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Assessing the Future of Energy Security in Egypt

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ABSTRACT

This research aims to study the future of energy security in Egypt using system dynamics approach. To achieve this objective, seven scenarios have been simulated for the period 2007-2030. The simulation results showed that, keeping other polices constant, raising the growth rate of new discoveries of oil and natural gas is the most effective policy for improving the future of energy security in Egypt, followed by removing energy subsidy and paying more investments in new and renewable energy respectively. In addition, targeting high economic growth rate is expected to have a negative effect on the future of energy security in Egypt, if it is not accompanied with more investments for increasing energy resources. On the other hand, the results showed that to improve energy security level and achieve sustainable economic development, a set of policies have to be adopted simultaneously to increase energy resources as well as rationalize energy consumption.

Keywords: Energy Security, Energy Forecasting, Simulation Modeling
JEL Classifications: F50, Q47, C63

1. INTRODUCTION

Energy is an important component for all economic activities; it is necessary for the production of goods and the provision of services. In fact, current world's power heavily depends on having access to secure supplies of energy at a reasonable price (Balat, 2010; AGECC, 2010;). Therefore, securing energy supply to meet national demand on both the short term and long term, is one of the most important priorities for any country overall the world, and some countries consider ensuring energy security as a national goal (Phdungsilp, 2010; OECD, 2007). However, as the population grows rapidly, the demand for energy is becoming critical challenge for the world's energy security. On the other hand, providing clean and safe energy by reducing harmful environmental impacts of energy production is another challenge that faces global energy security (World Bank, International Monetary Fund 2006).

Egypt, as one of developing countries, faces many challenges to ensure energy security; the Egyptian oil and natural gas proved reserves declined during the last period; the proved oil reserves decreased from 4.5 million barrel in 2009 to 4.2 million barrel in 2013, also natural gas reserves decreased from 78 trillion cubic feet in 2010 to 77.2 trillion cubic feet in 2014 (OAPEC, 2014). On the other hand, current energy mix in Egypt is not well diversified; it mainly depends on oil and natural gas by about 94.4% of total primary energy consumption in 2014 (EIA, 2015). Also, there is an imbalance between supply and demand of oil; where supply to demand ratio is <100% (about 52.7%) in 2014. Besides, Egypt imported about 4.9 million tons of oil from only three main suppliers; Kuwait, Iraq, and Oman in 2014 (Egyptian Ministry of Petroleum, 2014). The low diversity of oil imports sources increases the exposure of Egypt to geopolitical risks. In addition, the share of private sector in energy investment is low about 16% in 2014/2015 (MOPMAR, 2015), which negatively affects the technological content of energy production and consumption techniques. As well as, energy infrastructure in Egypt suffers from aging and low efficiency. Moreover, there is no one integrated strategy for energy sector in Egypt but many conflicting strategies developed by different energy institutions, which may hinder making appropriate policies for energy management. Such challenges make Egypt more vulnerable to energy supply disruption.

Although Egypt has proposed many policies to improve energy security situation such as subsidy policies, tax deduction, and technological support policies, most of these policies need considerable commitments in time, and a consolidation into one integrated long term strategy.

In Egypt, few studies have been made to model and study energy security performance; such studies as (Al-Ayouty and Abd El-Raouf, 2015), which aimed to draw some policies that can pave the way towards greater energy security in Egypt on the short run. In this research two different topics have been discussed which are liberating energy prices and different scenarios for energy mix in Egypt. On the other hand no attempts have been made to model and quantify energy security performance on the long run.

Based on that, the main objective of this research is modeling the future of energy security performance for Egypt under different policy scenarios using system dynamics approach. System dynamics is a comprehensive multi-dimensional modeling technique; it has the advantage to deal with complex and dynamic issues like energy security (Baumann, 2008) with simple and practical way.

The time span of the model extends from 2007 to 2030. The reason behind choosing 2007 as starting point for the simulation analysis is due to data availability limitation, while 2030 has been chosen as the end point for the simulation to be compatible with the Sustainable Development Strategy: Egypt Vision 2030, which has been launched by the government of Egypt in February 2016.

2. ENERGY SECURITY: A LITERATURE REVIEW

Although, the concept of energy security has been widely used in literature, it hasn't been defined explicitly. Historically, energy security concept focused on crude oil supply disruptions in the Middle East (World Economic Forum, 2006). The oil crises in the 1970s and 1980s made oil disruptions concerns more evident in large industrialized countries. (Kruyt et al., 2009; Wu et al., 2012). With an increase in natural gas use, security concerns also arose for natural gas, widening the concept to cover other sources of energy (Kruyt et al., 2009).

Energy security was firstly used to refer to energy availability required for accelerating economic growth; accordingly energy security has been defined as the availability of energy to economy (Kruyt et al., 2009; Franki and Višković, 2015). Then, this definition has been developed by several studies over time. For example, some studies attempted to distinguish between secure and insecure levels of availability by introducing some filters such as energy prices. Based on that, energy supply security defined as" the uninterrupted availability of energy sources at an affordable price" (Yergin, 2006; IEA, 2014). However, there is no international specific standard for energy affordability threshold; it differs between countries according to the cost of energy relative to some economic variables such as: Gross domestic product (GDP), inflation rate, and GDP per capita (Kruyt et al., 2009).

Other studies extend the scope of energy security definition to include the impact of energy on social welfare; these studies defined energy insecurity as the loss of welfare resulted from energy prices volatility or environmental pollution from burning fossil fuels (Winzer, 2011).

Regarding the time frame, there are two forms of energy security; the short term energy security, which deals with timely investment to supply energy required for economic development, and the long term energy security which aims to raise energy system efficiency to deal with sudden imbalances between energy supply and demand (IEA, 2014).

In addition to the above definitions, some studies used different concepts to refer to energy security such as: The desire of consumers and producers for affordable energy prices, high revenue from energy exports, access to new reserves by companies working in oil and gas discovery, and the ability of developing countries, like Egypt, to pay for imports of energy required for driving their economies (World Economic Forum, 2006).

Reviewing literature revealed that challenges that may impede achieving energy security can be categorized into five groups (Kocaslan, 2014; IEA, 2007) as follows:
1. Economic risk: Is mainly caused by energy price volatility.
2. Technical risk: Include system failure due to natural disaster (hurricane, volcano, rain, and earthquake), terrorism, and war (IEA, 2007).
3. Political risk: Is brought about by energy exporting countries employing energy as a political weapon.
4. Social risk: It arises from social rejection of certain polluting energy sources like coal and nuclear energy, and from conflicts due to increasing in energy prices.
5. Regulatory risk: Due to poor regulatory policies.

Hedging against previous risks to ensure energy security is highly related to energy system reliability (Makarov and Moharari, 1999). The system reliability has two sub concepts; system adequacy, which aims to raise the ability of the system to meet energy demand of consumers at all times, and system security which describes the ability of a system to cope with sudden imbalances between energy supply and demand (Winzer, 2011). Achieving system reliability requires employing integrated and a comprehensive set of policies such as: Diversifying sources of energy supply, improving energy efficiency, achieving the optimal energy mix, investing in energy infrastructure, encouraging innovation and competition through research and development, reducing vulnerability to energy price fluctuations, and achieving good energy sector governance (Balat, 2010).

This research adopts the definition of energy security from energy supply perspective which defines energy security as the availability of energy to economy. To quantify energy security in terms of availability, the research uses the ratio of total available energy resources (Reserves) to total energy consumption as an indicator for energy security in Egypt. This indicator measures the number of years in which available energy resources can meet expected energy demand. Therefore, higher value of this indicator refers to more improvement in energy security situation in Egypt.

3. RESEARCH METHOD

3.1. System Dynamics

"Jay Forrester" introduced System Dynamics Approach in mid 1950s as a system simulation methodology to understand, visualize, and analyze complex dynamic feedback systems (Feng et al., 2013). System dynamics modeling consists of three basic blocks including stocks, flow, and auxiliaries. The stock represents variable accumulation or depletion over time, stock changes can be done only through flow into or out of the stock, while auxiliaries are used to represent data and mathematical relations (Moumouni et al., 2014).

Feedback process is the major determinant of dynamics of a system. In reality, the complex behavior of the system usually arises from feedback among system's components, not from the complexity of the components themselves (Sterman, 2000). The important tools to represent feedback process within the system are causal loop diagram (CLD) and stock and flow diagram (SFD). The CLD is used for capturing feedback structure of systems. There are two types of feedback loops; positive (self-reinforcing) loops which amplify whatever is happening in the system, and negative (self-correcting) loops which counteract and oppose change (Sterman, 2000). On the other hand, SFD helps in studying, simulating, and analyzing the system in a quantitative way.

3.2. Model Structure

In the light of research objective and data availability, the structure of system dynamics model consists of four main sub-models; economic, population, environment, and energy.

There are interactions and feedbacks between system variables over time, and across sub models in the system.

The major feedback loop in the model is presented in Figure 1. This loop assumes that population provides the economic system with labors required to generate production, and hence increase in total energy consumption. At the same time, energy consumption affects the environment through CO_2 emissions produced by using fossil fuels; this environmental impact causes a decrease in population growth through raising mortality, and so on.

Details about sub-models are described in the next sections, and the equations of the model are illustrated in Appendix A (Tables A1-A4).

3.2.1. Economic sub-model

In the economic sub-model, GDP is assumed to be generated based on three main factors; labor, capital, and total multi factor productivity. This model is a macroeconomic growth model, and it consists of the following five equations:

$$K_{t+1} = K_t + I_t - D_t \text{ [Capital Accumulation Function]} \quad (1)$$

$$Y_t = K_t^{v*} L_t^{1-v} * MFP_t \text{ [Gross Domestic Product Function]} \quad (2)$$

$$C_t = cY_t \text{ [Consumption Function]} \quad (3)$$

$$S_t = Y_t - C_t \text{ [Saving Function]} \quad (4)$$

$$I_t = S_t * SI_t + LO_t \text{ [Investment Function]} \quad (5)$$

Where:

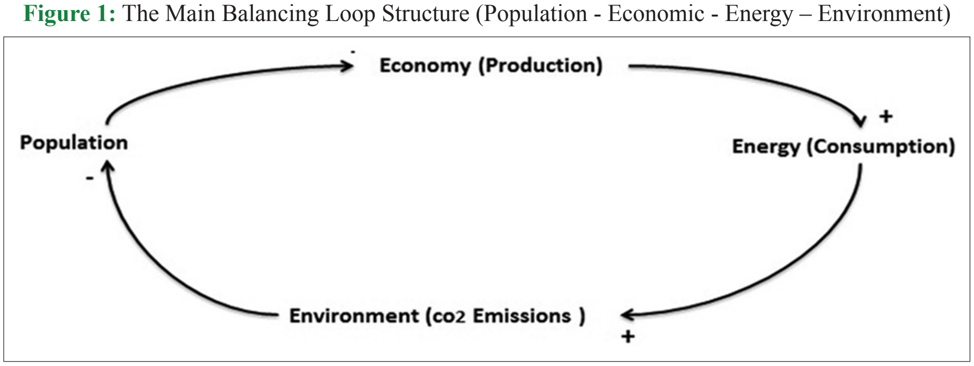
- K_{t+1} stands for capital at time t+1, L_t stands for labor at time t, D_t stands for capital depreciation at time t.
- Y_t stands for GDP at time t, MFP_t stands for total multi factor productivity, V and 1−V stand for capital and labor productivity respectively.
- C_t Stands for consumption at time t, c stands for average propensity to consume.
- I_t, S_t, and LO_t stands for investment, saving, and loans respectively at time t.
- SI_t stands for the ratio of investment to saving.

According to economic sub-model, consumption amount is assumed to be a portion of output; namely, average propensity to consume, saving is equal to output less consumption, and investment is financed from saving and loans.

The economic sub-model consists of two sub-modules; the capital stock module and total multi factor productivity module, in addition to labor factor which is represented in the model as a dynamic variable.

Since capital stock data isn't available in Egypt, it has been estimated in this research using capital output ratio. The value of capital output ratio has been estimated to take the value 4 for Egypt (Ibrahim, 2010). Thus, initial capital stock value is supposed to be 4 multiplied by output (GDP).

Figure 1: The Main Balancing Loop Structure (Population - Economic - Energy – Environment)



While, total multi factor productivity measures the part of economic growth that cannot be explained by increased utilization of capital and labor (Das et al., 2015), it is modeled using Cobb-Douglas function under the assumption that the income share going to labor and capital is equal to their contribution to productivity according to the following equation (Ibrahim, 2010):

$$MFP_{t+1} = MFP_t + \Delta MFP_t \quad (7)$$

$$MFP_t = \frac{HRGDP}{L_t^{ls} K_t^{ks}} \quad (8)$$

Where MFP_{t+1} is total multi factor productivity, HGDP, is historic real GDP at base year (2007). Ls, and Ks are labor income share and capital income share at time T respectively. The economic model SFD is illustrated in the following Figure 2.

3.2.2. Population sub-model

Population is an essential factor affecting energy demand and energy security through its impact on economic growth (Feng et al., 2013; Darmstadter, 2004). In this model, birth rate and mortality rates are assumed to be the main mechanisms of population growth according to the following equation:

$$P_{t+1} = P_t + BR_t - MR_t \quad (9)$$

Where P_{t+1} is the stock of population at time t+1 and BR_t and MR_t are birth rate and mortality rate at time t respectively. Accurate data about immigration are not available in Egypt; therefore, immigration factor is excluded from the model.

The annual mortality rate is decomposed into normal mortality rate and mortality rate due to CO_2 emissions.

The effect of CO_2 emissions on total mortalities can be estimated according to the following equation:

$$DCO_2 = CO_2 * DCO_2R \quad (10)$$

Where DCO_2 is the annual mortalities due to CO_2 emissions, CO_2 is the annual volume of CO_2 emissions by tones, and DCO_2R is the number of mortalities per ton of CO_2 emissions. The population sub-model SFD is presented in Figure 3.

3.2.3. Environment sub-model

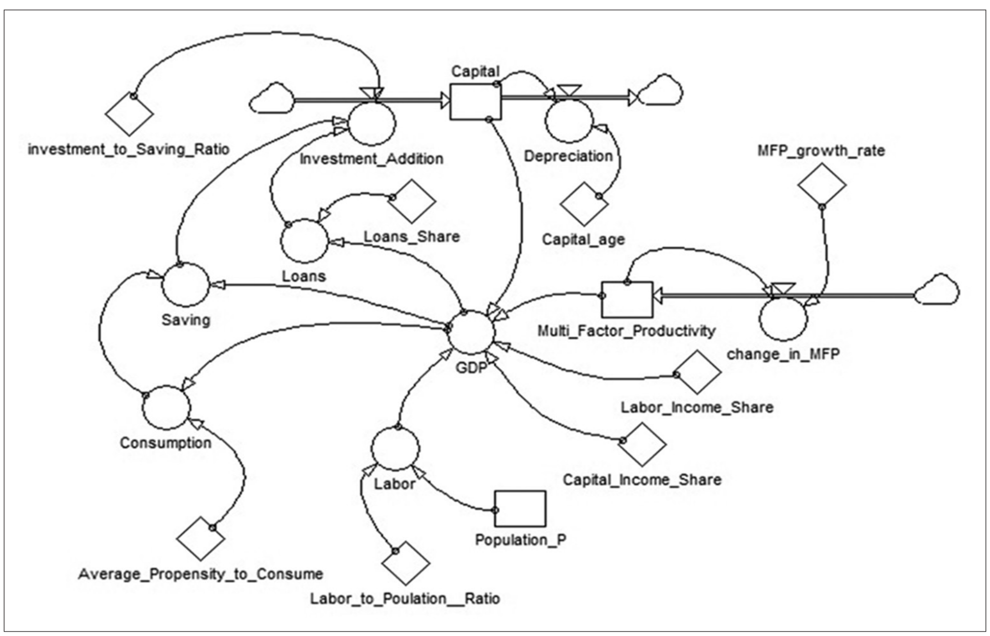
This model is based on CO_2 emissions as a major component. CO_2 emissions expanded rapidly during the last 7 years in Egypt by 23.9% average growth rate. Its value reached about 197.1 million tons in 2014 compared to 159 million tons in 2007. The high share of fossil fuels in energy consumption structure about 94.4% is considered the main contributor to the rise in total CO_2 emissions.

Investigating the contributions of economic sectors in CO_2 emissions due to energy use in Egypt showed that the largest share of CO_2 emissions comes from electricity sector with 40.8%, while transport sector is the second largest source with 17.6%, followed by industry sector with 16.7%, while only 8.1% comes from household sector (CAPMAS, 2015).

Thus, reducing CO_2 emissions become one of the main strategic objectives of the sustainable development strategy: Egypt Vision 2030, which aims to reduce CO_2 emissions resulted from using fossil fuel by 5% in 2020 and by 10% in 2030 (MOPMAR, 2016).

In this model, the projected CO_2 emissions were simulated according to sources of emissions which are categorized into five

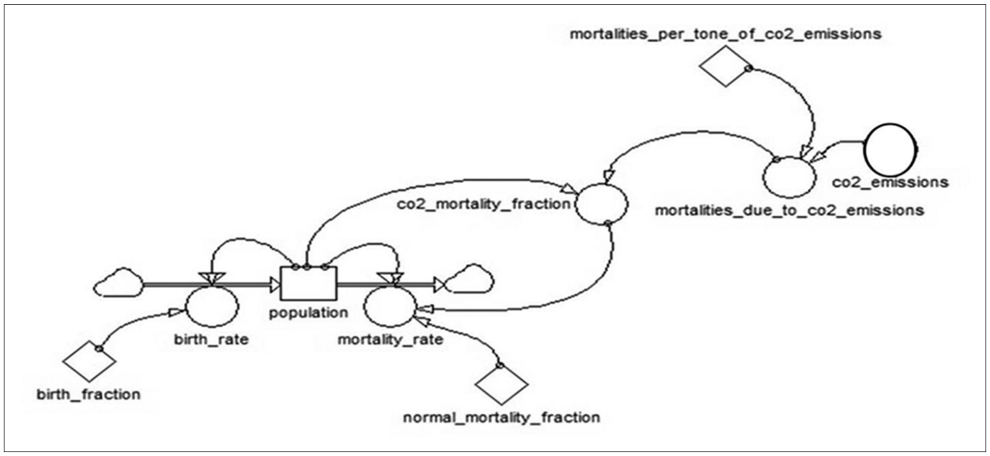
Figure 2: Economic model stock and flow diagram



MFP: Total multi factor productivity

Source: This model is modified from (Yamaguchi, 2011; Ibrahim, 2010).

Figure 3: Population sub-model stock and flow diagram



main sources; industry sector, electricity sector, transport sector, household sector, and other sectors[1]. The corresponding CO_2 emissions SFD is presented in Figure 4.

3.2.4. Energy sub-model

Energy sub model aims to assess the behavior of energy system in Egypt in terms of consumption, production, resources, imports, exports, and security. This sub-model includes three modules according to energy resources which are: Oil module, natural gas module, and renewables module. Oil and natural gas reserves have been used to measure energy resources for these two types of energy, while energy production from renewables (Hydro, solar and wind) has been used to measure resources of renewable energy.

In addition, energy sub-model classified energy consumption in terms of demand sources to industry energy consumption, transport energy consumption, electricity energy consumption, household energy consumption, and other sectors energy consumption, while in terms of energy sources, energy consumption was classified to renewable energy consumption, natural gas consumption, and oil consumption.

According to energy sector profile, Egypt doesn't import or export renewable energy and natural gas, at the time of analysis, accordingly their consumption is assumed to be equal to their production. While, Egypt import and export oil, so that production from oil plus oil imports is equal to oil consumption plus oil exports. The corresponding SFD of energy sub-model is shown in Figures 5-8.

3.3. Model Parameters

The impact of economic, population, environmental factors and the interaction between them on energy security in Egypt can be simulated by changing the eight decisive model parameters which are: Total multi factor productivity growth rate, labor to population ratio, investment to saving ratio, domestic average price of energy, growth rate of reserves from oil and natural gas, birth rate, and growth rate of renewables production.

1 Other sources include: Tourism, Agriculture, Roads and constructing.

Different parameters values in the proposed scenarios are assumed to be the most probable values in Egypt. These values have been developed based on a review of current economic, social, environmental and energy policies in Egypt, in addition to the Sustainable Development Strategy: Egypt Vision 2030.

3.4. Data

Data used in this research are mainly obtained from the published statistics of Egyptian Ministry of Planning, Monitoring, and Administrative Reform (MOPMAR, 2015), the Central Agency for Public Mobilization and Statistics of Egypt (CAPMAS, 2015), Egyptian Ministry of Petroleum (Egyptian Ministry of Petroleum, 2014), and Organization of Arab Petroleum Exporting Countries (OAPEC, 2014).

4. SCENARIOS

To understand the impact of the interaction between the four sub-models on energy security in Egypt, a System Dynamic Model was developed to evaluate seven different policy scenarios from 2007 up to 2030. These scenarios help in exploring available options to energy security with different potentials. These seven scenarios include:

a. Business as usual scenario (BAU).
b. Economic growth scenario (EG).
c. Energy subsidy removal scenario (ESR).
d. New discoveries scenario (ND).
e. Population growth scenario (PG).
f. New and renewable scenario (NR).
g. Multiple policies scenario (MP).

4.1. BAU Scenario

This scenario has been identified according to current economic, population, environment, and energy policies in Egypt. Thus, all model parameters in this scenario have been set to reflect the current trend, and no dramatically changes were assumed.

4.2. EG Scenario

This scenario discusses the impact of increasing economic growth on energy security of Egypt by 2030. High economic growth

Figure 4: Environment sub model stock and flow diagram

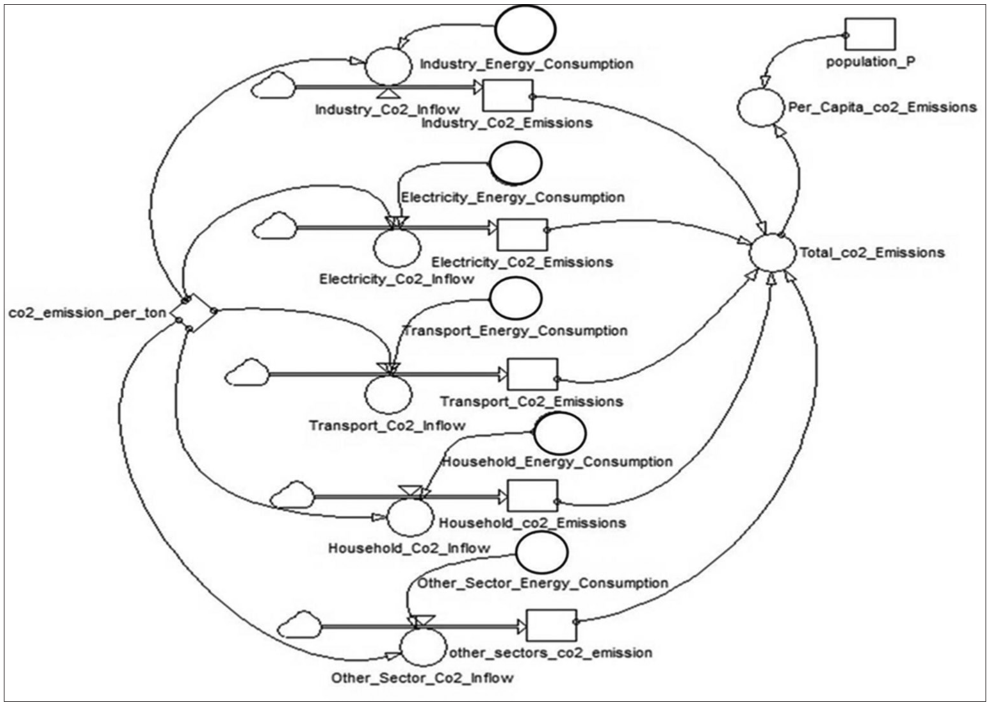
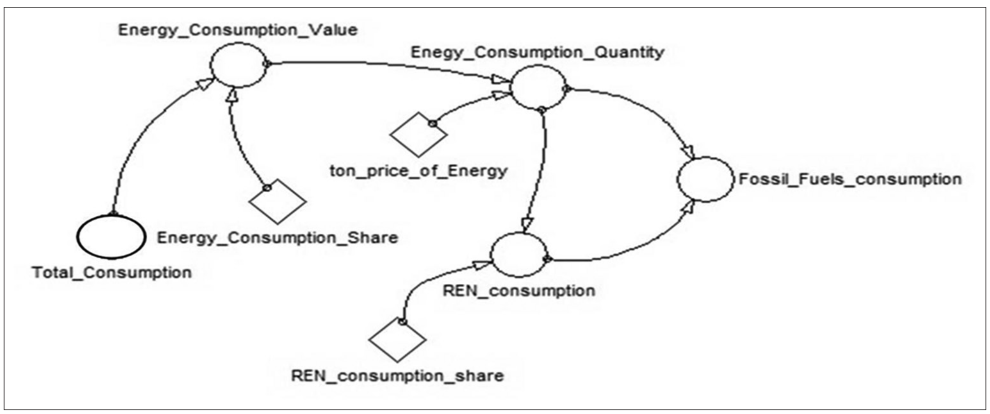


Figure 5: Consumption model of renewables and non-renewables energy



rate is assumed to be achieved by targeting about 6.5% average annual growth rate for total multi factor productivity, about 90% average investment to saving ratio, and about 40% average labor to population ratio between 2007-2030.

The target values for three parameters in this scenario have been calculated based on the targets of the Sustainable Development Strategy: Egypt Vision 2030 (MOPMAR, 2016).

4.3. ESR Scenario

Energy subsidy is one of the critical issues in Egyptian fiscal policies in recent years; due to government's expanding budget deficits.

The Egyptian government has decided, in the middle of 2014, to cut energy subsidies gradually (during 3-5 years starting from 2015) by increasing energy prices paid by businesses and households including (diesel, gasoline, natural gas, and electricity); to reduce energy subsidy burden on the budget. The government announced that this is only the first step in a longer process of energy subsidy reform, which refers to the intention for more increases in energy prices in the next few years. The higher price of energy will encourage consumer to rationalize their energy consumption, and encourage producer to adopt energy saving technology which in turn can reduce the amount of energy consumption. Therefore, by removing energy subsidies for all resources, this scenario assumes that energy prices are expected to double in the future.

4.4. ND Scenario

This scenario discusses how different policies regarding new discoveries of oil and natural gas can affect the future of energy security in Egypt. The largest new discovery of natural gas, declared in 2015 in Egypt, is expected to increase natural gas reserves, and strongly affect the future of energy security in Egypt. Also, in light of government efforts to increase oil reserves, this scenario optimistically assumes about 7% annual growth rate for natural gas reserves and 7.7% annual growth rate for oil reserves, these values represent the highest annual growth rates achieved in

Figure 6: Sectorial model of non-renewables energy consumption

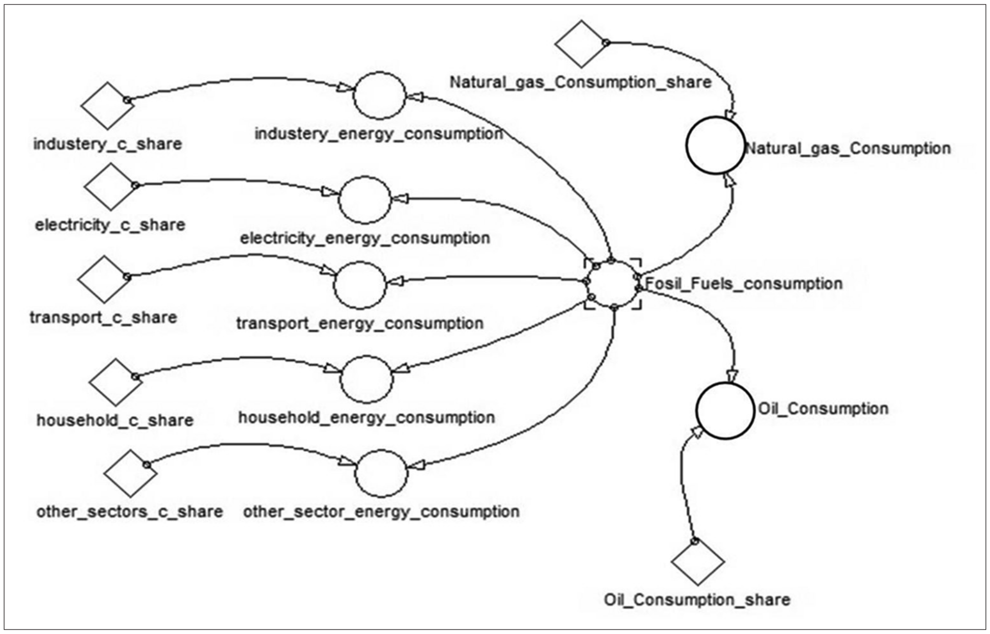
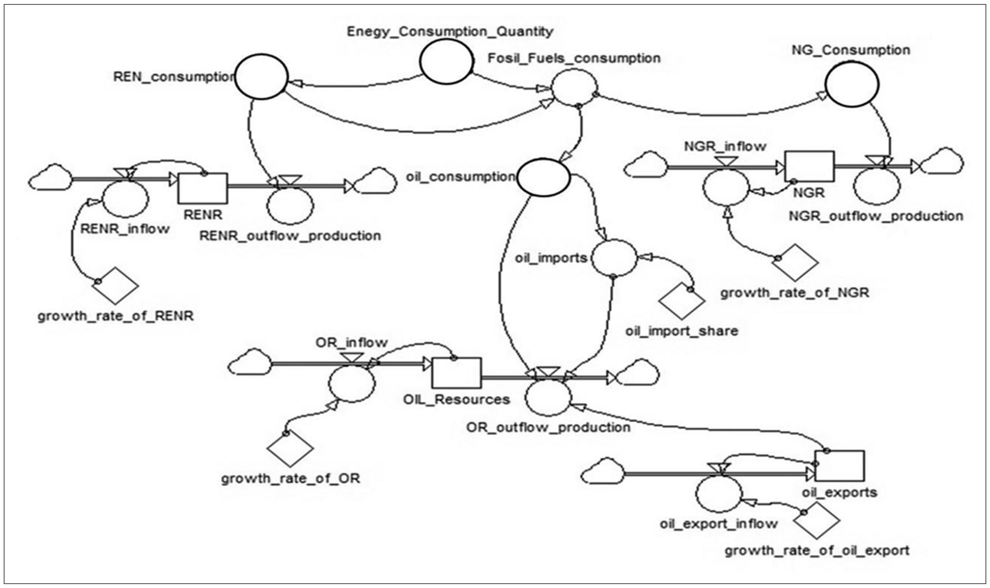
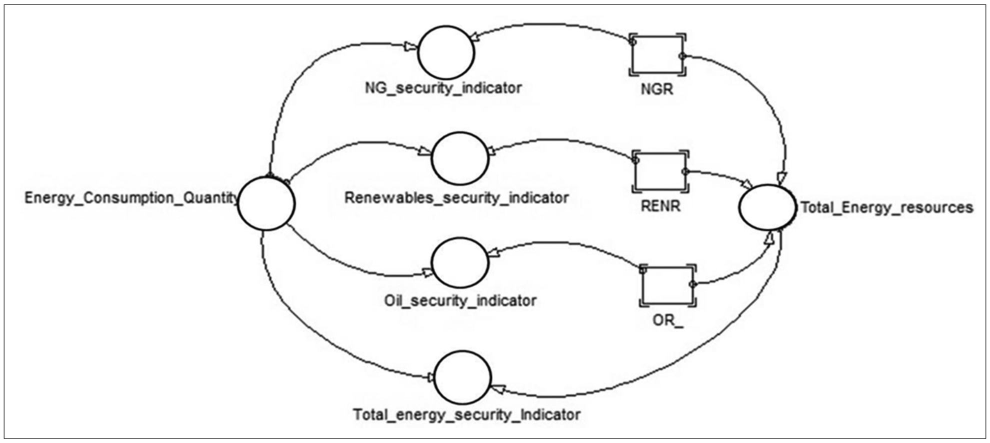


Figure 7: Model of energy resources



1: BAU, 2: EG, 3: ESR, 4: ND, 5: PG, 6: NR, 7: MP

Figure 8: Model of energy security indicators



REN: Renewables energy, NREN: Non-renewable energy, RENR: Renewable resource, OR: Oil resources, NG: Natural gas, NGR: Natural gas resources

Table 1: Values of the parameters in the proposed seven scenarios

Scenarios	Total MFP growth rate (%)	Labor to population ratio (%)	Investment to saving ratio (%)	Average price of energy (LE per Ton)	Growth rate of oil reserves (%)	Growth rate of NG reserves (%)	Birth rate (%)	Growth rate of renewables production (%)
BAU	4	29	83	339.2	4	2	2.9	2
EG	6.5	40	90	339.2	4	2	2.9	2
ESR	4	29	83	678.4	4	2	2.9	2
ND	4	29	83	339.2	7.7	7	2.9	2
PG	4	29	83	339.2	4	2	2.3	2
NR	4	29	83	339.2	4	2	2.9	12
MP	6.5	40	90	678.4	7.7	7	2.3	12

BAU: Business as usual scenario, EG: Economic growth, ESR: Energy subsidy removal, ND: New discoveries, PG: Population growth, NR: New and renewable, MP: Multiple policies

Egypt for the reserves of these two energy resources from 2007 to 2014.

4.5. PG Scenario

This scenario assumes a birth rate of 2.3% on average during the analysis period, where birth rate is expected to be controlled through some population polices to limit the population growth rate. The expected average value for birth rate in this scenario was calculated based on population predictions in 2030 published by Egyptian National Population Council (NPC, 2015).

4.6. NR Scenario

This scenario aims to assess the impact of paying more investments in new and renewable energy on the future of energy security in Egypt. Renewable resources in this scenario include hydropower, solar, and wind, while new energy includes nuclear energy. In the light of challenges facing fossil fuels energy, new and renewable resources can play an important role in the future of energy security in Egypt, which enjoys high potentials for renewable energy especially for solar and wind.

To increase the contribution of new and renewable resources in power generation to than 60% by 2030 in Egypt[2], a 12% average annual growth rate for the production of new and renewable resources is assumed in this scenario.

4.7. MP Scenario

The MP scenario illustrates the impact of considering set of different policies on the future of energy security in Egypt. In this scenario, a combination of different polices that have been discussed in the above scenarios are considered together, which include targeting high economic growth rate, subsidy removal policy, raising the growth rate of new discoveries of oil and natural gas, targeting low population growth rate, and investing more in new and renewable energy.

The assumed parameters values for the seven scenarios are presented in Table 1.

5. MODEL VALIDATION

The system dynamics model explained in the previous section has been simulated using Powersim Software. The model validity is based on "Theil Inequality Coefficient Test," which is defined as follow (Stephan, 1992):

$$U = \frac{\sqrt{\frac{1}{n}\sum (S_i - A_i)^2}}{\sqrt{\frac{1}{n}\sum S_i^2} + \sqrt{\frac{1}{n}\sum A_i^2}} \quad (11)$$

Where:
- S_i Represent simulated data;
- A_i Represent actual data (historical);
- And n represent number of historical data.

The Inequality Coefficient (U) is always between 0 (perfect prediction) and 1(worst prediction). The value of this coefficient for model data registered values lower than 0.2, which mean that the simulation results showed good conformity with most of the historical data as presented in Appendix B (Tables B1-B7).

6. THE RESULTS OF SIMULATION

This section discusses the impact of suggested polices in the different scenarios on available energy resources, energy consumption, GDP, CO_2 emissions, and energy security indicators.

6.1. Analyses of Available Energy Resources

Although the scenario of BAU includes assumptions about 4% and 2% growth rate for oil and natural gas respectively, total available energy resources are expected to decline by 54% on average between 2007 and 2030. This expected decline can be attributed to the high rate of outflow from energy resources to meet energy consumption and oil exports compared to the inflow to these resources. Regarding the different energy resources, findings showed that natural gas is expected to decline from 1831 million tons in 2007 to about 1104 million tons by 2030, also oil is expected to decline gradually and to be completely consumed by 2030, while the effect of new and renewable resources is expected to be ineffective to energy resources in Egypt; due to the weak investments in these energy resources.

Moreover, the simulation results of EG scenario showed a complete depletion in total energy resources by 2027. In this scenario natural gas is expected to be run out by 2029, oil resources are expected to be depleted by 2025, and the effect of

2 Based on unpublished data from ministry of Electricity and Renewable Energy.

Figure 9: Results of different scenarios for natural gas resources (Million tons)

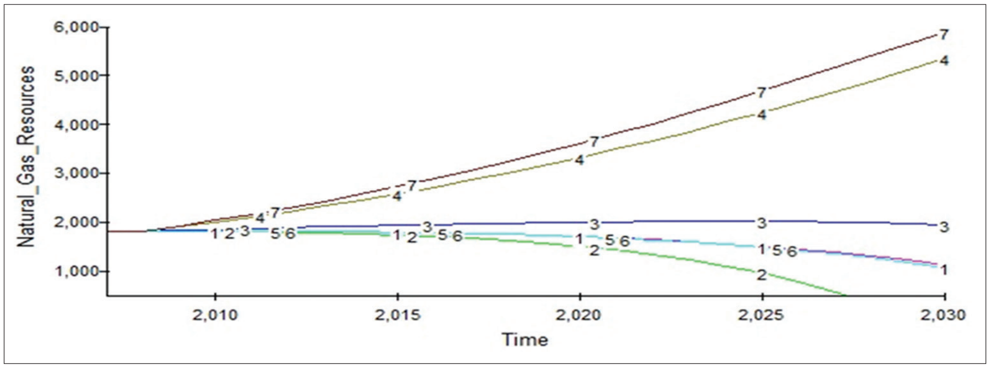
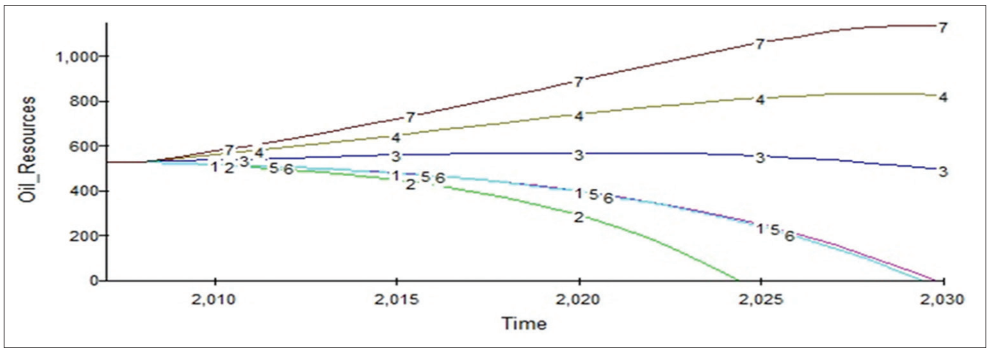


Figure 10: Results of different scenarios for oil resource (Million tons)



renewable resources is expected to remain ineffective. The results of this scenario means that, keeping the current situation of other polices, targeting high economic growth rate leads to an increasing in energy consumption, and therefore gradually decreasing in available energy resources (World Economic Forum, 2015).

While, the results of ESR scenario showed improvements in energy resources availability compared to BAU and EG scenarios; total energy resources is expected to increase by 6.2% between 2007 and 2030, natural gas is expected to grow from 1831 million tons in 2007 to 1995 million tons by 2030, while the timing of complete depletion of oil is expected to extend beyond 2030. Increasing total energy resources in this scenario can be attributed to the expected increase in energy prices due to ESR; high prices of energy leads to a rationalization in energy consumption and thus a reduction in withdrawals from reserved resources.

Similarly, ND scenario showed significant improvements in the performance of total energy resources, oil resources, and natural gas resources compared to all previous scenarios; they are expected to achieve positive growth about 170% for total energy resources, 215% for natural gas, and 38% for oil between 2007 and 2030. The assumption about more investments in new fossil fuels discoveries in this scenario is the reason behind this increase.

Besides, PG scenario showed a little improved result as compared with BAU scenario; total energy resources are expected to decrease only by 51% between 2007 and 2030. The reason behind the decline in energy resources is the assumption that the lower population growth rate leads to a decline in energy consumption and hence a reduction in the withdrawal from available energy resources.

Also, NR scenario showed better results regarding total energy resources comparing to BAU scenario; total energy resources are expected to increase by 5.8% during the analysis period. Beside, new and renewable resources are expected to increase by 147% between 2007 and 2030; this high increase is due to the optimistic assumption of 12% average annual growth rate for new and renewable energy resources in this scenario.

Regarding MP scenario, which is considered the most realistic one, the simulation results showed the best performance for the future of total energy resources. According to this scenario, natural gas, oil, and renewable resources are expected to register high growth rate in 2030 compared to 2007, about 243%, 131%, and 91% respectively. The rise in the growth rates of these resources leads to a remarkable increase in total energy resources between 2007 and 2030 by about 267%.

The simulation results of different scenarios for different energy resources are shown in Figures 9-12.

6.2. Analyses for Energy Consumption, GDP, and CO_2 Emissions

The simulation results showed that there aren't significant differences between BAU, ND, and NR scenarios regarding the expected value of total energy consumption; where this value is expected to reach approximately 262 million tons in 2030, indicating an increase by 201 million tons compared to 2007. For these three scenarios, GDP is expected to increase from 752 in 2007 to 3190 billion L.E in 2030[3]. Increasing in total energy

3 GDP is estimated at constant price for the base year 2006-2007.

Figure 11: Results of different scenarios for new and renewables resources (Million tons)

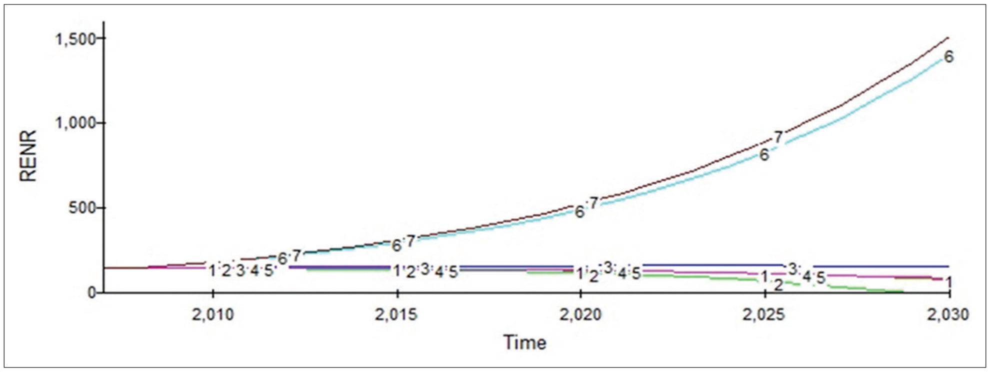


Figure12: Results of different scenarios for total energy resources (Million tons)

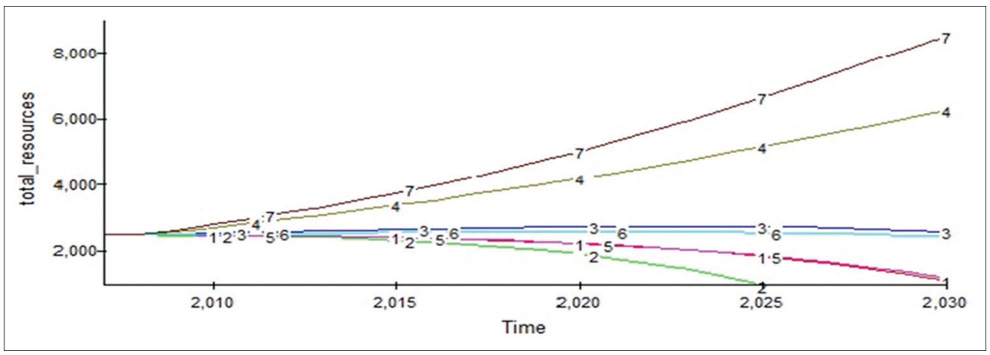
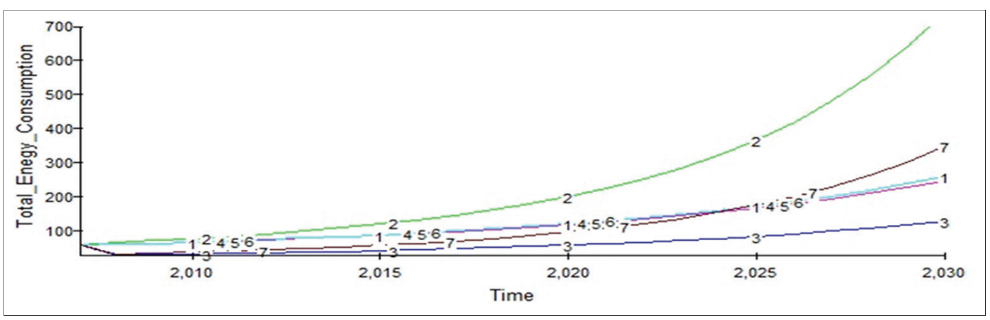


Figure 13: Results of different scenarios for energy consumption (Million tons)



consumption is expected to be followed by increasing in the value of CO_2 emissions from 171.5 million tons in 2007 to about 434 million tons in 2030.

Moreover, the other scenarios showed different impacts on energy consumption, GDP, and CO_2 emissions. Among these scenarios, EG scenario showed the highest expected value for GDP; about 8907 in 2030 compared to 815 billion L.E in 2007, and thus highest energy consumption value about 732.5 million tons, as well as highest CO_2 emissions about 652 million tons in 2030.

On the other hand, ESR scenario recorded the lowest value for total energy consumption, which is expected to reach about 131 million tons in 2030, and accordingly lowest CO_2 emissions about 302 million tons.

The simulation results of different scenarios for energy consumption, GDP, and Co_2 emissions are shown in Figures 13-15.

6.3. Analyses of Energy Security Indicators

The simulation results of BAU scenario showed significant decrease of energy security indicator (total available energy resources to total energy consumption) between 2007 and 2030; the indicator value is expected to decline from 40.6 to 4 years. In this scenario, oil resources is expected to be completely depleted by 2029, natural gas is expected to cover energy consumption for 4 years by 2030, and renewable energy is expected to be ineffective to ensuring energy security due to the assumption of keeping the current situation of weak contribution of new and renewable resources.

Besides, the results of EG scenario showed the lowest energy security performance in 2030; total energy resources are expected to be depleted by 2027, while oil and natural gas resources are expected to be consumed by 2028 and 2022 respectively, thus ensuring energy security after this year is expected to highly depend on imports of oil and natural gas.

Figure 14: Results of different scenarios for gross domestic product (Million L.E)

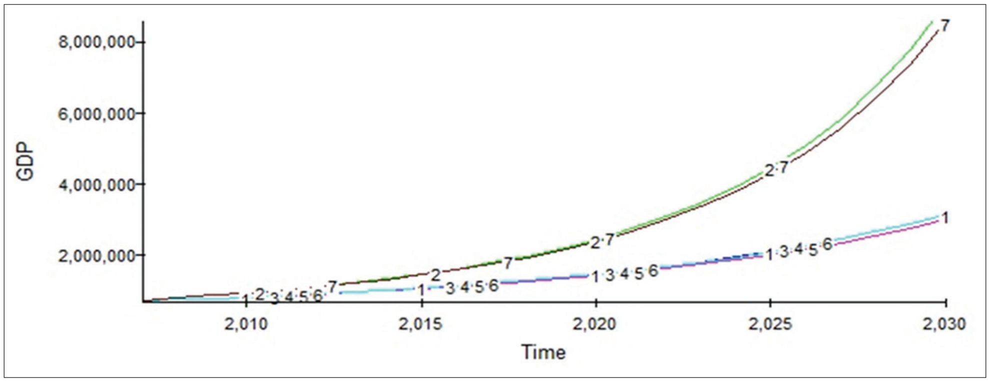
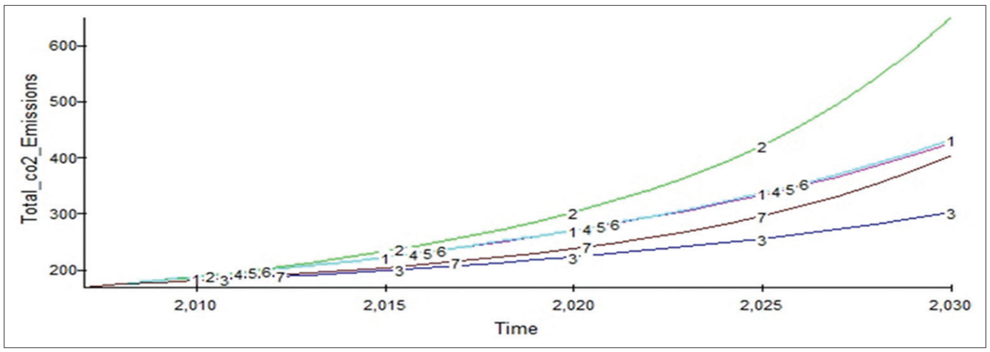


Figure 15: Results of different scenarios for CO_2 emissions (Million tons)



On the contrary, ESR showed improvements in the performance of energy security situation compared to previous scenarios; the value of total energy security indicator is expected to reach 20.4 years in 2030. According to this scenario, natural gas and oil are expected to cover total energy consumption for 15 and 9 years respectively, and new and renewable energy contribution is expected to be still ineffective to energy security.

Among the proposed scenarios, ND scenario showed the best energy security performance especially from 2027 to 2030; the value of total energy security indicator is expected to reach 25.8 years by 2030. In this scenario energy security indicator for oil and natural gas are estimated at 8.4 and 22 years respectively by 2030.

Similarly to the above scenarios, the value of total energy security indicator according to PG scenario is expected to decline during the analysis period; its value is expected to reach 4.9 years by 2030 compared to 40.6 in 2007. Oil is expected to be run out by 2030 and natural gas is expected to cover energy consumption for 4.6 years by 2030.

The NR scenario witnesses the highest contribution of new and renewable energy resources in ensuring energy security in Egypt among other assessed scenarios. According to this scenario, new and renewable resources are expected to contribute by 59% of energy mix in Egypt in 2030, while natural gas contributes by 41%. Moreover, natural gas and new and renewable energy are expected to cover energy consumption for 4.2 years and 6 years respectively, while oil is expected to be depleted by 2030.

Finally, simulation results of MP scenario showed that the value of total energy security indicator is expected to reach about 24.8 years in 2030. Also, energy mix in 2030 is expected to include oil by 13.3%, natural gas by 68.2% and new and renewables by 18.5%. In addition, the expected value of energy security indicator is estimated at 17 years for natural gas and 7.7 years for oil, and about 4.5 years for renewables.

Energy security indicator for total energy, natural gas, oil, and new and renewable energy for the different scenarios are presented in Figures 16-19.

The following Figure 20 summarizes the relationship between expected total energy consumption and energy security indicators for the different seven proposed scenarios in 2030.

7. SUMMARY AND CONCLUDING REMARKS

To project the future of energy security in Egypt, an integrated System Dynamics Model was developed from 2007 to 2030. Energy Security Model in this research is based on the fact that energy security is not a one-dimensional issue; other dimensions including economic sustainability, environmental conservation, and social consideration should be addressed.

The model simulation results showed that continuity of current Egyptian economic, social, environment, and energy policies are expected to have a negative effect on the future of energy

Figure 16: Results of different scenarios for total energy security indicator (years)

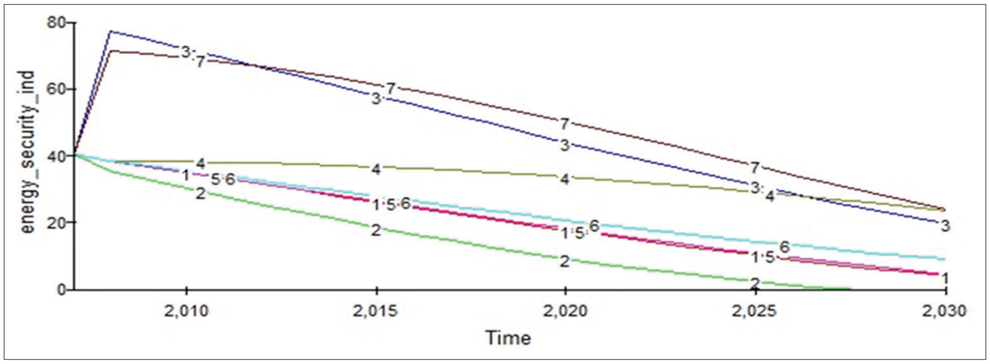


Figure 17: Results of different scenarios for natural gas security indicator (years)

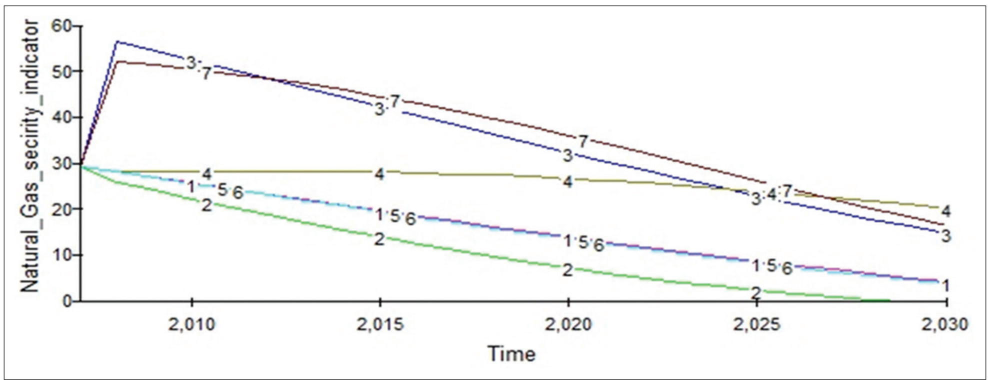


Figure 18: Results of different scenarios for oil security indicator (years)

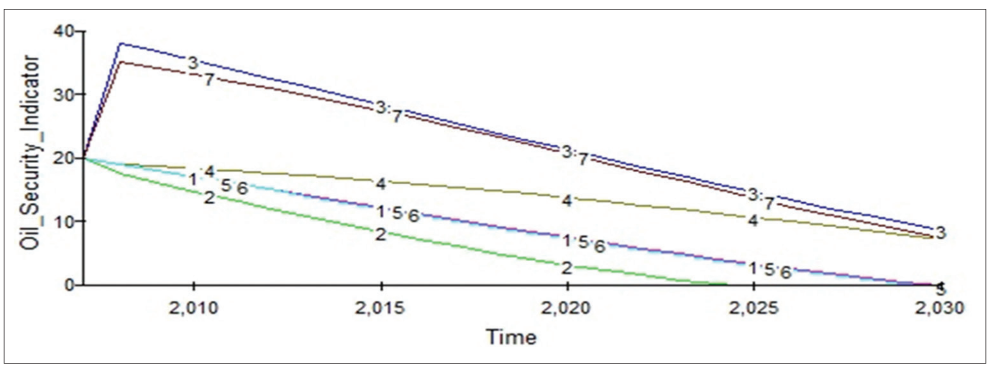
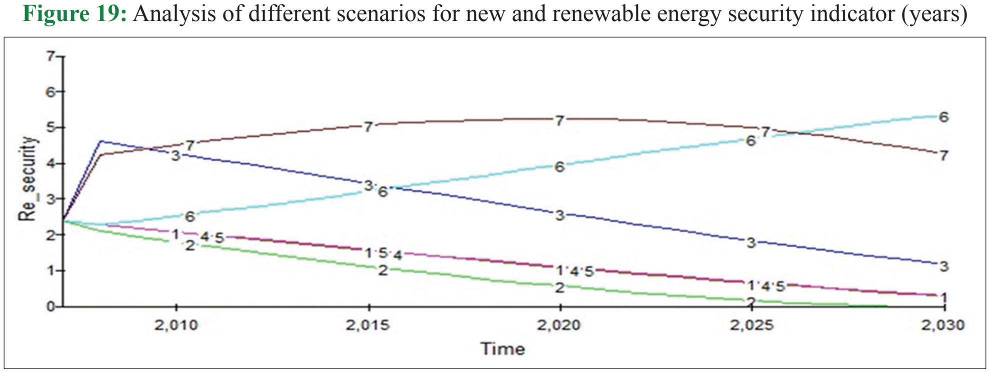
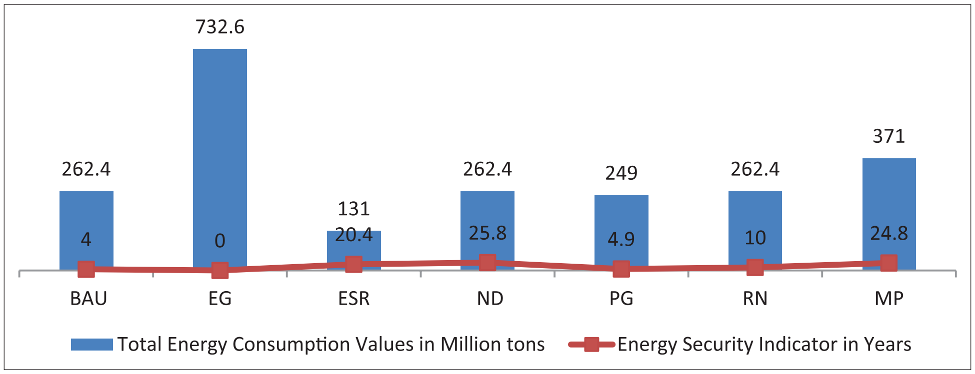


Figure 19: Analysis of different scenarios for new and renewable energy security indicator (years)



security; as the value of total energy security indicator is expected to decline from 40.6 years in 2007 to about 4 years by 2030. On the other hand, the model results showed that maintaining the current level of economic growth rate, and improving energy management policies, through paying more investment in fossil fuels discoveries, removing energy subsidy, and increasing growth rate of new and renewable energy, are expected to improve the value of energy security indicator, which is expected

Figure 20: Total energy consumption and energy security indicator in 2030



to reach about 25.8, 20.4, and 10 years for these three policies respectively.

However, targeting high economic growth rate, in addition to considering a package of energy policies, are expected to have a good effect on the future of energy security in Egypt. According to this perspective, available energy resources are expected to cover energy consumption for 24.8 years by 2030.

Moreover, the simulation results indicated that natural gas is expected to play an important role for the future of energy security in Egypt in most proposed scenarios. Thus, it can act as a bridge for the transition to renewable resources; it provides cleaner and more efficient alternative to oil.

Besides, it is worth to mention that although most of the assumptions in this model are optimistic, simulation results showed that energy security indicator is expected to gradually decline between 2007-2030 for all proposed scenarios. Based on that, to achieve better expectations for the future of energy security in Egypt, the government has to adopt more ambitious policies than assumed in this research.

8. FUTURE WORK

This research is mainly based on the interactions between four sub-models; economic, population, environment, and energy, to assess the future of energy security in Egypt. However, there are other dimensions which can have a great influence on the future of energy security such as technical, political and social factors, which did not taken into consideration in this research due to data limitation. The interactions between these aspects need to be studied further.

Moreover, due to data limitation, this research considered renewable energy as one resource; also it assumes one average price for all energy resources. In case of data availability, future studies can discuss renewables energy separately, also different prices for each energy resource can be considered to precisely describe the future of energy security in Egypt.

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APPENDIX TABLES

Appendix (A): Models equations

Table A1: Economic sub model

Variable type	Left hand side of equations	Right hand side of equations	Units
Stock	Capital	Capital(t-dt)+(Investment Additions –Depreciation)*dt Initial value=Capital output ratio*historic real GDP	LE
Stock	Total MFP	MFP(t-dt)+(Change in MFP)*dt Initial value=Historic Real GDP/[(Capital^Capital Income Share)*(Labor^Labor Income Share)]	LE/year/FP
Inflow	Change in MFP	MFP*MFP growth rate	[LE/year/FP]/year
Inflow	Capital addition	Loans+saving	LE/year
Outflow	Depreciation rate	Capital/average life of capital	LE/year
Parameter	Loans share*	0.077	1/1
Parameter	Capital income share	0.75	1/1
Parameter	Labor income share	1-0.75	1/1
Parameter	Average life of capital	25	Years
Parameter	Average propensity to consume	0.9	1/1
Parameter	Labor to population share	0.29	1/1
Parameter	MFP growth rate	4%	1/year
Parameter	Investment/saving ratio	0.83	1/1
Variable	GDP	(Capital^Capital Income Share)*(Employment^Labor Income Share)*MFP	LE/year
Variable	Labor	Population* labor force rate	People
Variable	Consumption	GDP* Average propensity to consume	LE/year
Variable	Saving	(1-0.9)*GDP	LE/year
Variable	Loans	GDP*Loans share	LE/year

*Only loans share to finance capital addition, MFP: Multi factor productivity, GDP: Gross domestic product

Table A2: Population sub model

Variable type	Left hand side of equations	Right hand side of equations	Units
Stock	Population	Population(t-dt)+(population inflow – population outflow)*dt	People
Inflow	Population inflow	Population* population birth fraction	People/year
Outflow	Population outflow	(Population*normal mortality fraction)+ mortalities due to CO_2 emissions	People/year
Parameter	Population birth fraction	2.9%	1/year
Parameter	Mortalities per ton of CO_2 emissions	0.0000065	(People/ton)/year
Parameter	Normal mortality fraction	0.06%	1/year
Variable	Mortalities due to CO_2 emissions	CO_2 emissions* mortalities per ton of Co_2 emissions	People/year

Table A3: Environment sub model

Variable type	Left hand side of equations	Right Hand side of equations	Units
Stock	Industry CO_2 emissions	Industry CO_2 emissions (t-dt)+(CO_2 inflow)*dt	Ton Co_2
Stock	Electricity CO_2 emissions	Electricity CO_2 emissions (t-dt)+(CO_2 Inflow 1)*dt	Ton CO_2
Stock	Transport CO_2 emissions	Transport CO_2 emissions (t-dt)+(CO_2 inflow 2)*dt	Ton CO_2
Stock	Household CO_2 emissions	Household CO_2 emissions (t-dt)+(CO_2 Inflow 3)*dt	Ton CO_2
Stock	Other sectors CO_2 emissions	Other sector CO_2 emissions (t-dt)+(CO_2 Inflow 4)*dt	Ton CO_2
Inflow	CO_2 inflow	Industry energy consumption* CO_2 emissions per ton	Ton CO_2/year
Inflow	CO_2 inflow 1	Electricity energy consumption* CO_2 emissions per ton	Ton CO_2/year
Inflow	CO_2 inflow 2	Transport energy consumption* CO_2 emissions per ton	Ton CO_2/year
Inflow	CO_2 inflow 3	Household energy consumption* CO_2 emissions per ton	Ton CO_2/year
Inflow	CO_2 inflow 4	Other sectors energy consumption* CO_2 emissions per ton	Ton CO_2/year
Parameter	CO_2 emission per ton	0.09	Ton CO_2/Ton
Variable	Total CO_2 emissions	Industry CO_2 emission+electricity CO_2 emission+transport CO_2 emission+household CO_2 emission+other sectors CO_2 emission	Ton CO_2
Variable	Per capita CO_2 emissions	Total CO_2 emissions/population	Ton CO_2/Ton/people

Table A4: Energy sub model

Variable type	Left hand side of equations	Right hand side of equations	Units
Stock	Renewable resources (RENR)	RENR (t-dt)+(RENR inflow - RENR outflow (production))*dt	Ton
Stock	Oil resources (OR)	OR (t-dt)+(OR inflow - OR outflow (Production))*dt	Ton
Stock	NGR	NGR (t-dt)+(NGR inflow - NGR outflow(Production))*dt	Ton
Stock	Oil export	Oil Export (t-dt)+(Oil Export Inflow)*dt	Ton
Inflow	RENR inflow	RENR* growth rate of renewable resources (RENR)	Ton/year
Outflow	RENR outflow (production)	REN consumption	Ton/year
Inflow	OR inflow	OR* growth rate of OR	Ton/year
Outflow	OR outflow (production)	Oil consumption –oil imports+Oil Exports	Ton/year
Inflow	NG inflow	NGR* growth rate of NGR	Ton/year
Outflow	NG outflow (production)	NG consumption	Ton/year
Inflow	Oil export inflow	Oil export* growth rate of oil exports	Ton/year
Parameter	Energy consumption share	0.031%	1/1
Parameter	Price per ton	339.2	L.E/Ton
Parameter	NREN consumption share	0.045	1/1
Parameter	Industry consumption (C) share	0.21	1/1
Parameter	Electricity consumption (C) Share	0.4	1/1
Parameter	Transport consumption (C) share	0.16	1/1
Parameter	Household consumption (C) share	0.07	1/1
Parameter	Other sectors consumption (C) share	0.16	1/1
Parameter	Oil consumption share	0.45	1/1
Parameter	NG consumption share	0.55	1/1
Parameter	REN consumption share	0.045%	1/1
Parameter	NREN consumption share	1-0.045%	1/1
Parameter	Oil import share	0.32	1/1
Parameter	Growth rate of renewable resources (RENR)	2%	1/year
Parameter	Growth Rate of NGR	2%	1/year
Parameter	Growth rate of OR	4%	1/year
Parameter	Growth rate of oil export	2%	1/year
Variable	Energy consumption value	Consumption*energy consumption share	L.E/year
Variable	Energy consumption quantity	Energy consumption value/price per ton	Ton/year
Variable	REN consumption	Energy consumption quantity * REN consumption share	Ton/year
Variable	Non REN consumption	Energy consumption quantity - REN consumption	Ton/year
Variable	Oil consumption	NREN consumption* oil consumption share	Ton/year
Variable	Oil imports	Oil consumption* oil import share	Ton/year
	NG consumption	NREN consumption* NG consumption share	Ton/year
Variable	Industry energy consumption	NREN consumption* industry consumption (C) share	Ton/year
Variable	Electricity energy consumption	NREN consumption* electricity consumption (C) share	Ton/year
Variable	Transport energy consumption	NREN consumption* transport consumption (C) share	Ton/year
Variable	Household energy consumption	NREN consumption* household consumption (C) share	Ton/year
Variable	Other sectors energy consumption	NREN consumption* other sectors consumption (C) share	Ton/year
Variable	Total energy resources	RENR+OR+NGR	Ton
Variable	Oil security indicator	Total energy consumption/oil resources	Years
Variable	Renewable security indicator	Total energy consumption/renewable resources	Years
Variable	Natural gas security indicator	Total energy consumption/natural gas resources	Years
Variable	Total energy resources security indicator	Total energy consumption/total energy resources	Years

NGR: Natural gas resources

Appendix (B): Model validation results (historical versus simulated data)

Table B1: GDP in Egypt from (2007/2008-2014/2015)

Years	GDP at constant price for year 2006/2007 in million LE	GDP simulated data	Error %
2007-2008	761398.2	752166	1.2
2008-2009	796835.7	784946	1.5
2009-2010	837741.3	820220	2.1
2010-2011	853970.2	858233	−0.5
2011/2012	873054.3	899256	−2.9
2012/2013	892516.7	943593	−5.4
2013/2014	912504.7	991583	−8.0
2014/2015	941082.4	1043606	−9.8

GDP: Gross domestic product

Table B2: Population in Egypt from (2007-2014)

Year	Population in million person	Population simulated data	Error %
2007	73.6	73.6	−0.06
2008	75.2	75.1	0.01
2009	77	76.9	0.10
2010	78.7	78.6	0.02
2011	80.5	80.5	0.05
2012	82.4	82.3	0.12
2013	84.3	84.6	−0.39
2014	86.2	86.8	−0.71

Table B3: CO_2 emissions in Egypt from (2007-2014)

Years	CO_2 emissions in million tons	CO_2 simulated data	Error %
2007	159	171	−7.0
2008	166.7	177	−5.8
2009	177	183	−3.3
2010	182	189	−3.7
2011	192	195	−1.5
2012	197	202	−2.5
2013	197.1	209	−5.7

Table B4: Natural Gas Reserves in Egypt from (2007-2014)

Years	Natural gas reserves in million tons	Natural gas simulated data	Error %
2007	1831	1831	0.01
2008	1947	1835	−5.73
2009	2000	1837	−8.15
2010	1984	1839	−7.29
2011	1850	1838	−0.64
2012	1977	1836	−7.15
2013	1977	1831	−7.40
2014	1961	1824	−7.00

Table B5: Oil reserves in Egypt from (2007-2014)

Years	Oil reserves in million tons	Oil simulated data	Error %
2007	534.2	534	−0.05
2008	575.3	531	−7.71
2009	616.4	528	−14.35
2010	589	523	−11.21
2011	589	518	−12.06
2012	575.3	511	−11.18
2013	575.3	503	−12.57
2014	575.3	494	−14.14

Table B6: Energy consumption in Egypt from (2007-2013)

Years	Energy consumption in million tons	Energy consumption simulated data	Error %
2007	70	61	−13.0
2008	74.2	64	−13.8
2009	77	67	−13.0
2010	81	70	−14.2
2011	83	74	−10.8
2012	87	78	−10.9
2013	86	82	−5.5

Table B7: Theil coefficient test

GDP	0.05
Population	0.007
CO_2 emissions	0.044
Natural gas reserves	0.189
Oil reserves	0.164
Energy consumption	0.130

GDP: Gross domestic product