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Energy and Exergy Use in the Utility Sector of Jordan during 2007-2010

A. Al-Ghandoor*[,a], J.O. Jaber[b], I. Al-Hinti[c]

[a] *Department of Industrial Engineering, Hashemite University, Zarqa, Jordan*
[b] *Faculty of Engineering Technology, Al-Balqa' Applied University, Amman, Jordan*
[c] *Department of Mechatronics Engineering, German Jordanian University, Amman, Jordan*

Abstract

In this study, an analysis of energy and exergy utilization in the utility sector of Jordan by considering the sectoral energy and exergy flows for the years 2007-2011 has been conducted based on real data obtained from main generators in Jordan. The overall energy and exergy efficiencies, for the entire utility sector, are found to be in the range of 35.1 to 38.1%. It is expected that the results of this study will be helpful in developing highly applicable and productive planning for future energy policies, especially for the power sector.

Keywords: Energy; Exergy; Efficiency; Utility Sector; Jordan

1. Introduction

In this day and age, the search for optimum utilization of energy resources is becoming increasingly important. This is due to the alarming depletion rates of high quality energy carriers, finite natural resources, the rapid growth in population and industrialization, and the associated increase in energy demand and consumption. Over the past few years, concern about energy consumption in Jordan has taken a new dimension. The annual fuel bill has been rapidly increasing over the past few years due to population and economic growth combined with consecutive increases in oil prices. In 2010, Jordan's consumption of primary energy amounted to 7.357 million Ton Oil Equivalent (TOE) [1]. Nearly 97% of this consumption came in the form of imports of crude oil, natural gas and petroleum products.

The present paper is among a series of practical articles, by authors, aimed to model various sectors and applications by employing insightful energy and exergy analysis [2-5]. Thus, the prime objective of the present study was oriented towards determining energy and exergy losses and related efficiencies as first step to understand influence and weight of different factors in the Jordanian utility sector. As Jordan is considering and in the process of implementing the updated national energy strategy, with more emphasis on energy efficiency policies in different sectors, it is believed that this investigation will provide a scientific judgment and insight to general performance of main generators and possible future improvements for energy policy implementation within the utility sector and may be useful to engineers and scientists working in the field of energy, in Jordan and some neighbouring countries.

2. Electricity Generation in Jordan

Figure 1 shows the percentage of electrical energy by type of generation in 2010 [6]. It is obvious that almost all generated power came out from thermal power plants and combined cycle power plants ranked first with sharing ratio exceeding 50% of total generated power. This was followed by steam power plants and gas turbines. Others, which represents only 0.5%, include wind, biogas and hydro power units. The electricity sector ranked first in primary energy consumption with a percentage of 44.4% of the total energy consumed in 2010 compared to 40.7% during 2007 [6].

In 2010, the installed capacity was about 3,273 MW. The system's peak load, in 2010, was 2,670 MW compared with 2,320 MW in 2009 with a growth rate of 15.1%. 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.

The interconnected system in Jordan consists of the main generating power stations, 132 kV and 400 kV transmission network. This transmission network interconnects the power stations with the load centres and different areas in the kingdom. The system also includes the 230 kV, 400 kV tie lines with Syria and 400 kV tie line with Egypt. The distribution networks serve about 99.9% of the total population in Jordan. In addition to that, the electrical power system in Jordan includes some private power stations, which are synchronized with the rest of the power stations in the integrated network and there are a few private power stations, which are not connected with the interconnected network and serve only their owners.

* Corresponding author. e-mail: gandoor2002@yahoo.com

Before 2003, HFO was the dominant fuel used because the two main power stations, i.e. Aqaba and Hussein, are conventional thermal plants employing Rankine steam cycle and fired by such an inexpensive fuel. However, since 2003, imported natural gas from Egypt replaced HFO in Aqaba power station and in early 2006 replaced diesel fuel at Rehab and Asamrah power plants. The dominant role of steam turbines, diesel-fuel fired gas-turbines, and combined cycle power plants is leading to increase dependence on imported oil: less than 8% of the electrical-power generation, at present in Jordan, arises from the exploitation of the indigenous domestic natural gas from the Risha field.

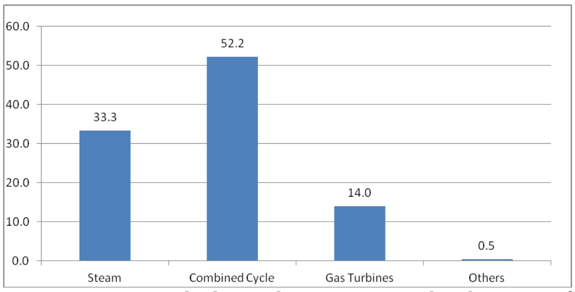

Figure 1: Generated electrical energy in Jordan by type of generation in 2010 (%).

3. Methodology

In order to compare the quality levels of various energy carriers, e.g. fuels, it is necessary to determine the equivalents of each energy quantity at a particular grade level. This can be done by using exergy concept, which overcomes the limitations of the first law of thermodynamics and is based on both the first and second laws of thermodynamics [7-8]. An exergy analysis can identify the locations of energy degradation and rank them in terms of their significance [9]; this knowledge is useful in directing the attention of process design, researchers and practicing engineers to those components of the system being analyzed that offer the greatest opportunities for improvement. Furthermore, exergy analysis has been used to analyze energy utilization on the national level, and for various sectors of the economy, in order to better understand energy utilization efficiency. This approach was first used by [10] who applied it to the overall U.S. economy in 1970. Since then, it has been adopted by several researchers for other countries such as Japan [11], Canada [12], and Brazil [13]. A summary of exergy analyses for different countries can be found in Ertesvag [14]. The concept has been also applied to cross-country analysis of some industrial segments [15-19, 5], residential sector [20, 2], transportation sector [21-24, 4], agricultural sector [25-26, 3], and utility sector [27-29]. The purpose of this section is to discuss the main mathematical relations necessary to conduct energy and exergy analyses in the utility sector.

3.1. Exergy calculation:

By describing the use of energy resources in society in terms of exergy, important knowledge and understanding can be gained, and areas identified where large improvements could be obtained by applying efficient technology, in the sense of more efficient energy-resource conversions. In principle, the exergy of matter can be determined by bringing it to the dead state by means of reversible processes. The basic formulas used in exergy analysis modelling for this study are given below.

3.1.1. Exergy of fuel:

The specific exergy of the fuel at environmental conditions reduces to chemical exergy, which can be written as:

$$\varepsilon_f = \gamma_f H_f \tag{1}$$

Where is the fuel specific exergy, the exergy grade function, and Hf the higher heating value of the fuel. Table 1 shows higher heating value, chemical exergy, and fuel exergy grade function of different fuels considered in this study [8, 10, 19, 30]. As shown, in Table 1, all values of the exergy grade function are very close to unity. Consequently, the common practice in such cases is to assume that the exergy of the fuel is approximately equal to the higher heating value [31-32].

Table 1: Higher heating value, chemical exergy, and exergy grade function for different fuels (at 25°C and 1 atm) [8, 10, 19, 30].

Fuel	H_f (kJ/kg)	ε_f (kJ/kg)	γ_f (ε_f /H_f)
Diesel	39,500	42,265	1.070
HFO	40,600	40,194	0.990
Natural Gas	55,448	51,702	0.930

3.1.2. Exergy of electricity:

From the definition of exergy, electricity, We, is identical to the physical work exergy, EWe:

$$E^{We} = W_e \tag{2}$$

3.2. Energy and exergy efficiencies:

Energy efficiency (first law efficiency) is the ratio of energy contained in useful products of a process to energy contained in all input streams, while exergy efficiency (second law efficiency) is the ratio of exergy contained in the useful product to the exergy contained in all input streams. Energy efficiency (η) and exergy efficiency (ψ) are defined as:

$$\eta = \left(\frac{\text{energy in products}}{\text{total energy input}}\right) \times 100\% \tag{3}$$

$$\psi = \left(\frac{\text{exergy in products}}{\text{total exergy input}}\right) \times 100\% \tag{4}$$

Energy, η_e, and exergy, ψ_e, efficiencies for electricity generation through fossil fuels, mf, can be expressed as follows:

$$\eta_e = (W_e / (m_f H_f)) \times 100\% \tag{5}$$

$$\psi_e = (E^{We} / (m_f \varepsilon_f)) \times 100\% = (W_e / (m_f \gamma_f H_f)) \times 100\% = \eta_e \tag{6}$$

Therefore, exergy efficiency for electricity generation process can be taken as equivalent to the corresponding energy efficiency [32].

4. Results and Discussion

As stated previously, electricity is mainly produced by means of thermal power plants in addition to small portions produced by using available renewable sources. Figure 2 shows an illustrative presentation of electricity production in Jordan. In order to simplify the analysis of energy and exergy efficiencies for this sector, energy consumption and electric production flows are analyzed, for three power plants namely steam, combined cycle, and gas turbines that consume most of fuels, i.e. 99.5%, supplied to the utility sector.

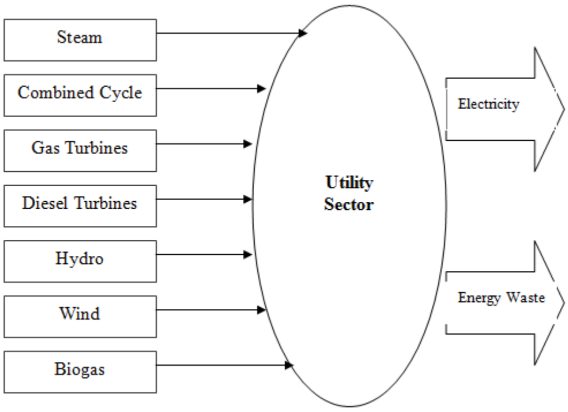

Figure 2: An illustrative presentation of the electricity production in Jordan.

Real data, from the field, have been obtained by compiling and analyzing scattered data collected from electricity generation companies for a period spanned from 2007 to 2010; this forms a unique point in this study by developing data that are not published elsewhere. Table 2 summarizes the collected data.

Table 2: Total primary energy consumption and electricity generation according to type of generator during the period 2007-2010.

	Primary Energy Consumption (1000 toe)	Electricity Generation (GWh)			
		Steam	Combined Cycle	Gas Turbines	Others
2007	3026	6525	5061	949	74
2008	3275	5726	5043	2664	74
2009	3430	5424	5393	3123	69
2010	3270	4824	7561	2028	73

As clearly can be seen from Table 2, the share of combined cycle power plants, fired by imported natural gas, has been increased by almost 12% during the period of study. This will have a dramatic effect on the performance of the utility sector, in Jordan, since it has the highest efficiency as compared with other available thermal technologies of power generation.

The analysis has been carried out based on input and output energies and exergies given in Table 2. Energy and exergy efficiencies for each year have been determined by using equations 5 and 6, considering energy grade function as unity. Table 3 shows both of energy and exergy efficiencies for the whole electricity generation sector.

Table 3: Calculated energy and exergy efficiencies during 2007-2010 (%).

Year	Overall Efficiency (%)
2007	35.8
2008	35.5
2009	35.1
2010	38.1

In general, for the utility sector, several investigators have come up with the same results that the energy and exergy efficiencies for similar activities are almost identical for the utility sector. This result indicates that inefficiencies in this sector are not caused by mismatch in the input-output quality levels but rather by the presently available techniques used for conversion processes. Substantial improvements in this sector are expected to be difficult to obtain and will involve major changes in the conversion methods [32].

For comparison purposes, energy and exergy efficiencies for main generating plants for year 2010 are indicated in Figure 3. It is obvious that combined cycle units have the highest values. This should attract the attention of planners and policy makers to upgrade all existing power plants based on gas turbines to operate as combined cycle in the near future. Moreover, future expansion in power generation projects should be limited to combined cycle plants, especially when fired with natural gas. Such trend has the extra advantage of reducing total gaseous emissions, including greenhouse gases, from the power sub-sector [33].

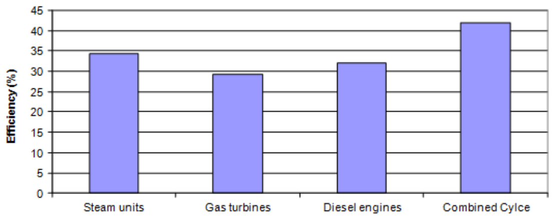

Figure 3: Energy and exergy efficiencies of power plants of the utility sector in Jordan for the year of 2010.

5. Conclusion

In this study, energy and exergy efficiencies of the Jordanian utility sector were determined for period spanning from 2007 to 2010. Calculated exergy efficiency of the utility sector is same as its corresponding energy efficiency since for fossil fuels energy, which is the prime energy source for electricity production in Jordan, the exergy grade function is almost unity. The average overall energy and exergy efficiencies are found to be about 38.1% in 2010.

The calculated efficiencies over the studied period can be considered as an important tool for policy makers, energy planners and operators to get deeper insight into the performance of the utility sector. Furthermore, such results could provide important guidelines for future research work since large energy and exergy losses, which are reported in this study, should be taken as a challenge by the society, concerned governmental institutions and generators to achieve sustainability goals.

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