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Comparison of Energy Mix Scenarios for the Kingdom of Saudi Arabia Considering Nuclear Energy as an Option

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1. Introduction

King Abdullah City for Atomic and Renewable Energy (K.A.CARE) and Korea Atomic Energy Research Institute (KAERI) are conducting a joint research project with respect to the optimal energy mix for Saudi Arabia. This project aims to conduct a national case study on energy planning of the electricity sector, particularly the effect of introducing the nuclear power as an option.

The introduction of a new nuclear power plant to the country is expected to contribute highly to its economy. For the case of the Kingdom of Saudi Arabia, which shows a remarkable oil and gas reliance on its power sector, and as an embarking country for the nuclear technology, it is highly suggested to diversify energy supply option to satisfy energy demand and to maximize the benefit of its natural resources of oil and gas.

Given that the Kingdom of Saudi Arabia and the Republic of Korea are member states of the International Atomic Energy Agency (IAEA), the joint team was able to utilize one of the best tools/models that the IAEA is providing for its Member States in the field of energy planning. Model for Energy Supply System Alternatives and their General Environmental Impact (MESSAGE) is used to conduct the analyses required in this paper's objectives and outcomes.

2. Objectives

The main goal of this research paper is to provide a comprehensive analysis and the effect of introducing the nuclear power to KSA energy mix. To do so, IAEA best practices of using MESSAGE is being utilized. Ultimately, MESSAGE model will provide the results based on total system cost minimization.

Moreover, MESSAGE is giving the user many advantages. These advantages may include; the system environmental emissions, local resources utilization, and ultimately the system cost. The system cost is concerned with long-term planning. MESSAGE is considered as a long-term planning tool, hence it does not take into account the balancing cost and network cost attributable to operating electric system from the short-term perspective.

In addition, IAEA is suggesting that the outcomes of MESSAGE model could be used to provide EMPOWER (Extended input-out Model for sustainable Power generation) with the economical input for further analysis related to the macroeconomics analysis of the energy system.

3. Methodology

In order to successfully achieve the objective of this study, MESSAGE has to be provided with the data that reflects the Kingdom's accurate resources status,
the long-term electricity demand forecast and the time series behavior/pattern of electricity consumption over a year, historical power supply system in the technical and economic aspects, available power technologies in the future, and etc.

As a first step, the electricity demand should be forecasted in order to draw an estimation of the electricity needed yearly. As some of the forecasted energy would be covered by the existing technologies/power plants; an estimation of the existing power plants' capacities over the study period is needed along with the generating costs and the de-commissioning dates. In addition, all necessary information or factors such as photovoltaic (PV) capacity, heat rate conversions, cost data, carbon emission rates and electricity storage options should be provided.

For the analysis of electricity consumption pattern within a year based on historical data, the electricity usage is categorized into small segments of time depending on the variation of energy demand on different seasons or day type (working days, weekends or national holidays). In this case study, 88 of time segments, which is also called load regions in MESSAGE, are introduced where the electricity load keeps constant during any given segment.

As the earlier information is provided to MESSAGE, a list of available technologies with their technical and economic data should be defined in order for the optimizer to find the optimal energy mix, which gives the least system cost (discounted) during the study period. The user may define any constraint which might reflect any realistic condition to use or construct any given technology. These constraints may include the specific time of operation or construction for a technology, the cost data, emission coefficients and predetermined share of energy mix.

In this case study, nuclear, renewable and different types of fossil energy sources are considered in each scenario where a certain share of the energy mix is considered as a constraint to see the various plausible ways to supply the needed energy. We established five scenarios in this study which are:

1.1. 70% Gas + 30% Oil
1.2. 50% Gas + 50% Oil
1.3. 30% Gas + 70% Oil

2. 70% Fossil + 30% Renewable

3. 50% Fossil +25% Nuclear + 25% Renewable

On top of the above 5 scenarios, we introduced additional scenario called Realistic. This scenario is introduced to limit the ambitious high installation of nuclear energy of scenario # 3, due to realistic human resources capabilities, construction capacity, operational capacity and investments limitations for an embarking country to the nuclear technology. To propose a doable introduction of nuclear power, it has been assumed that two units of 1.4 GW each to be operating every five years, starting from 2035.

With respect to the input data, Table 1 summarizes the main input parameters to MESSAGE.

Table 1: Main input parameters to MESSAGE

Parameter	Value
Total Electricity Generation in 2019	375,100 GWh
Electricity demand in 2019[1]	34,847 MWyr
Forecasted Electricity demand at 2060	160,564 MWyr
Transmission & Distribution Loss	10 %
System Load Factor	66.2 %
Capacity Reserve Margin	20 %
Total installed Cap. (All licensees) in 2019	86 GW
Average PV Capacity Factor	22.2 %
CO_2 Emissions of Oil Power Plants (PP)	6,537 ton/MWyr_e
CO_2 Emissions of Gas PP	5,127 ton/MWyr_e
CO_2 Emissions of Combined Cycle Gas Turbine (CCGT) PP	3,558 ton/MWyr_e

Furthermore, Table 2 summarizes the cost input data.

Table 2: Cost input data

	Overnight Cost	Fixed O&M (FOM)	Variable O&M (VOM)	Fuel Cost	
	$/kWe	$/MWe/year	$/MWh		
CCGT	1014	29435	2.70	9.04	$/MMBTU
Nuclear	4896	68800	6.90	9.33	$/MWh
PV	1436	26667	0.00	0	
Gas turbine	935	15827	3.66	9.04	$/MMBTU
Steam turbine	1546	57243	2.66	19.26	$/MMBTU

4. Results and Discussion

The study of the scenarios was conducted based on a period started from 2018 until 2060. The outcomes shown in the tables below covers the entire period of the study.

4.1 Total System Cost[2]

MESSAGE shall find the most optimal energy mix that satisfies the energy demand while keeping the constraints valid. The objective function of the optimizer is built to minimize the total system cost (discounted at a given discount rate). For the previous scenarios, the total system costs are calculated in Table 3.

Table 3: Total system costs

Scenario	System Cost
1.1. 70% Gas + 30% Oil	$ 1,621 E+9
1.2. 50% Gas + 50% Oil	$ 1,920 E+9
1.3. 30% Gas + 70% Oil	$ 2,242 E+9
2. 70% Fossil + 30% Renewable	$ 1,332 E+9
3. 50% Fossil +25% Nuclear + 25% Renewable	$ 1,140 E+9
Realistic	$ 1,185 E+9

4.2 Total CO_2 Emissions

Since the Kingdom of Saudi Arabia is moving toward carbon emissions reduction, it becomes a major parameter to consider in energy planning. MESSAGE is a flexible tool to measure the expected emissions and to maintain constraints on them.

For the established scenarios, the CO_2 emissions are calculated in Table 4.

Table 4: Total CO_2 Emissions

Scenario	CO_2 Emissions (ton)
1.1. 70% Gas + 30% Oil	17,354 E+6
1.2. 50% Gas + 50% Oil	19,697 E+6
1.3. 30% Gas + 70% Oil	22,470 E+6
2. 70% Fossil + 30% Renewable	11,005 E+6
3. 50% Fossil +25% Nuclear + 25% Renewable	7,712 E+6
Realistic	10,081 E+6

4.3 Total Fossil Fuel usage

KSA should fully utilize its natural reservoirs of fossil fuel by considering the opportunity cost of the huge economic impact of fossil fuel full utilization in trades with other countries or using it for petro-chemical industries instead of using it to generate electricity. In the established scenarios, the fossil fuel usage is calculated in Table 5.

[1] It is assumed that the electricity demand increases at 6% yearly till 2030, then it increases at 3% till the end of the study period at 2060.

[2] As system cost in MESSAGE is the total capital and operational costs including fuel cost, discounted at a given discount rate, it does not include balancing or network costs.

Table 5: Total Fossil Fuel usage

Scenario	Fossil resources usage (Barrel)
1.1. 70% Gas + 30% Oil	19,101 E+6
1.2. 50% Gas + 50% Oil	31,633 E+6
1.3. 30% Gas + 70% Oil	44,246 E+6
2. 70% Fossil + 30% Renewable	6,408 E+6
3. 50% Fossil +25% Nuclear + 25% Renewable	185 E+6
Realistic	195 E+6

Based on the outcomes of this case study, it has been noticed that scenario #3 is the ideal scenario in terms of system cost, CO_2 emissions, fossil fuel usage. As scenario #3 shows too much ambitious plans for nuclear power, hence the realistic scenario is considered to be the doable version of scenario #3. The next figure illustrates the energy mix for the Realistic scenario:

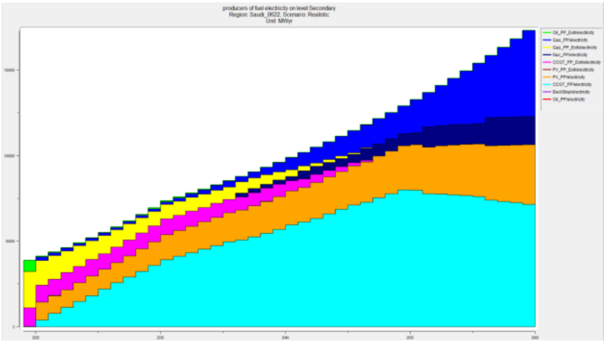

Figure 1: The energy mix for the Realistic scenario

Where:

- *Green: the existing PP*
- *Red: the newly built oil PP*
- *Blue: the newly built Gas PP*
- *Yellow: the existing Gas PP*
- *Dark Blue: Nuclear PP*
- *Pink: the existing CCGT PP*
- *Light blue: the newly built CCGT PP*
- *Brown: the existing PV solar energy*
- *Orange: newly built PV plants*

5. Conclusions

While the energy mix planning should consider many dimensions, all of them cannot be reflected in any molding tool including MESSAGE. In addition, strategic energy planning is not always based on the most economical options.

Based on the current electricity market situation in Saudi Arabia which was used as an input to MESSAGE, and with respect to the scenarios introduced in this case study, it is clear that scenario # 3 (50% Fossil +25% Nuclear + 25% Renewable) gives the most economic system cost, the least CO_2 emissions, the least Fossil Fuel usage. Moreover, to keep the conclusion of this case study realistic and able to be implemented, the Realistic scenario is shown as the best applicable scenario.

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