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Energy Policy 32 (2004) 357–366

ENERGY POLICY

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Medium-range planning economics of future electrical-power generation options

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Abstract

In their continuous planning for load growth, electricity utilities search for the most economic generation schemes. But this will be subject to a number of constraints, such as the type of fuel available and compliance with national environmental standards. In this paper, medium-range planning economics of using alternative fuels options for electrical-power generation systems in Jordan is discussed. Imported natural gas, heavy fuel oil, coal and local oil shale are compared. A net-present-value model was used to compare electricity generation cost for different types of thermal power plants. Sensitivity analysis was performed to determine the influence of the most important variables, such as unit capital and fuel prices, discount and inflation rates. It was found that imported natural gas, as a future primary fuel, to supply new combined cycle and/or upgraded existing gas turbine stations, in Jordan, represents the best option during the study period.

Keywords: Fossil fuel; Generation cost; Thermal power plant; Electricity demand; Jordan

1. Introduction

Electricity utilities usually require that power plants to be available for operation with simple control and low operation and maintenance costs. But, typically, electricity power stations require high capital investments and long construction time of 3–5 years. Usually, they have an average economic life of about 25 years. Therefore, careful planning should be adopted in order to select the most appropriate generation technology and type of fuel to be employed. According to recent studies, electricity demand in Jordan is predicted to grow at an average annual rate of about 6%. The annual rate of electricity demand will reach 13,500 GWh and the maximum peak demand will be approximately 2200 MW by the year 2015 (Jaber et al., 2001a; National Electrical Power Company, 2001). In the future, the dependence on imported energy, such as heavy fuel oil, natural gas or coal, for electricity generation will continue to increase because it is unlikely to have sufficient local natural gas and/or other fossil fuels that can satisfy the total national demand. In Jordan, heavy fuel oil is the prime fuel used to supply thermal power stations, in addition to limited amount of local natural gas that fired directly in small and open cycle gas turbines. There is no experience, locally or within the neighbouring Arab countries, concerning other fossil fuels, such as coal, oil shale and natural gas to fuel conventional steam and/or combined cycles.

In this paper, imported heavy fuel oil, natural gas and coal, which are the most likely fuels that can be employed in Jordan for electricity generation, are compared using the net-present-value analysis. In order to exploit indigenous oil shale deposits, one-generation unit utilising oil shale as the prime fuel is scheduled to come on line during the study period. It is not the aim of the current analysis to discuss issues relating to fuels combustion and their storage or environmental impacts on the global scale. But preliminary and important indicators are derived to draw attention of those working in energy planning and decision-making to predict electricity unit generating costs and possible improvements.

2. National energy supply and demand

2.1. Indigenous energy resources and primary energy consumption

Jordan is a poor country in terms of commercial energy sources. This suggests that Jordan will remain as

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0301-4215/04/$ - see front matter © 2002 Elsevier Science Ltd. All rights reserved.
PII: S0301-4215(02)00297-5

a net energy importing country, spending significant amount of its scarce hard currency resources on such imports. In 2000, oil imports cost was approximately 42% of the total domestic commodities exports and about 10% of the gross domestic product (Ministry of Energy and Mineral Resources, 2001a). Primary energy resources consumed in Jordan include crude oil, natural gas and solar energy. However, imported crude oil and petroleum products constitute more than 96% of the annual rate of energy consumption in 2000 (Ministry of Energy and Mineral Resources, 2001a, b). The domestic natural gas resource, which used to fuel 4×30 MW gas turbines for electricity generation, satisfies less than 4% of the annual energy demand (Ministry of Energy and Mineral Resources, 2000). On the other hand, there are vast oil shale deposits in Jordan. The proven reserves are exceeding 4×10^{10} tonnes, and these are yet to be exploited (Jaber and Probert, 1997; Natural Resources Authority, 2000; Mamlook et al., 2001). In a recent study, shale oil prepared by pyrolysis of Jordanian oil shale was characterised and compared to crude oil and some refined product (Akash and Jaber, 2002). It was shown that shale oil compared well to crude oil and its heavy fractions.

Based on the present and likely future annual energy consumption, these deposits could satisfy national energy demand for several hundred years, if developed and utilised wisely. Thus, such an indigenous resource could have a major role in reducing Jordan's dependence on imported crude oil, petroleum products and natural gas.

2.2. National energy policy in the 21st century

Energy forecasts show that primary energy demand will be about 6, 8 and 10 million toe in the years 2005, 2010 and 2015, respectively, reflecting a rapid trend of increase (Jaber et al., 2001a; National Electrical Power Company, 2001; Ministry of Energy and Mineral Resources, 2001a, b). To meet this substantial growth in demand, large capital expenditures will be needed in all the energy sub-sectors. The main highlights of the Jordanian energy sector, during the study period, includes:

- Demand and supply projections reveal that indigenous primary energy production will decrease in the future, and the share of imported energy will increase progressively.
- As a long-term strategy, it is planned to select imported natural gas as the future fuel for power generation, and this will be included in the energy-mix in 2005.
- In order to reduce the financial burden resulting from importing energy, it is expected that the government will pay more attention towards developing and exploiting indigenous resources. These include the utilisation of oil shale and renewable sources to empower electrical-power plants.
- For planning purposes a capacity of about 100–130 MW could be imported as an additional reserve and considered to be available from the interconnection with Egypt and Syria.

In summary, Jordan will face major challenges in trying to meet the growing energy and especially electricity demands. While, concurrently, developing the energy sector in a way that ensures reducing the adverse impacts on the economy, the environment and social life.

2.3. Electricity generation and consumption

In 2000, the installed capacity was about 1660 MW. Of which 99.99% is thermal and the remaining small percentage represents hydropower and wind turbines. About 65% and 28% of the installed capacity are conventional steam power plants and gas turbines, respectively. The percentage of primary energy consumption that went for electricity generation, in 2000, was equivalent to 1.8×10^6 toe compared with 1.75×10^6 toe during the previous year (National Electrical Power Company, 2001; Ministry of Energy and Mineral Resources, 2001a, b; Central Electricity Generation Company, 2001). Which is considered as the largest single consumer of primary energy in Jordan, of this about 93% was consumed in the Central Electricity Generation Co. power plants, which provide almost all the electric power to the national network. The latest annual consumption consists of 1478×10^3 tonnes of heavy fuel oil; 218×10^3 toe as natural gas; and 35×10^3 tonnes of diesel fuel. Heavy fuel oil is the dominant fuel used because the two main, i.e. Aqaba and Hussein base load, power stations are conventional thermal plants employing Rankine steam cycle and fuelled by inexpensive heavy fuel oil as the prime source of energy. In 2000, about 87.9% of the total electricity generated was produced using heavy fuel oil (Central Electricity Generation Company, 2001). Diesel fuel is used mainly to supply gas turbines, which are operated only to satisfy electricity demands during peak-load periods and emergencies: its share was 2% and 1.06% for electricity generated in 1999 and 2000, respectively (Central Electricity Generation Company, 2000, 2001). Electricity harnessed via renewable sources, such as hydropower and wind, accounted for only a very small percentage. This was about 0.5% of the total electricity generated in 2000 compared with 0.25% in the previous year. Thus, the dominant role of steam turbines and diesel-fuel fired gas-turbines is leading to increased dependence on imported oil: less than 11% of the electrical-power generation, at present in Jordan, arises from the exploitation of the indigenous natural gas from the Risha field.

The system's peak load, in 2000, was 1238 MW compared with 1137 MW in 1999 and about 440 MW in 1985 (National Electrical Power Company, 1997–2000, 2001). This represents an average annual growth of approximately 10%. The peak load always occurs late in the summer, i.e. during the July September period. This is due to the excessive use of air-conditioning and ventilation systems as a result of the dry climate and high temperatures, as well as being the holiday season for tourists and many returning Jordanians, who normally work abroad.

During the year 2000, electricity consumption was 6133 GWh, with an average annual growth rate of approximately 10%. Household and industry are the largest consumers, with a contribution ratio of about 32.2% of the total consumption, each. These followed by water pumping, 16.1%, commercial sector, 13.1%, and street lighting, 2.8%. The average annual consumption per capita was 1464 kWh compared with 1444 kWh in 1999 and approximately 950 kWh in 1985 (National Electrical Power Company, 1997–2000, 2001).

3. Economical comparison of imported various fuels

3.1. Economic evaluation

In this investigation, levelised electricity unit generation costs are compared using the "net-present-value analysis" for the period 2001–2015. The final unit cost of electricity consists of three main components. These are the generation, transmission and distribution costs. The last two items are constant regardless of the technology or type of fuel being employed. Therefore, such costs will not be considered here. In the current study only economic comparison of various fuels are studied to determine the generation cost. The latter is made of two major items. Fixed cost, this generally remains constant regardless of the number of hours of the facility is used, i.e. the capital investment. The variable cost is related to the actual production level of the facility. Which include fuel, operation and maintenance (O&M) costs. In Jordan, during the last few years, fuel costs formed more than two-thirds of the final cost of unit electricity sold (Central Electricity Generation Company, 2000, 2001; Jordan Electricity Authority, 1986). On the other hand non-fuel operation and maintenance cost represented, on average, about 25% for relatively small and old steam turbines and 18% for large and new steam turbines of the total cost for thermal power plants. Furthermore, the power sub-sector in Jordan is considered extremely vulnerable to fluctuations in heavy oil prices due to lack of fuel diversity: most of electricity generated by burning heavy fuel oil. Hence, security of fuel supplies that difficult to quantify, especially in such a volatile region, is very important and the current situation can be improved when other types of fuels or sources are considered for power generation.

In their continuous planning for load growth, electricity utilities search for the most economic generation schemes. But this will be subject to a number of constraints, such as the type of fuel available, peak-to-base demand ratio and compliance with national environmental standards. To assess the behaviour of a power plant over its expected ranges of operation, appropriate mathematical models, which can predict the performance under both design-point and off-design or part-load operating conditions have been developed. In this investigation, the economics of different fuel and technologies, that are most likely to be employed in the future in Jordan, is discussed. The calculations of electricity generation cost, for various fuels, were carried out by means of a specially designed computer programme. The main points of computation procedure for determining electricity unit cost using basic relations are listed below.

The first year operation cost can be determined using the following formula (Adrian et al., 1996; Li and Priddy, 1985):

$$C_{(2000)} = \frac{c_1}{(1+i)^m}, \tag{1}$$

where $C_{(2000)}$ is the first year costs converted to values of the reference year 2000, c_1 is the nominal cost of the first operating year, m is the number of years between the commissioning year and the reference year, i is the rate of inflation.

The levelised cost was calculated using the following mathematical model, which is based on present value analysis and compares the costs of alternative production method:

$$C_{\text{levelised}} = (1+i)^{-m} \frac{\sum_{n=1}^{N} c_n/(1+r)^n}{\sum_{n=1}^{N} u_n/(1+r)^n}, \tag{2}$$

where $C_{\text{levelised}}$ is the levelised energy cost in terms of reference year (US$/kWh), c_n is the nominal cost in the nth year, u_n is the number of units produced in the nth year, N is the total life span of the plant, m is the number of years between the commissioning year and the reference year, r is the nominal discount rate, i is the rate of inflation.

3.2. Basic assumptions and reference data

Ideally, cost data can be obtained from in-field investigations, but in reality such data are not always available or reliable. For example, in the case of oil shale projects, it is difficult to discuss the exact economics of oil shale processing because, as yet, with the exception of those plants in Estonia and China, for which detailed

Table 1
Reference data and basic assumptions

Input	Fuel oil	Natural gas	Coal	Oil shale
Capacity (MW)	$1\times100+2\times130$	2×225	2×130	1×100
Economic life time (year)	30	30	25	25
Construction time (year)	4	3	4	5
Investment distribution per year (%)	15, 35, 35, 15	30, 40, 30	20, 30, 35, 15	15, 20, 25, 15, 15
Load factor (%)	80	80	75	75
Capital investment (US$/kW)	1000	500	1200	1550
O&M costs (US$/kW-year)	40	30	50	60
Specific fuel consumption (kJ/kWh)	9300	7000	9800	11,000
Average fuel price (US$/kJ)	3×10^{-6}	$3–3.5\times10^{-6}$	2.25×10^{-6}	1×10^{-6}
Debt asset ratio (%)	100	100	100	100
Discount rate (%)	7–10	7–10	7–10	7–10
Annual inflation (%)	0–5	0–5	0–5	0–5

information remains esoteric, there are no established operations on a commercial scale (Jaber et al., 1998a). But during the last decade, many experimental and hypothetical investigations were carried out aiming to study prospects of utilising indigenous oil shale deposits (Ahmad et al., 1994a, b; Hamdan et al., 1995; Hammad et al., 1995; Salameh, 1997; Jaber and Probert, 1998, 1999, 2000; Jaber et al., 1998b, 1999a, b, 2000a, b, 2001a-c; Nazzal, 2002; Khraisha and Shabib, 2002; Akash and Jaber, 2002). On the international level, many researchers discussed oil shale utilisation to produce synthetic fuels and/or electricity generation (Burnham, 1989; Jianqiu and Qi, 1991; Ingel et al., 1991, 1992; Casavechia et al., 1991; Green, 1991; Harada, 1991; Holopainen, 1991; Ots, 1992; Ingal and Levy, 1993; Schaal et al., 1994; Lausmaa, 1994; Veski, 1994; Roberts et al., 1994; Tiikma, 1994; Veson and Reha, 1995; Flechsenhar and Sasse, 1995; Kashirskii, 1995; Williams and Nazzal, 1995; Fainberg and Hetsrni, 1996; Williams and Nazzal, 1998; Volkov, 1998; Kribii et al., 2001; Torrente and Galan, 2001; Williams and Chishti, 2001). The main conclusion of all these lab-scale and theoretical studies is that future beneficial use of the vast oil shale deposits depends not only on the development of suitable process economics but also on the availability of suitable environmental controls. Thus, oil shale's future will be a mixture of promise and risk. So more research and experience concerning commercial exploitation of oil shale deposits is highly needed. It is stressed that the oil shale data used in this study are based on the limited published information about oil shale processing technologies.

The basic assumptions for the financial model are given in Table 1. These values are based on available data about the local and commercial power plants worldwide (Harrison, 1993; Joshi and Lee, 1996; Jaber et al., 1998a; Organisation for Economic Co-operation and Development, 1998; Khartchenko, 1998; Whittington and Bellhouse, 2000; Jaber et al., 2001a, b; Central Electricity Generation Company, 2001). For example, fuel prices were taken as average unit price from the latest International Energy Agency (2001) statistics.

It should be noted that different values for the considered parameters might vary depending on the actual operating conditions adopted, such as the coal and/or oil shale grade employed and other site-specific conditions. Also, costs related to insurance, property, sales and revenue taxes as well as waste and ash disposal are ignored. In addition, there are other issues that have not been considered, in the present evaluation, which are the financial benefits arising from (i) reducing annual foreign exchange for the purchase of imported fuels, when local oil shale is used, and (ii) the growth in the Gross National Product due to the creation of a new and large oil shale industry.

4. Discussion and analysis

The model enables to compare the generation costs of different types of power plants firing various kinds of fuels and using different technologies. By applying the previously stated formulas (1) and (2) and design data, will permit the fuel consumption and the involved costs to be predicted. Fig. 1 shows the reference solution, obtained from this model, which includes the first year operation costs and levelised unit electricity costs throughout the expected life of the power plant. First year unit production costs are computed based on prevailing prices in 2000, and levelised cost is used for comparison of different power plants.

It can be seen that oil shale power stations with high capital and O&M costs become relatively a viable alternative due to the low fuel costs. Variables that may have the biggest influence on the generation cost, and consequently on investment decisions, are the unit

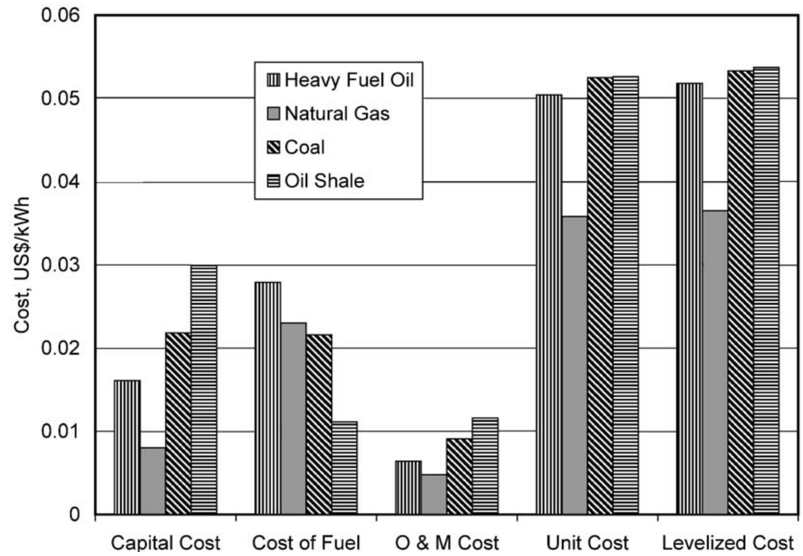

Fig. 1. Predicted generation cost in the base year.

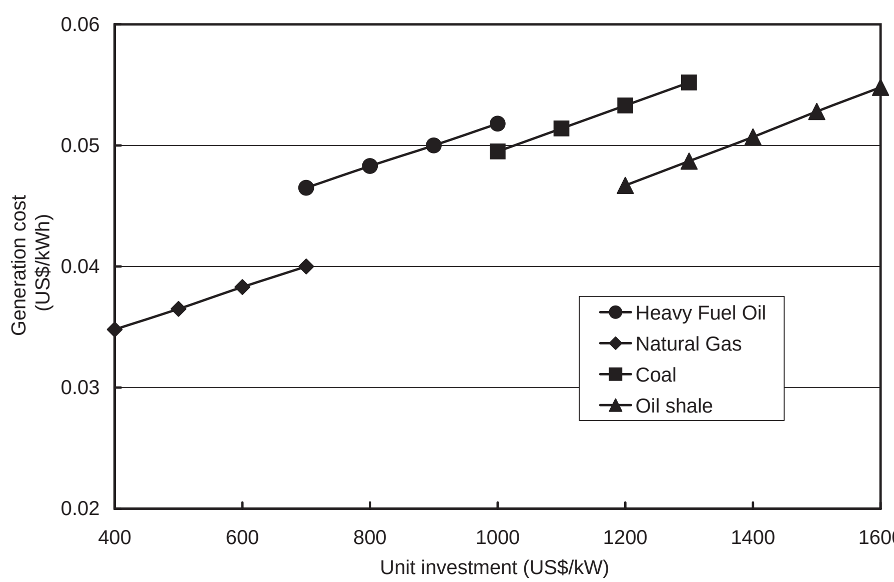

Fig. 2. Levelised unit electricity generation cost variation with respect to unit investment.

investment cost, discount rate, inflation rate and the unit fuel price. The predicted effects of these factors are assessed using different scenarios in order to provide an idea about the most likely unit generation costs during the period 2001–2015. In Fig. 2 results of about 20 sets of alternative solutions are presented, based on variations in capital costs, which alter over a wide range. For example, the cost of installed kW in coal- and oil-fired power plants vary between 800 and 1500 US$ depending on the technology being selected. In the case of natural gas such cost may be as low as 400–800 US$ (Organisation for Economic Co-operation and Development, 1998). Because the oil shale power plant is new and not yet commercially employed, both the capital and operating costs are uncertain. Thus, the installed cost of oil shale plant will be higher, i.e. 1500 US$/kW or even more, than those fuelled by coal or biomass, due to the low energy-content of such a fuel. But this cost can be reduced by applying careful engineering, optimising the design and maximising the amounts of the assembly operations undertaken in a factory in order to reduce the overall construction time and field labour costs. If the unit installed cost of oil shale power plant reaches 1200 US$/kW, then it would be an attractive option for electricity generation in Jordan.

The effect of varying discount rate between 7% and 10% is shown in Fig. 3. The unit generation cost in oil shale plants, which have the biggest investment, rises

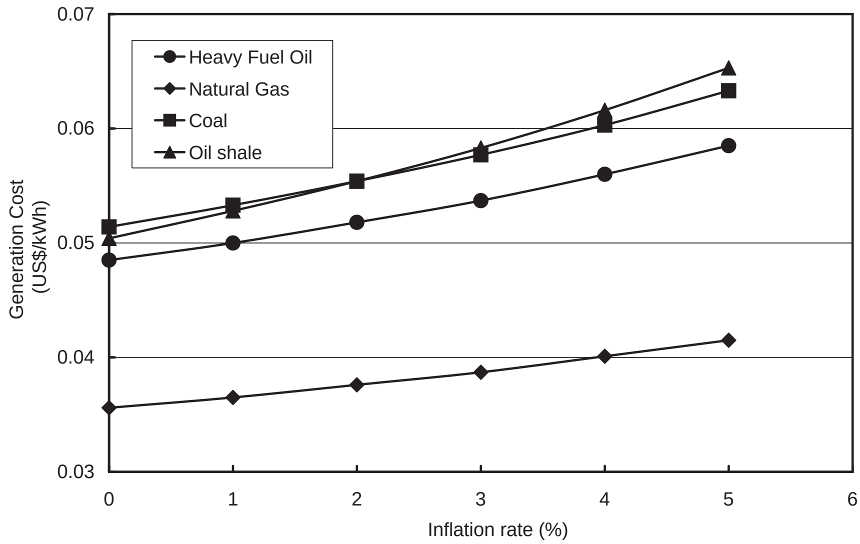

Fig. 3. Influence of interest rate on levelised generation cost.

rapidly with increasing the interest rate. Whereas a much slower increase in the unit electricity generation costs occurred in the case of natural gas plants, having a relatively far smaller unit capital cost. For a discount rate of less than about 8.5%, oil shale power stations may become more economical than oil- or coal-fired power plants. Assuming the maximum inflation rate of 5%, five scenarios in addition to the reference case were determined as presented in Fig. 4. It is clear that all types of power stations are affected almost at the same degree. However, the cost of unit electricity produced in oil shale fuelled power station will rise at relatively a higher rate with increasing the inflation rate. This can be attributed to the fact that the oil shale plant is having the largest investment cost. But such plant may still provide electricity at a competitive cost compared with that produced by employing imported coal.

Fig. 5 illustrates the effect of employing various technologies supplied by the same fuel at different heat rates. As shown the unit electricity generation cost was nearly constant, i.e. around 0.05 US$/kWh, in oil shale power plant. Such result is expected because of relatively low price of locally available oil shale. While for the other three types of power stations, generation cost rise with higher heat rates, i.e. low thermal efficiency, especially for power plants fuelled by natural gas. In the latter, when the thermal efficiency of the combined cycle power plant increased from 51% to about 60%, the generation cost of unit electricity is reduced by approximately 10% to reach around 0.03 US$/kWh, or even less depending on the unit investment cost. This is comparable to what can be achieved for similar advanced power plants in developed world (Organisation for Economic Co-operation and Development, 1998; International Energy Agency, 2001). The electricity production costs could be further reduced by the use of an advanced intercooled combined cycle power plant. Because for the same basic gas turbine, the net power-output could then be nearly twice that for the conventional combined cycle. Compared to other three fossil fuels, natural gas has considerable environmental advantages. With a higher calorific value and greater inherent efficiency, it contributes lower levels of carbon dioxide per unit of electricity generated. There is also no ash produced in the combustion of gas, it has negligible emission of sulphur oxides and lower production levels of nitrogen.

Future increases in fuel prices will directly affect the lievelized unit generation costs. Fig. 6 shows the effect of increasing fuel prices when the same inflation rate is applied to all types of power stations. It is obvious that all curves, representing different kinds of the proposed power stations, have similar slope. Which means that these are nearly affected with the same degree. Unit electricity cost produced from power plant fuelled by natural gas is still the lowest, followed by oil-fired power station.

In the case of Jordan, the oil shale plant will have to compete with conventional steam cycle systems fired by heavy fuel oil and/or simple cycle gas turbines burning natural gas or diesel fuel. The average, weighted on the national level without accounting for any adverse environmental impacts, electricity unit cost in Jordan, in 1999–2000, was approximately 0.05 US$/kWh (National Electrical Power Company, 2001). This rate is almost similar to that obtained from large-scale power plants based on a steam-cycle burning coal or oil in the developed world (International Energy Agency, 2001; Consonni and Larson, 1996; Kuemmel et al., 1997), and some Arab countries (Arab Union of Producers, Transports and Distributors of Electricity, 1997, 1998, 2000). Fig. 7 shows average generation cost of electricity

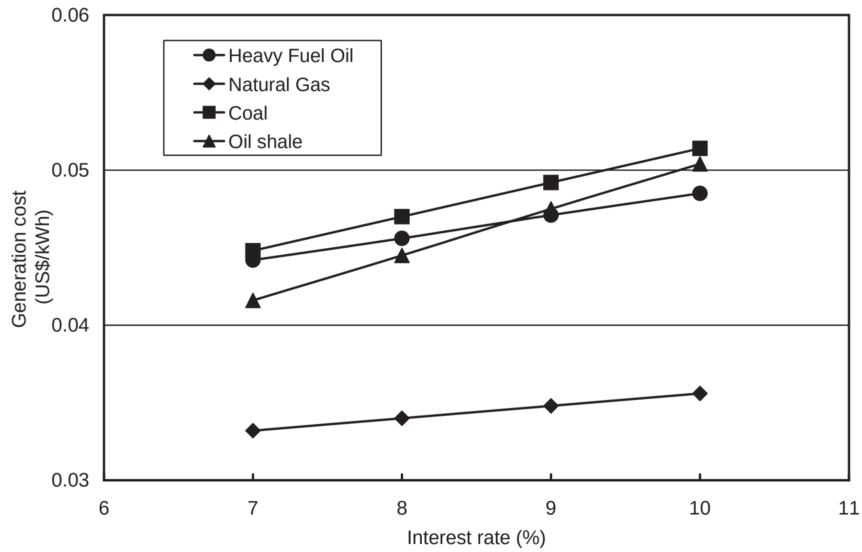

Fig. 4. Variation of levelised unit generation costs in relation to future inflation rate.

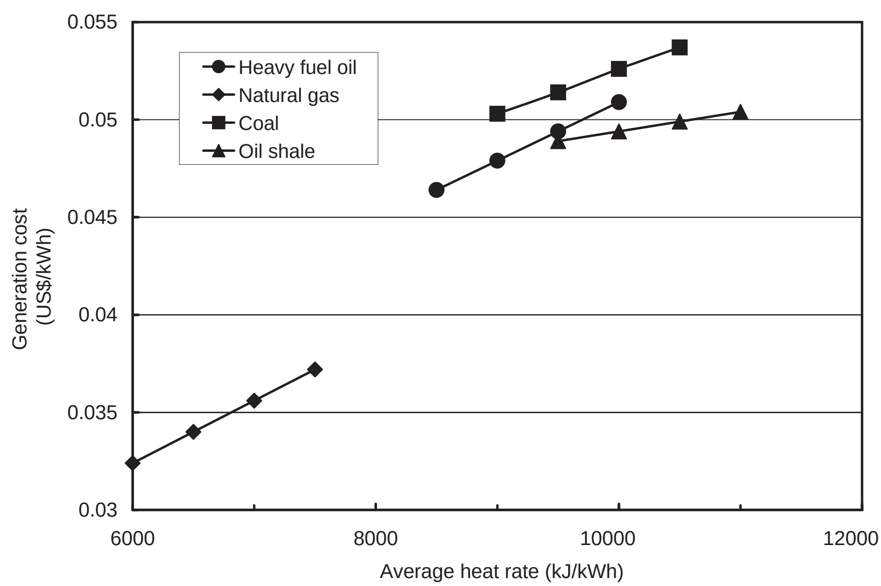

Fig. 5. Effect of variation in heat rate on levelised generation cost for various power plants.

in some Arab countries, including Jordan. As the electricity unit price is raised in the local market, the total net revenues, for a certain discount rate, as a result of such an operation and the net present value, i.e. the discounted cash flow over the project life minus the initial investment, of the oil shale plant would be increased. Hence, the expected financial performance of the proposed plant appears attractive. But it is important to realise that, if the electricity tariff is set on a base load electric-power supplies scenario, it is likely that revenues will be too low in the immediate future to motivate the choice of oil shale for electric-power generation in Jordan.

When environmental costs are taken into consideration natural gas represents the best option, because there is no need for pollution abatement technologies. Additional costs will incur in other types of power plants due to the combustion of heavy fuel oil or coal or oil shale. For example, both the bottom- and fly-ash resulting from coal or oil shale fired power stations should be collected and transferred to an intermediate storage facility, then removed and disposed of permanently. In case of firing heavy fuel oil, with high sulphur content of about 4% by weight, in conventional power stations will release flue gases to the atmosphere with high concentrations of sulphur oxides (SO_x), particulate matter (PM) and other pollutants, such as heavy metals. This will require additional equipment in order to control emissions and increase the number of staff members. Consequently the operating costs increase

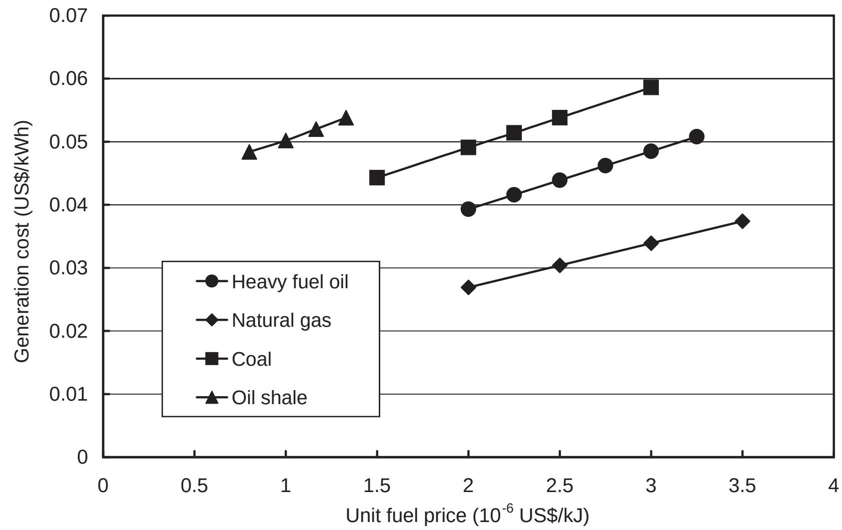

Fig. 6. Levelised generation cost versus unit fuel price.

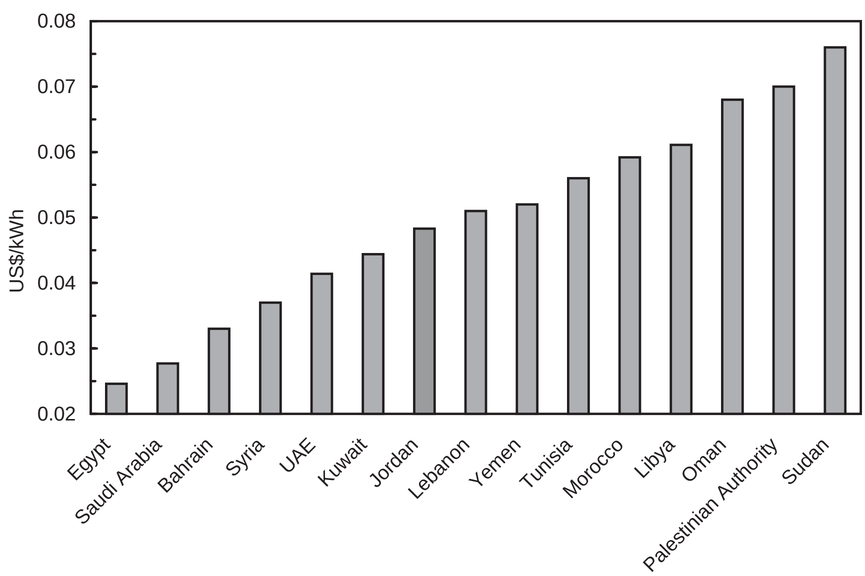

Fig. 7. Average generation cost in some Arab countries.

remarkably, and as a result the final cost of unit electricity produced will be higher.

The use of natural gas as a future fuel in electric-power stations is highly recommended in Jordan. Because the trend worldwide is to use new combined cycle gas turbine systems. Such systems are taking an increased share of the world market because of their reliability, low capital cost, shorter time for installation and high efficiency. The latter may be as much as twice, i.e. 60%, as in the Hussein thermal power station when natural gas is used. Emission levels, especially the greenhouse gas emissions, are also lower, by more than 25%, when natural gas is used as the prime fuel for the combined cycle plants compared with traditional thermal power station fired by heavy fuel oil.

5. Conclusion

Jordan's domestic recoverable energy resources are limited and lag far behind the demands of increasing population and economic growth. Thus, the country at present relies, and will continue to do so in the near future, almost solely on the combustion of imported fossil fuels in order to satisfy its national energy demand. This adds on pressure on government to act swiftly and adopt wise plans in order to ensure a reliable and secure energy supply for economic and social developments with serious considerations to minimise adverse environmental consequences.

Electricity demand is predicted to grow at an average annual rate of about 6%, with maximum peak demand exceeding 2200 MW by the year 2015. This will be met by building new power stations that consume imported fuels. Available options, which would suit the case of Jordan, of present technology are either importing heavy fuel oil or natural gas or coal and/or developing local oil shale resources. Analysis carried out in this investigation showed that generation costs of heavy fuel oil, natural gas and coal as well as oil shale are close to each other. These varies in the range of 0.035–0.055 US$ per kWh produced, which corresponds to those occurring in different parts of the world. The cheapest generation cost resulted from employing natural gas, followed by heavy fuel oil. Where such costs are almost similar for coal and oil shale power stations. However, this ranking may alter in the future, due to increasing unit prices of heavy fuel oil, natural gas and coal in the international market. According to sensitivity analysis, generation costs of coal and oil shale are highly affected by fluctuations in inflation and interest rates. At lower discount and inflation rates the cost of unit electricity produced from the oil shale power plant would be less than that obtained from coal fired power station. But significant information gaps exist, regarding the technical and financial behaviour of the oil shale power plant. So inhibiting the making of accurate assessments of the unit electricity generation costs at this time. Whilst the current electricity sub-sector reform plan is encouraging the trend towards commercial decision-making on the basis of economic efficiency, other policy priorities, in particular environmental policy, are increasingly important. Finally, authors believe that this analysis can be applied to other non-oil and gas producing Arab countries, such as Morocco, Lebanon and the Palestinian Authority.

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