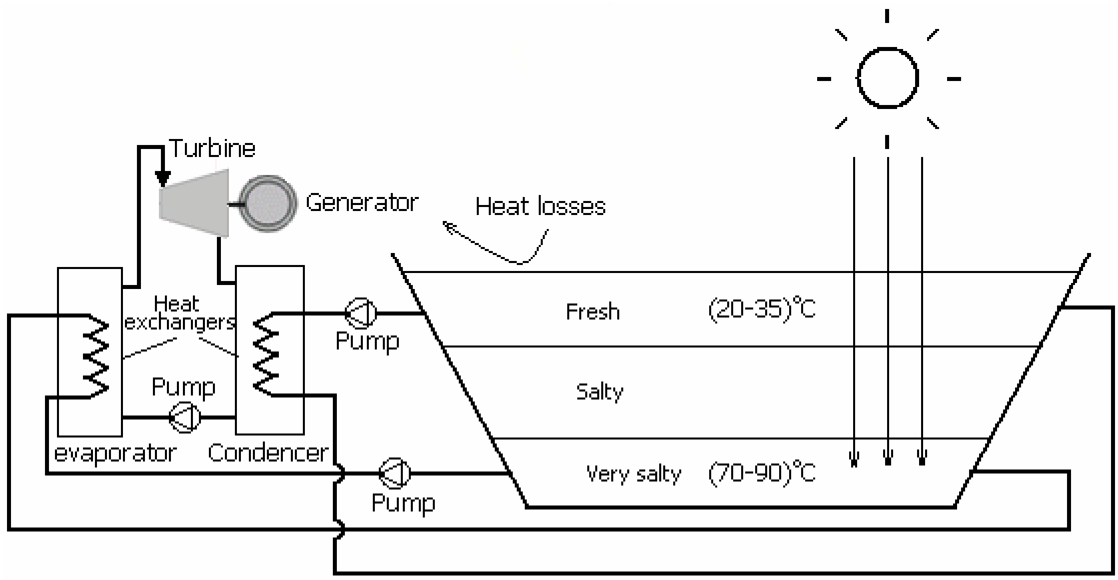

Figure 2. Solar pond power plant schematic for generating electricity

power by solar pond will be up to 2000 MW (Sukhatme, 1996) (Bronicki, 1981). Khalil et al (1997) presented 5 MWe electric solar pond power plant in the dead sea part of Jordan with surface area 1.5 km^2, they found that the solar pond could generate electricy with a levelized cost of 0.234JD/kWh under Jordanian climate.

In India, the first solar pond having an area of 1200 m^2 was built at the Central Salt and Marine Chemicals Research Institute in 1973. Experimental research ponds having areas of 100 and 240 m^2 respectively were operated for a few years at Pondicherry and at the Indian Institute of Science in Bangalore, while a 1600 m^2 solar pond was built in Bhavnagar again in the eighties. The largest pond built in India so far is located at Bhuj (Gujrat). The pond has an area of 6000 m^2. It has been operating since September 1993 and supplies the process heat need of a nearby dairy (Sukhatme, 1996).

2.2 Photovoltaic (PV)

Photovoltaic's (photo for light, voltaic for electricity) converts sunlight directly to electricity. Modules are mounted on a stationary array or on single- or dual-axis sun trackers (Abu-Khader et al 2008). Arrays can be ground-mounted on all types of buildings and structures. The DC output from PV can be conditioned into grid-quality AC electricity, or DC can be used to charge batteries or to split water to produce hydrogen (electrolysis of water) (Aabakken, 2006).

The photovoltaic (PV) market has grown extensively since 1992. R&D efforts, together with market deployment policies, have effectively produced impressive cost reductions: every doubling of the volume produced prompted a cost decrease of about 20%. But market deployment is concentrated: Japan, Germany and the United States account for over 85% of total installed capacity (Figure 3). PV still requires substantial R&D investments, as well as deployment supports, to gain market learning. In the near term, R&D efforts will focus on improving the balance-of-system components for both grid connected and stand-alone applications. Even with these supports, PV is not expected to be generally competitive until after 2025 – although it will continue to compete well in a growing range of market niches in which the cost of deployment supports is moderate (IEA, 2007) (Stierstorfer, 2006).

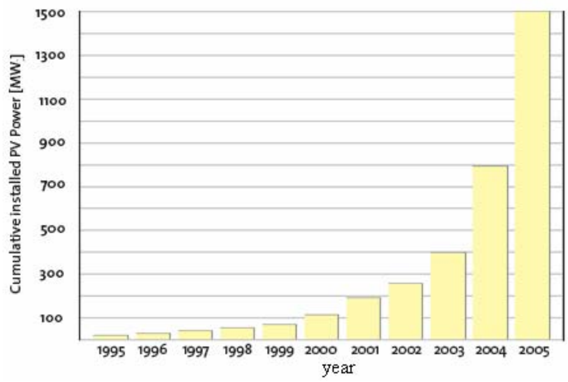

Figure 3. PV annual cumulative installation in Germany

Jordan utilizes PV cells for limited applications (water-pumping systems, powering radio–telephone stations, as well as supplying electrical energy for clinics, (Hrayshat, 2007) (Jaber et al, 2004). There are future plans consisting of installation of large number of PV for power generation connected to the grid line (Hrayshat, 2007), (Badran 2001). Durisch et al (2007) performed calculations for five commercial PV modules in Al Qawairah site in Jordan and developed efficiency model for them.

3. Fuzzy Methodology

After Zadeh's work on fuzzy sets (1965), many theories in fuzzy logic were developed in Japan, Europe, United States, and elsewhere. Since the 1970s Japanese researchers have been advancing the practical implementation of the fuzzy logic theory; they have been commercializing this technology and they have now over 2000 patents in the area from fuzzy air conditioner, fuzzy washing machine, fuzzy toasters, fuzzy rice cookers, fuzzy vacuum cleaner, and many other industrial fuzzy control processes. They have a subway system that is totally controlled by fuzzy computer. It is smooth enough that riders do not need to hold straps, and the controller makes 70% fewer judgmental errors in acceleration and braking than human operators. The U.S. Space Administration has been involved in the use of fuzzy logic in space control decision making. Energy consumption could be analyzed using fuzzy sets (Oder et al, 1993). Also systems could be controlled using fuzzy (Mamlook et al, 1998).

3.1. Determining the linguistic variables and the fuzzy sets.

In order to decide between parameters which are fuzzy, vague, or ambiguous, MATLAB fuzzy toolbox was used to generate decision based on the benefit and the cost for each solar thermal power plant technology.

The fuzzy logic decision selection between PV systems and solar pond technology was applied according to benefits, namely, (B1= power plant capacity or size (MW), B2= Annual solar to electric efficiency, B3= Thermal efficiency, B4= Peak solar to electric efficiency, B5= Availability, B6= Annual capacity factor (CF), B7= storage hours, B8= maturity or popularity, B9= Temperature (T), B10= Safety, B11= Concentration ratio (CR)) to make a decision on the selection between the different solar technologies that cost less and have better benefits. Many factors affect the decision (costs) (Figure 4), i.e., (C1= Hardware cost, C2= Electricity cost, C3= Water usage, C4= Land usage, C5= Maintenance cost, and C6= environmental constrains).

The Fuzzy input/ output combination is shown in the Figure 4 as follows:

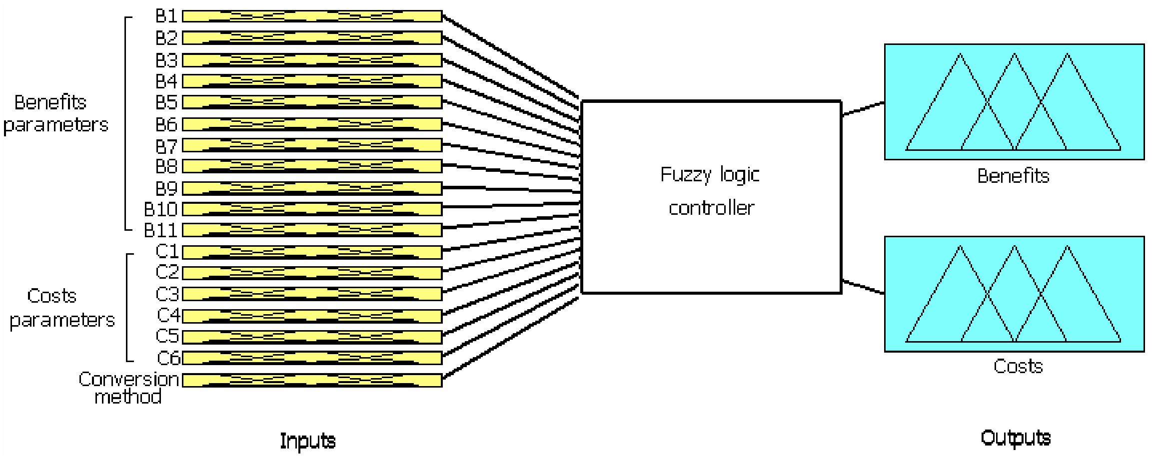

Figure 4. Fuzzy Inputs/Outputs Combination.

The fuzzy logic decision selection of the best solar technology options was applied according to their costs and benefits (Tables 1 and 2).

Table 1. Overall fuzzy weights of solar technologies for optimum benefits.

	Power	Annual efficiency	thermal efficiency	Peak efficiency	Availability	annual CF	storage h	Maturity	T	Safety	CR	Relative weight	Normalized relative weight*
Parameter importance	1.00	0.71	0.71	0.5	1.00	0.50	0.50	1.00	0.71	0.43	0.71	-	-
Pond	0.01	0.1	0.24	0.1	0.8	0.85	0.85	0.2	0.08	1	0.1	0.378	0.71
PV	0.05	0.7	-	0.97	1	0.19	0.42	0.65	-	0.35	-	0.532	1

* Normalized relative weight = relative weight/maximum relative weight

Table 2. Overall fuzzy weights of solar technologies for optimum costs

	Hardware Cost	Electricity Cost	Water Usage	Land Usage	Maintenance Cost	Environmental Constrains	Relative weight	Normalized relative weight*
Parameter importance	0.5	0.5	0.5	0.4	0.5	0.25	-	-
Pond	0.29	0.18	1	1	0.25	0	0.441	0.768
PV	0.84	1	0.05	0.36	1	0	0.574	1.000

* Normalized relative weight = relative weight/maximum relative weight

Data in Tables 1 and 2 are actual data obtained from different literature such as [(Braun and Skinner, 2007) (Schott, 2006), (Brakmann et al, 2005), (Dersch et al, 2004), (Mills, 2004),(Wibberley et al, 2006), (Mukund, 1999) (Porta, 2005), (Zumerchik, 2001), (Aabakken, 2006), (Groenendaal, 2002) (Sukhatme, 1996) (Badran 2001) (Hrayshat, 2007) (Jaber et al, 2004) (Khalil et al, 1997) (Tahat et al, 2000)

The inputs for fuzzy implementation in Table 1 and 2 are considered to be fuzzy variables, each of which can vary over a fixed weight (0-1), the inputs' and output's sets are shown in Figure 5.

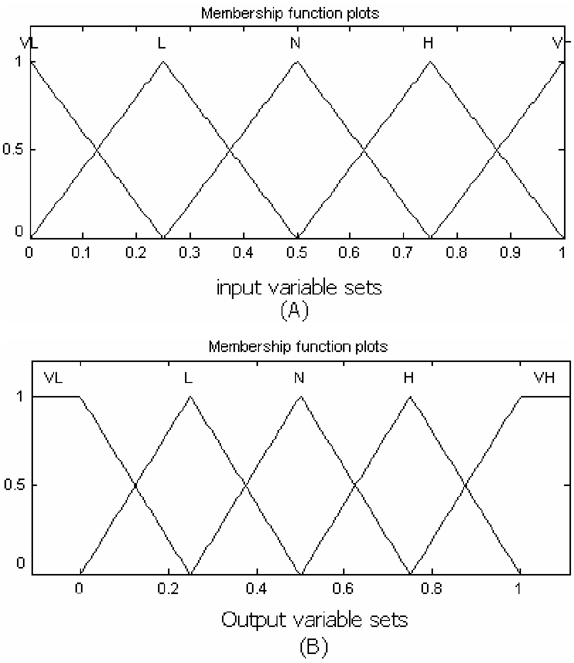

Figure 5. Fuzzy sets, (A) input sets (B) output sets.

The linguistic variables that were used to describe the fuzzy sets in Figure 5 are very low (VL), low (L), normal (N), high (H) and very high (VH).

The "conversion method" input shown in Figure 6 is responsible for determining the solar technology type; whether it is direct solar conversion (PV) or indirect (thermal conversion) excluding the "thermal efficiency", "temperature" and "concentration ratio" to have an accurate decision making as shown in Figure

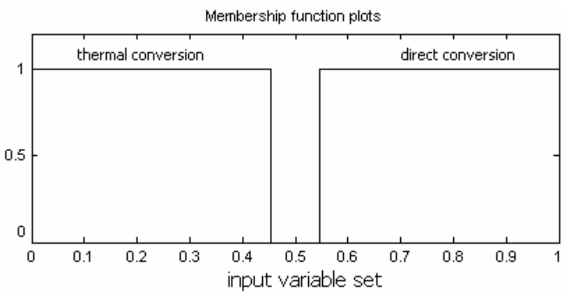

Figure 6. Binary fuzzy sets.

3.2. Constructing Fuzzy Rules

In the present section, 85 rules were used to predict the most preferable option(s) out of the two solar technologies, they are in a statements form as shown in the Figure 7.

1. If (B1 is VL) then (B is VL) (1)
2. If (B1 is L) then (B is L) (1)
3. If (B1 is N) then (B is N) (1)
4. If (B1 is H) then (B is H) (1)
5. If (B1 is VH) then (B is VH) (1)

:

55. If (C1 is VH) then (C is VH) (0.5)
56. If (C2 is VH) then (C is VH) (0.5)
57. If (C2 is H) then (C is H) (0.5)
58. If (C2 is N) then (C is N) (0.5)
59. If (C2 is L) then (C is L) (0.5)
60. If (C2 is VL) then (C is VL) (0.5)

:

80. If (C6 is VH) then (C is VH) (0.25)
81. If (B3 is VL) and (con is thermal__conv) then (B is VL) (0.71)
82. If (B3 is L) and (con is thermal__conv) then (B is L) (0.71)
83. If (B3 is N) and (con is thermal__conv) then (B is N) (0.71)
84. If (B3 is H) and (con is thermal__conv) then (B is H) (0.71)
85. If (B3 is VH) and (con is thermal__conv) then (B is VH) (0.71)

Figure 7. Fuzzy rules.

3.3. Performing Fuzzy Inference into The System

This procedure is used to compute the mapping from the input values to the output values, and it consists of three sub-processes, fuzzification, aggregation and defuzzification (Negnevitsky, 2005) as shown in the following figure.

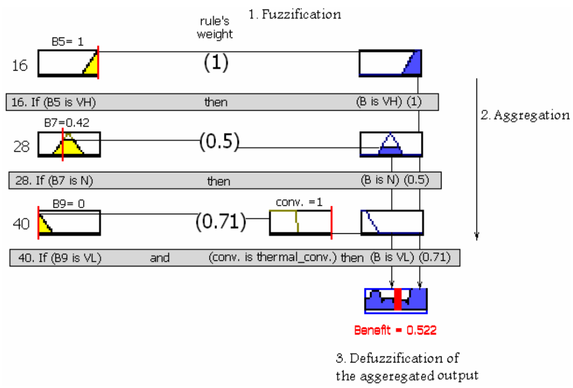

Figure 8. Fuzzy implementation sequence.

4. 4. Results and Discussion

The fuzzy sets enabled us to utilize large amount of collected data to compare between the two solar technologies systems, into a smaller set of variable rules (see Tables 1 and 2).

The benefit to cost ratio is shown in Table 3 as follows:

Table 3. Benefit to cost weight ratio.

Solar technology	Normalized benefits relative weight	Normalized costs relative weight	B/C
Pond	0.71	0.768	0.92
PV	1.000	1.000	1

The final results are shown in Figure 9 as follows:

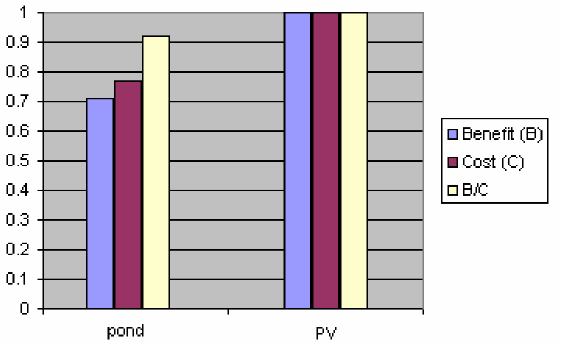

Figure 9. Comparison between benefits, costs and normalized benefit to cost ratios

As can be inferred from Table 3, Fig 9, and from the fuzzy sets analysis, photovoltaic technology (PV) has higher benefit to cost ratio than solar pond and it is considered to be better option for power generation. It has high growing rate in the world wide in spite of its high cost. Solar pond is considered to supply cheaper electricity that PV technology but in the other hand it has lower benefits (Figure 9). This is because the output power is lower in this technology and the maintenance cost is considered to be high, due to high salinity of water. So that the best option according to this study will be PV technology.

5.Conclusions

The foreseeable shortages due to the increased population and the industrial activities in the world, and today's already unreliable and distinctly expensive fossil resources are forcing a diversification of energy sources and driving the demand toward solar technologies in the near term.

Fuzzy logic methodology for evaluating the solar thermal power technology enabled us to condense huge amount of data into smaller sets, it has the ability to decide between different solar technologies in the bases of their benefits and cots. Based on fuzzy logic results, photovoltaic technology (PV) has the higher benefit to cost ratio than solar pond and it is considered to be better option for power generation. PV has high growing rate in the world wide in spite of its high cost. Solar pond is considered to supply cheaper electricity that PV technology but in the other hand it has lower benefits, due to its low solar energy.

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