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THE ENVIRONMENTAL PERFORMANCE OF FUTURE POWER GENERATION SCINARIOS IN JORDAN

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ABSTRACT

Jordan has experienced a sharp increase in electricity demand due to rapid development and sudden increase in population as a result of political unrest in the region. At the same time the energy security of the country is threatened by the disruption of the vital Egyptian natural gas supply. As a result, more carbon intensive imported fossil fuel alternatives were used to meet the demand. Nevertheless, alternative sources are needed to meet the increasing demand as well as to secure the energy future of the country. Four potential future energy scenarios which included a mix of indigenous and imported energy resources were assessed. The results suggest that an electricity generation scenario based on 10% renewables, 20% natural gas, 3% heavy fuel oil, 31% diesel, 14% oil shale and 12% nuclear power is likely to lower the carbon intensity of the electricity generation to 0.645 kg CO_2-eq/kWh which is below the 2009 levels.

Keywords: *Carbon footprint; Energy security; Life cycle assessment; energy policy; Jordan*

INTRODUCTION

Access to modern and clean energy sources is essential for global development and particularly for achieving the Millennium Development Goals (UNDP, 2014). As such, energy security is a key global issue that needs to be addressed. 'Energy security' is defined by the International Energy Agency (IEA) as having uninterrupted access to energy sources at affordable price (IEA, 2014b). On the other hand, a lack of access to safe, clean and efficient energy sources for domestic needs is referred to as 'energy poverty' (IEA, 2014a). Globally, there is a need for reliable, efficient and clean energy services as the current energy systems are failing to sustainably meet the needs of people especially those in developing nations (UN-Energy, 2008).

Jordan is an example of an 'energy poverty' case. Although, Jordan is located in the Middle East region surrounded by the world's largest producers of oil, the country has little indigenous oil and gas resources. The country imports 97% of its energy need to sustain a rapidly growing population. Table 1 shows the quantities of primary energy imported and indigenous over the period between 2005 and 2012, as published by the Jordanian Ministry of Energy and Mineral Resources (MEMR), (2013). According to table 1, the energy demand has increased by 11.7% over the seven year period. The demand is expected to rise dramatically over the coming years.

Table 1. Primary energy sources (ktoe). Data source MEMR, 2013.

Year	Imported Energy			Indigenous	
	C.O.*	NG**	Elect.	C.O.*	NG**
2012	7295.8	538.1	196.1	1.1	120.9
2011	6137	738.8	312.9	0.9	133.9
2010	5078	2152.3	167.6	1.2	136.4
2009	4510	2923.7	98.3	1.5	161.9
2008	4544	2572.6	136.8	1.7	152.5
2007	4869	2241	53.2	1.2	165
2006	5015	1818.3	124.3	1.3	185.2
2005	5678	1205.2	237.6	1.1	178.7

*Crude oil and products, **Natural Gas

Fig. 1 shows the energy consumption by economic sector for the financial year ending December 2012. As evident from figure 1, the largest consumer of primary energy is the electricity generation sector followed by the transportation sector. Therefore, securing sustainable energy sources for electricity production can play a significant role in the overall energy security of Jordan.

The energy sector (transportation and industrial energy activities), due to its heavy reliance on fossil fuel and low efficiency, is the major emitter of greenhouse gases (GHG) accounting to 74% of the total GHG emissions of Jordan (Ministry of Environment, 2013). For example, according to the MEMR, 99% of the electricity supplied to the grid in 2012 came from fossil origin. Therefore, it is not surprising that the Jordanian National Climate Change Policy calls for improving the energy efficiency and increasing the renewable energy share (Ministry of Environment, 2013).

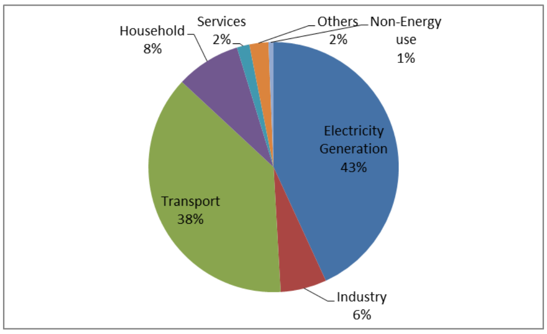
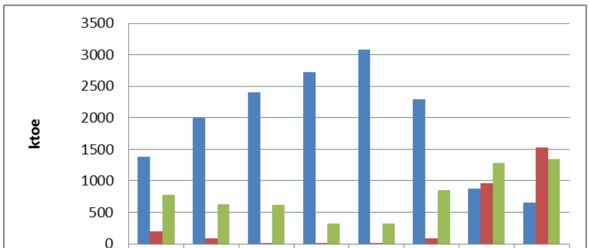


Fig.1. Energy consumption by economic sector (Data source MEMR, 2013).

The Impact of the Arab Spring on Jordan's Energy Security

The 'Arab Spring' has brought many challenges to the country, not the least is energy security. On one hand, the country experienced a sharp increase in population due to refugee influx from affected countries. For example, according to the UNHCR, as of the 10th of April 2014, there were 590,515 registered cases of Syrian refugees who live in Jordan (UNHCR, 2014). This sharp increase in population places extra demand on the limited energy resources. At the same time, the Egyptian uprising and the following political instability in Egypt, has resulted in disruption of the natural gas supply from Egypt to Jordan. Prior to the uprising in Egypt, natural gas imported from Egypt at preferential prices fuelled 90% of the power generation sector in Jordan. Figure 2 shows the relative share of different fuels in the national electricity grid mix of Jordan. As evident from Figure 2, the share of natural gas has been decreasing since the uprising in Egypt in 2010, due to frequent interruptions of supply and sustained attacks on the gas pipeline. At the same time the demand has sharply increased in 2012 following the uprising in Syria in 2011 and the subsequent influx of refugees. As a result, Jordan was forced to switch to other more carbon intensive fuels to meet the increased electricity demand.

The switch to more carbon intensive fuels, although necessary, may pose a challenge to Jordan's ability to meet its targets under the National Climate Change Policy. This paper investigates the carbon footprint of potential future pathways to achieve energy security.



	2005	2006	2007	2008	2009	2010	2011	2012
Natural gas	1383.9	2003.5	2406	2725.1	3085.6	2288.7	872.7	658.9
Diesel	203.7	89.9	7.7	15.4	15.4	90.7	962	1534.3
Heavy fuel	782.3	623.7	620.8	321	321	851.9	1284.2	1340.5

Fig. 2. Electricity grid mix of Jordan over the period 2005-2012.

METHODS

Life cycle assessment approach following the ISO 14040:2006 (ISO, 2006) is used to account for GHG emissions. IPCC 2007 impact method is used to evaluate the global warming potential impact (GWP) of each scenario (Solomon, 2007). OpenLCA software (GreenDelta, 2014) was used in the modelling exercise. The life cycle inventory data was collected from different sources in the literature, the ELCD (Joint Research Centre,

2013) and USLCI (NERL, 2013). GHG emissions for electricity production form oil shale were sources from Koskela et al. (2007) and Brandt (2008) for the Estonian direct combustion and Shell in situ models, respectively. The functional unit chosen for this study is the production of 1 kWh of electricity at the power plant.

Scenarios

Six scenarios were constructed using different technologies and available fuel sources which are flagged by the MEMR as potential pathways to achieve energy security in Jordan. The GWP of future scenarios where compared to the current and historical cases of the Jordanian electricity sector.

The 2009 grid mix (S0)

This scenario is included to evaluate the impact of the interruption of the Egyptian gas on the carbon intensity of the Jordanian electricity generation sector. In this scenario, the grid mix consisted of 90.2% natural gas, 9.4% heavy fuel oil and 0.4% diesel.

The baseline scenario 2012 (BAU)

This scenario is included to assess the current carbon intensity of the Jordanian grid to establish a baseline to compare future potential scenarios against it. In 2012, the grid mix was made up of 18.6% natural gas, 37.9% heavy fuel oil and 43.4% diesel.

MEMR preferred scenario with oil shale direct combustion (S1A)

The MEMR has announced plans to secure the energy future of Jordan through diversifying energy sources and increasing the share of indigenous energy resources. Uranium is one of Jordan's indigenous natural resources. It can be refined to fuel a nuclear reactor to generate electricity. Oil shale is another natural resource that is abundant in Jordan. The use of oil shale to produce electricity is common in Estonia where it supply 92% of the electricity in the grid through direct combustion (Koskela et al., 2007). Another method for harvesting the energy content of oil shale is the Shell in Situ conversion process (Brandt, 2008).

MEMR announced that by 2020, nuclear power will supply 12% of the electricity in the grid. In earlier plans oil shale was earmarked to supply 14% of the electricity demand by 2020. MEMR plans also call for increasing the share of renewable energy to 10%. The remaining electricity demand will be met by oil and gas fired plants.

In this scenario we assume that the future grid mix will be made up of: 9% heavy fuel oil, 43% diesel, 20% natural gas, 12% nuclear, 10% renewables (wind and solar) and 6% oil shale (Estonian direct combustion model).

MEMR preferred scenario with oil shale Shell in Situ model (S1B)

This scenario is the same as S1A except that electricity generated from oil shale using Shell in Situ method.

Modified MEMR preferred scenario with lower nuclear share (S2A)

This scenario is based on earlier plans announced by MEMR in 2012. The scenario assumes that the grid mix is made up of: 40% oil products (9% heavy fuel oil, 31% diesel), 29% natural gas, 6% nuclear, 10% renewables, 14% oil shale (6% direct combustion and 8% in Situ), 1% imported electricity.

Diversified mixed maximized indigenous resources (S2B)

This scenario is similar to S2A except that the share of nuclear power generation is assumed to be 12% offsetting some of the share of heavy fuel oil. Table 2 shows a summary of the 5 scenarios.

Table 2. Summary of electricity generation scenarios

Scenario	Fuel						
	Heavy fuel oil	Diesel	NG	Nuclear	Oil shale (in situ)	Oil shale (Direct combustion)	Renewables
S0	9.4%	0.4%	90.2%	-	-	-	-
BAU	37.9	18.6%	18.6%	-	-	-	-
S1A	9%	43%	20%	12%	-	6%	10%
S1B	9%	43%	20%	12%	6%	-	10%
S2A	9%	31%	29%	6%	8%	6%	10%
S2B	9%	31%	29%	12%	8%	6%	10%

RESULTS AND DISCUSSION

All scenarios considered for electricity production are likely to have lower GWP than the current electricity production mix (BAU) case as evident from fig. 3. S2B is likely to deliver the lowest global warming potential impact among the scenarios, considered in this analysis, for the future electricity generation in Jordan. The carbon intensity of the grid mix using S2B scenario is expected to be 0.649 kg CO_2-eq/kWh followed by S1A and S1B at 0.689 and 0.701 kg CO_2-eq/kWh, respectively. S2A is likely to be the least performing option at 0.73 kg CO_2-eq/kWh. Nevertheless, it is interesting to note that S1A, S1B and S2A are likely to have higher GWP than the S0 case when the Egyptian natural gas accounted to nearly 90% of the electricity generation in Jordan. This is despite the fact that these scenarios call for at least 16% of the electricity to be generated from less carbon intensive sources (nuclear and renewables). Yet, the increased dependence on fossil fuels, especially diesel, heavy fuel oil and oil shale are likely to push GHG emissions higher.

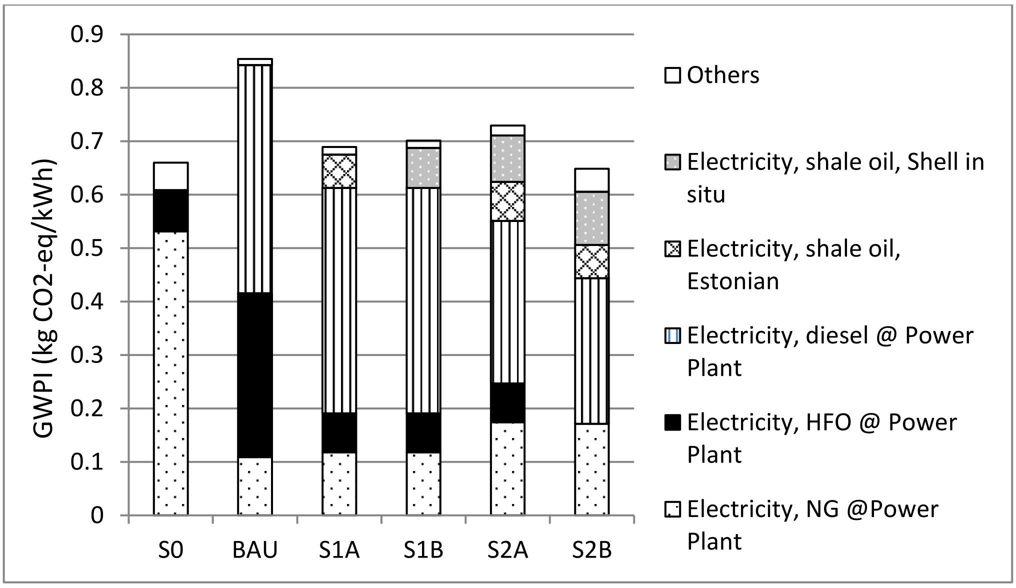


Fig. 3. GWPI of the different electricity production scenarios

S2B, in addition to its better performance in reducing GHG emissions and contribution towards meeting the National Climate Change Policy of Jordan; it also maximizes the share of indigenous energy resources. As can be calculated from Tables 1 and 2, the total share of indigenous resources in S2B is nearly 36.6% which may improve the future energy security of Jordan.

Fichter, Trieb, and Moser (2014) concluded that 47% of the electricity demand in Jordan could be met using a balanced mix of solar and wind energy by 2022. However, Fichter et al. (2014) did not consider nuclear and oil shale resources. Combining Fitcher et al. (2014) conclusions with this study's findings, one may suggest that Jordan could generate up to 73% of its electricity demand from indigenous sources. Although, this may be highly optimistic; nevertheless, it is a possible scenario that can improve the energy security status of the country.

Although, it is not the focus of this paper, the results may have significant implications to the economic development of the country. According to MEMR (2013), energy imports are estimated to cost the government 5.0 billion Jordanian dinars, significantly contributing to the budget deficit of the country. Reducing the dependence on imported fossil fuel may help in reducing this deficit, thus freeing much needed capital for economic development projects.

CONCLUSION

This study assessed four future energy scenarios for electricity generation in Jordan for their carbon intensity using life cycle methodology. The results were compared to the current grid mix as well as to the 2009 (prior to Egyptian natural gas disruption) grid mix. The results found that the current carbon intensity of the grid mix is 0.854 kg CO_2-eq/kWh is significantly higher than the 2009 case of 0.66 kg CO_2-eq/kWh. The results further suggest that a well-balanced mix of energy resources which includes the use of indigenous energy resources and imported fossil fuel can improve the energy security of the country; while at the same time reduce the carbon intensity of the grid mix to 0.649 kg CO_2-eq/kWh which is below the 2009 levels.

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