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An Integrated Energy Economic Interaction Model with Application to Egypt

Yassin Yehia Rady

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An Integrated Energy Economic Interaction Model with Application to Egypt

A Thesis Submitted to

The Ph.D. in Engineering Program

In partial fulfilment of the requirements for

The degree of Ph.D. in Engineering

(with specialization in Mechanical Engineering)

By: *Yassin Yehia Rady, M.Sc.*

Under the supervision of:

Prof. M.A. Serag-Eldin, American University in Cairo
Prof. Emanuela Colombo, Politecnico di Milano
Dr. Matteo V. Rocco, Politecnico di Milano

The American University in Cairo

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Dedication

To my parents, my best identity is that I am your son.

To Yasmin,

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NOMENCLATURE

Symbol	Name, Unit
$\mathbf{Z}_0$	Endogenous transaction matrix, hybrid units
$\mathbf{Z}_N$	Endogenous transactions in monetary value between the non-power generation sectors, USD
$\mathbf{Z}_E$	Endogenous transactions in physical units between the power generation sectors and themselves, TWh
$\mathbf{Z}_U$	Endogenous flow of products in monetary values from the common sectors to the power generation sectors, USD
$\mathbf{Z}_D$	Electrical energy supplied to the common sectors of the economy from electrical energy production plants, TWh
$\mathbf{y}_0$	Final demand vector, hybrid units
$\mathbf{y}_N$	Final households demand on economic sectors other than power generation sectors, USD
$\mathbf{y}_E$	Final households demand on power generation sectors. TWh
$\mathbf{A}_0$	Technical coefficients matrix, hybrid units
$\mathbf{A}_N$	Technical coefficients matrix of the production sectors other than power generation sectors, USD/USD
$\mathbf{A}_E$	Technical coefficients matrix of the energy sectors, TWh/TWh
$\mathbf{f}_0$	Households' final demand vector, hybrid units
$\mathbf{f}_N$	Households' final households demand on economic sectors other than power generation sectors, USD
$\mathbf{f}_E$	Households' final households demand on power generation sectors. TWh
$\mathbf{b}_0$	Exogenous transactions coefficients matrix, hybrid units
$\mathbf{b}_N$	Exogenous transactions coefficients matrix of non-electricity generation sector, ton_{CO2}/USD
$\mathbf{b}_E$	Exogenous transactions coefficients matrix of electricity generation sector, ton_{CO2}/USD
$\mathbf{C}_U$	Upstream Cut-off matrix, USD/TWh
$\mathbf{C}_D$	Downstream Cut-off matrix, TWh/USD
$\mathbf{R}_0$	Exogenous transactions matrix, Physical units
$\mathbf{x}_0$	Total production vector, USD
$\hat{\mathbf{x}}_0$	Diagonalized Total production matrix, hybrid units
I	Identity matrix, -
C_{ren}	Renewables installed capacity, GW
EE_{prod}	Electrical energy production, TWh
α, β	Econometric production function coefficients
ε	renewable effectiveness
e_{PE}	primary energy intensity, toe/MUSD
e_{CO2}	emissions intensity, ton/MUSD

Subscripts

n	Number of production sectors in the country
0	Baseline year
N	National economy
E	Energy sector
i	i-th year

Acronyms, Abbreviations

BAU	Business As Usual
BCM	Billion Cubic Meters
BMI	Business Monitor International (A Fitch Group Company)
CAAGR	Compounded Average Annual Growth Rate
CB	Consumption-Based
CGE	General Equilibrium Models
Coal	Imports of Coal
Coal.PP	Ultra-Super Critical cycle
COP21	21st Climate Change Conference in Paris
CSP.PP	Concentrated Solar Power
CSPNG.PP	Hybrid CSP plants
D1-D3	Three hourly time intervals
EEHC	Egyptian Electricity Holding Company
EJ	Exajoules
EI	Energy Intensity
EIA	US Energy Information Administration
EORA	Eora database
EORA 26	Full Eora 26 Multi-Regional Input Output 2015 Tables
EU	European Union
GDP	Growth Domestic Product
GHG	Green House Gases
GLPK	GNU Linear Programming Kit
GW	Gigawatt
HVI	High Voltage Import
HYD	Hydropower resources
Hydro.PP	Hydroelectric power plant
IEA	New Policies scenario developed by International Energy Agency
INDC	Intended Nationally Determined Contributions
IOA	Input-Output Analysis
IRENA	International Renewable Energy Agency
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
MUSD	Million US Dollar
MW	Megawatt
MWh	Megawatt hour

NG	Natural Gas
NG.CCPP	Natural Gas Combined cycle
NG.CHP	Natural Gas Combined heat and power
NG.GCPP	Natural Gas Simple gas cycle
NG-Imports	Natural Gas (imports)
NG-Local	Natural Gas (domestic production)
NPV	Net Present Value
NG.SCPP	Natural Gas Steam cycle
Nucl.PP	Nuclear plant
NUC Res	Nuclear power
OSeMOSYS	Open Source Energy Modelling System
PB	Production-based
PE	Primary Energy
PJ	Petajoules
PV	Photovoltaic
PVL	Photovoltaic large utility plant
PV.roof	Photovoltaic rooftop plant
RAS	A method applied to update the direct coefficients table of input-output tables
RES	Reference Energy System
S1-S5	Five time period, on monthly basis, of the years
SAM	Social Accounting Matrices
SDGs	United Nations Sustainable Development Goals
SOLCSP	Solar power available for CSP
SOLPV	Solar power available for Photovoltaic
TD	electricity Transmission and Distribution sector
TFC	Total Final Consumptions
toe	Ton Oil Equivalent
TWh	Terawatt hour
UN	The United Nations
UNFCCC	United Nations framework Convention on Climate Change
USC	ultra-super critical
WEM	World Energy Model
Wind.PP	Wind plants
WND	Wind power resources

Abstract

Traditional bottom-up energy models have been widely applied to date to assess the impact of the future energy technologies over a specific time horizon, quantifying the direct economic and environmental implications caused by the evolution of the energy sector. However, such approaches ignore the interactions that the energy sector has with other sectors in the economy, hence failing in quantifying the global impact associated with their technologies: this may produce an unfortunate bias in the definition of future energy and environmental policies. The present study assesses, on a nationwide economy scale, the economic and environmental impacts due to the optimal future power generation mix in Egypt, by soft-linking a bottom-up, technology-rich model (OSeMOSYS) with a top-down Input-Output Analysis model (IOA, based on the EORA 26 dataset).

Based on the OSeMOSYS energy modeling framework, the *OSeMOSYS-Egypt* model is developed. The least cost power generation mix is determined for two different electricity demand forecasts, based on both the New Policies demand forecast scenario developed by International Energy Agency and the market research performed by Business Monitor International. The robustness of the obtained results is assessed through a sensitivity analysis on the main exogenous parameters, including costs, efficiency and production targets of energy technologies, capital discount rate, water and natural gas resources availability. The evolution of the Egyptian power sector in years 2018 to 2040 is analyzed: results of the bottom-up energy model are adopted as exogenous parameters to the top-down multi-sector model, as a way of coupling the two aforementioned models.

It is revealed that Combined Cycles, Wind, and Photovoltaic rooftop systems are viable technologies that should be considered in the future Egypt's power generation mix. In particular, among Egypt's abundant renewable energy resources, it is shown that wind

power technology comes first in achieving the proposed target on renewables penetration in the country’s generation mix, and it might be a feasible alternative to replace part of the natural gas share.

To increase the accuracy of the analysis, the original OSeMOSYS framework has been enhanced by imposing the discount rate on capital investments for the energy technologies, as a time dependent exogenous variable; in developing countries in general and in Egypt in particular, discount rates have been known to fluctuate widely.

The derived power generation mix, predicted by the bottom-up model, has been applied to the IOA model in the form of a change in energy technology mix and a change in final demand of electricity. To account for the growth in the national GDP during the temporal planning horizon, an econometric function that relates the growth in GDP to increase in the production of electricity is formulated. Besides the results of the energy model, this approach enables the decision maker to assess the expected primary energy requirements, GHG emissions and water use induced by the evolution of the energy mix in a broader perspective.

It is worth to note that, the results of the bottom-up energy optimization model indicates that the anticipated increase in the penetration of renewables in the power generation mix, would decrease the primary non-renewable energy consumption and GHG emissions directly caused by the power generation sector over the considered temporal planning horizon (2018-2040). However, the application of the IOA model reveals that decarbonizing the power sector alone is not sufficient in achieving neither, the decoupling of the GDP growth and the total primary energy consumption, nor the GHG emissions within the Egyptian economy.

Table of Contents

List of Figures

List of Tables

1. CHAPTER 1: Introduction

1.1. Background

Security and affordability of energy supplies are aspects of paramount relevance in shaping future energy policies and countries' energy power mix. These aspects will become increasingly important in the future, since according to the International Energy Agency (IEA) the global demand for electricity is expected to increase with respect to the current consumption levels between 50% (Sustainable Development Scenario) and 70% (Current Policies scenario) by 2040 [1]. In addition, the IEA estimates that the final consumption of electricity in 2040 will account for 40% of the world Total Final Consumptions (TFC) [1]. Indeed, the main driver for the aforementioned significant increase in the world TFC is the prospective increase in the global population that will reach 10.9 billion in 2100 and the associated increase in the global production [2]. As, illustrated by Figure 1, the six folds increase in the world population between 1900 and 2016 has been associated with a 24 folds increase in the total energy production during the same period [2]. In particular, considering the period between 1900 and 2016, the world population has increased from 1.2 to 7.2 billion and the total energy production has increased from 23 to 548 exajoules (EJ). Therefore, the total energy production is expected to increase considerably during the coming decades to satisfy the expected increase in the demand on energy supplies induced by the globally increasing population.

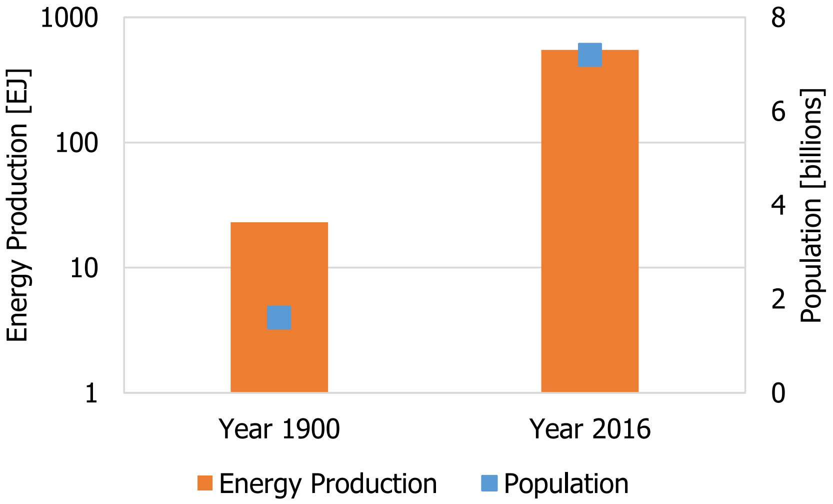

Figure 1. Global population and total energy production, data from [2].

According to various studies, there is a causal relationship between the GDP growth and the energy consumption. This could be justified by the fact that the availability and affordability of energy commodities has apparently become major pillars for the socioeconomic development and the welfare of nations [3,4]. Indeed, disruptions and the associated price shocks of energy supplies could negatively affect the production sectors, and consequently, the economic growth. For instance, the embargo imposed by the major oil producers during the 1970s energy crises has affected the multi-sector performance of the United States [5]. Similarly, Japan has faced unprecedented socioeconomic implications because of the exclusion of approximately 50 MW nuclear electricity generation facilities, after Fukushima accident in 2011 [6]. Prior to the Fukushima accident, Japan power generation mix was planned to be dominated by the nuclear technologies because of the scarcity of fossil fuels. In response to the accident, the Japanese government has increased the installed capacity of the fossil-fuel fired power plants.

Hence, increasing the fossil-fuels imports leading to significant negative effects in the Japanese trade balance [6].

Adding to the requirements of secure and affordable energy supply to assure a continual economic growth and welfare, the term sustainable has been added by the UN in its Sustainable Development Goals (SDGs) for 2030 [7]. In such perspective, the UN encourages deploying energy systems that contribute to the global efforts on climate change control (countries should contribute to keep the global rise in temperature less than 2° C), according to the accord reached during the UN framework Convention on Climate Change (UNFCCC) conference of Paris 21st (COP21) [1]. Fortunately, starting 2015 a decoupling between the global emissions and the growth in the GDP has been reached. That decoupling could be explained by the significant increase in the installed capacity of renewables, the introduction of electric vehicles, and the impact of efficiency programs on the various final energy sectors [1].

Amalgamating the aforesaid characteristics of energy systems, raises a challenging task for policymakers, who are required to define adequate energy policies and take investment decisions over long planning horizons [8]. In this perspective, the definition of effective energy policies requires a holistic overview about the evolution of the power sector which is capable of including the direct, indirect and induced economic and environmental effects caused by the increase in the energy supply and the structural changes in the energy mix. In other words, policymakers must be informed about the global implications that accompany future energy plans defined by means of traditional energy planning approaches.

1.2. Major definitions of energy modeling and optimization models

Energy modeling frameworks are widely recognized as useful approaches for planning future investments towards a viable and sustainable national power sector, one of the various energy sectors. They can be employed to identify the optimum future energy power mix that enables fulfilment of the demand for electricity at lowest cost, in compliance with technical, environmental and political constraints. Moreover, energy modeling frameworks enable policymakers to assess the effects of various uncertainty sources that might arise at both local and global levels, such as fossil fuels prices increase due to geopolitical instabilities [9]. In addition, a proper use of energy models may support the sustainable economic growth of national economies: while contributing in facing the current environmental challenges, an efficient power mix enables to reduce the cost of electricity, thus encouraging foreign investments in sectors different than the energy one, and hence resulting in positive spillover effects.

So far, *bottom-up* energy optimization models have been applied to address the evolution of the power sector by adopting a *Production-based* perspective (PB). The bottom-up models define the least cost energy mix required to satisfy an exogenously defined energy demand [10–12], hence assessing the *direct*[1] economic and environmental implications of future energy scenarios. On the other hand, *top-down* models enable the adoption of a *consumption-based* perspective (CB), allowing to understand the direct and indirect economic and environmental implications of policies and technological changes at a global scale [13]. The CB approaches are always based on Leontief's Input-Output Analysis

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[1] Direct economic and environmental implications are those related to the energy sector only; e.g. the costs of the power generation and CO_2 emissions produced by a power plant.

(IOA), which in its basic form provides a representation of the interlinked monetary flows among segments of the economy [14]. However, while top-down models foreground a reliable analysis of the associated implications of new energy policies on a macro level scale, their high level of aggregation limits their capabilities in estimating the expected impacts due to future changes in the power generation mix. Due to their own features, the two aforementioned approaches may benefit from their integration: establishing a link between bottom-up and top-down models may provide more comprehensive and informative insights related to future energy scenarios at the nationwide economy scale [15]. In particular, bottom-up modeling may support a sustainable economic growth by defining the least cost feasible electricity production alternatives, assuming different scenarios that may occur on the future. Additionally, a top-down approach may enable energy analysts to assess economic and environmental feasibilities of implementing the solutions provided by the bottom-up models, considering the competitive use of natural resources by economic sector other than the power generation sectors.

1.3. Emerging needs for energy models in developing countries

The use of energy models to support policymaking and energy planning activities in developed countries is a well-established practice: the European Commission has financially supported several research projects to model sustainable scenarios related to the evolution of European energy sector. As an example, the PRIMES [16] model allows analysis of national energy sectors to forecast their future energy demand, prices, and supply, while considering the development of their related technologies. For similar purposes, the DICE [17] and MERGE [18] modeling frameworks have been proposed. While developed economies make extensive use of energy models calibrated with high quality data, the same cannot be always said for developing countries, where the financial availability needed to support energy analysts with the state-of-the-art models and solvers packages, and the access to high-quality data are two major challenges.

Developing countries are considered to be the major driver for the expected increase in the demand for energy in 2040, due to their expected socio-economic transformations resulting from a 65% increase in the population living in urban areas and a 135% increase in their per capita income, with respect to the levels of 2017 [1,19]. Fortunately, there is an increase in the application of energy models in developing countries. Among other modeling frameworks, Howells et al. [20] have developed the Open Source Energy Modeling System (OSeMOSYS), defined as a partial equilibrium long-term, energy planning supportive tool with a bottom-up representation of energy conversion technologies. Several recent application of OSeMOSYS can be found in literature: as an example, the recent assessment of the evolution of Sub-Saharan and Tunisian power sectors [21,22]. Due to its open-source nature, which ensures data transparency and results reproducibility, OSeMOSYS is defined as particularly suited to be applied to shape country's energy mix in future energy scenarios [23].

1.4. Egypt's power sector

Among other developing countries, the economy of Egypt is expected to grow rapidly in the next decades [24]: between 2014 and 2015, its average population and GDP growth rates were respectively about 2.1% and 4.4%, resulting in an increase in the electricity peak load by 7.2% (28 GW), with a forecasted value of 85 GW in 2035 [25,26]. Egypt is characterized by a regulated energy market, of which the electricity sector is managed by the state-owned Egyptian Electricity Holding Company (EEHC), which manages electricity production, transmission, and distribution sectors. In order to meet the annual increase in electricity demand between 2011 and 2015, the installed capacities have increased approximately by 30%, from 27 up to 35 GW. In 2015, the installed capacity generated 174 TWh as gross energy. The average annual increases of installed capacity and gross energy generation from 2011 to 2015 are 6.8% and 4.5% respectively. According to 2015 statistics provided by EEHC [26], the natural Gas (NG) fueled thermal power plant is the dominant technology in Egypt's electricity generation mix with 90% share of the total installed capacity. As a result, the natural gas consumption by power plants has increased by approximately 10% from 2014 to 2015 to satisfy the production needs of the new additional capacities [26]. Hydropower (7%) is the second major resource used in electricity generation; however, its utilization is driven by the irrigation and residential demands. Finally, power generated from the other renewable sources is 2%. The electricity produced by the power generators is fed into the country's national transmission grid and delivered to meet various sector demands through distribution networks that cover the majority of the territory [26]. Various alternatives are considered to meet the forecasted demand increase. In particular, additional 15 GW capacity of natural gas combined cycle technology is planned to be in service by 2018. Moreover, to promote the diversification of the power generation mix, the Egyptian government considers adding 7.1 GW coal-fired capacity by 2022: however, this alternative is debatable, as Egypt does not have coal reserves. For that reason, the operating cost of such plants might be escalated due to the incurred coal transportation costs. Considering the increase in the share of the renewable technologies in the production mix, the target share of renewables is set to be 22% by 2022, according to Egypt's Intended Nationally Determined Contributions (INDC) presented in the United Nations conference on climate in Paris, 2015 [26,27]. Furthermore, investments are planned in the electricity trade infrastructure with neighbor countries. Egypt's transmission grid is currently connected to Libya, Sudan, Jordan, and Lebanon [26]. A 3 GW trade connection is planned to link Egypt with Saudi Arabia, which has a different peak load demand profile [26].

According to the data provided by the *Egyptian Electricity Holding Company* (EEHC), the reliability and security of electricity supply of the current mix could be disrupted by eventual shortages in supplies of natural gas. The strong dependence on fossil energy supplies is mainly due to the strong subsidies on fossil energy utilities imposed by the Egyptian government, and it makes Egypt's power generation mix fragile and vulnerable to socio-economic events that may affect the availability of natural gas supplies (like the 2011 turmoil) [28]. Also, the same disruptive effect on Egypt's economic production sectors, including the energy sector, may be caused by a shortage in water, which already occurred in 2016, when Egypt suffered a shortage of 13.5 Billion cubic meter in the available water supplies, which is likely to continuously increase in the future, as the Ethiopian Renaissance dam starts its reservoir filling phase [29].

The demand for electricity and the related demand for primary resources, are strongly related to the growth in economic productivity of all the national sectors. Certainly, the consumption of natural resources by the energy sector is strongly dependent by both the composition of its technology mix and the growth in the national economic productivity. Moreover, since natural resources are also directly invoked by all the sectors of the economy and by the households, it is of paramount importance to analyze the economic system as a whole. Indeed, due to the forecasted significant increase in population and the unsustainable energy market caused by governmental subsidies, managing the evolution of the power generation sector is a challenging task for the Egyptian policymakers, as it may severely affect all the other production activities.

For such reasons, the development of Egypt’s power sector will be a challenging task, and energy modeling could play a key role in assessing optimal future scenarios, hence providing crucial information to policymakers. In this regard, the Egyptian government has already started to consider the use of energy models to plan for a more reliable electric supply [11]. Unfortunately, accurate technical and economic data required to setup reliable energy models are not readily available; this is particularly true regarding references to the costs, average efficiencies and availabilities of the various power generation plants.

1.5. Objective of the Study

The main objective of this research is to construct an Energy-Economy Interaction model by linking a bottom-up model to a top-down model to provide a quantitative assessment of the results of future development scenarios for the power generation sector in Egypt, as an example of a typical developing country. In comparison with developed countries, the developing countries usually suffer from scarcity of reliable data, unpredictable currency exchange rates and discount rates, and unsustainable energy polices; all of which make the proper energy modelling more challenging, yet more vital. The evolution of the Egyptian power generation sector is here assessed within a time period between 2018 and 2040.

Two main energy modelling challenges are addressed. The first of these is while traditional energy models allow deriving the optimal arrangement of the energy sector in future scenarios, only few of them are capable to consider the links and interrelations between the energy sector and the other sectors of the economy: this may cause a bias in results, thus leading to misleading decisions; this shortcoming is equally relevant to both developed and developing countries. Secondly, the few energy models capable to have a holistic and integrated approach (e.g. TIMES-MACRO) are complex and difficult to be implemented in critical contexts, characterized by high level of uncertainty of input data, such as the case of the developing countries.

1.6. Thesis Outline

The rest of the thesis is organized as follows: Chapter 0 provides a general literature overview related to the topic of energy modeling; Chapter 3 presents the Reference Energy System (RES) for Egypt; it also describe the applied energy models, and the soft-link approach adopted for the analysis. This chapter also presents and describes the adopted future scenarios. Chapter 4 reports and discusses the obtained results and their sensitivity analysis to test the uncertainties of the most relevant exogenous parameters as well as the quantitative effectiveness of investing in renewable technologies. Finally, the concluding remarks, and recommendations for future extension of the work are provided in Chapter 5.

2. CHAPTER 2: Literature Review

2.1. Applications of energy optimization models to define the least cost energy mix

2.1.1. Linear Programming Mathematical Models

There are numerous optimization models that are available to determine the optimum contribution of various energy resources in the mix of power generation, among the others, linear programming mathematical models. Komiyama et. al. [30] developed a linear programming model to define the optimum mix of energy sources in Japan. The Japanese energy mix's reliability is mainly affected by the imported fossil fuels from politically unstable regions [30]. In addition, there is a risk associated with the deployment of nuclear power plants after the accident of Fukushima in 2011 [30]. In that study, authors have considered deployment of the available renewable energy resources and energy storage systems to meet Japanese electricity demand by 2030. The developed model in that study aimed to achieve the least cost energy mix, considering costs and capacities of nine available electricity generation technologies, energy demand, the required minimum output of each energy conversion systems, and emissions constraints [30]. The results of that work showed that huge storage batteries were not mandatory in having such systems that rely on massive renewable energy sources [30].

Rentizelas et. al. [31] discussed the cost of externalities associated with various power generation technologies. Although, renewable technologies might be the most environmentally sustainable during their operating phase, the situation might be altered, if a Life Cycle Assessment (LCA) was applied [31]. Rentizelas et. al. [31] developed a linear programming model that included LCA inventory analysis and based on "Cradle to Gravel

Basis" [31]. The model included all of the processing, foundation, operation and decommissioning of each technology. In addition, an estimation of emissions to the atmosphere was considered. The model was applied for the case of Greece for the period of 2012-2050 to reach a decision that minimizes the cost of the power generation. The results of that work showed that external costs of various technologies have a large contribution at the total costs [31].

Muis et. al. [32] developed an optimization model for reducing carbon emission in Malaysia. During the past 50 years, the Malaysian economy has been transformed from an agriculture-based to be an industrial-based [32]. As a result, the amount of greenhouse gases emitted has increased. Unfortunately, Malaysia is ranked to be the most air polluting country in South Eastern Asia region [32]. In that study, the objective function of the developed model was to define the resources' mix that reduces the electricity generation cost and GHG emissions to the atmosphere. In that study, objective function considered the costs of investments, operations and maintenance, of various electricity generation capacities. The constraints of the model considered issues related to the situation of Malaysian electricity market, at the time of performing that study [32]; in particular, the model was constrained to the aggregate demand on electricity, available reserves of primary fuels, GHG emissions limits, and the availability of renewable energy. The results of Muis et. al [32] showed that the proposed model was effective in determining the optimum values of generating mix while meeting the emission limits.

Ozcan et. al. [33] discussed optimization of energy resources considering various factors such as, social, economic, and environmental. The optimization model presented at that study aimed at defining the optimal resource mix for Turkey considering the major generating sources; coal, fossils fuels, solar, wind, and nuclear. The temporal boundary of that study was 11 years. The formulated model was a multi-objective mixed integer programming. Six weighted objective functions were developed that minimize electricity generating cost, carbon emissions, imported energy, and conversion of fossil fuels to electricity. Other objective functions of the model aimed at maximization of social acceptance of the proposed plan and maximization of employment rate. The constraints of the model were set to consider generating capacities and the forecasted demands. The results of that study showed that renewable energy is preferred to the traditional generating technologies [33].

2.1.2. Models based on Financial Portfolio Optimization Theory

The concept of financial portfolio optimization is a tool that could be applied to select the optimum energy mix [34]. Portfolio analysis is well established concept that has been used at the field of the financial sector [35]. This concept of investment mix optimization has been first applied to investment in financial assets by Markowitz in 1950’s [35]. The Markowitz theory could be simply described as, maximizing the expected return and simultaneously reducing the associated risks [35]. Markowitz concluded that every asset assessment should be based on its expected return and variability; the latter is the risk that this asset will have on the whole portfolio of investments. The results obtained by Markowitz shows that diversification of investment usually results in maximizing the expected return and reducing the total risk of the investment value [35]. By definition, a portfolio of multiple assets is considered efficient “if there is no other portfolio available that gives the same return at lower variance of returns” [36] .Consequently, efficient frontier is defined as the set of efficient portfolios for a given problem, from which a one can be considered to be an efficient solution [35].

Shimon Awerbuch and Martin Berger were among the early contributors to the field of energy policies planning, they have adopted Markowitz portfolio theory to the process of selecting portfolios of electricity generation technologies [34]. According to Awerbuch, the objective of defining the energy planning mix should not give excessive weight to the least cost between alternatives, because of the fluctuations in prices and development of technologies over the planning horizons. For instance, if thermal power plants were the most efficient and reliable energy source during the past 50 years, the same decision could not be the same for the next 10 years. Instead, it would be more acceptable to calculate the cost of the energy produced with the associated risks considering the whole generating portfolio, not the cost of the risk of each individual technology only [34]. Similar to the concept of diversification of the financial Markowitz portfolio theory, it was found that adding renewable resources, such as wind and Photovoltaic cells, to the generating mix results in portfolios with reduced costs and risks [34]. In those models, the cost was estimated in terms of the expected return of each technology; in other words, it is the amount of energy generated from investing a unit of money, kWh/$. Awerbuch has considered the European Union (EU) electricity planning problem and tested various scenarios to determine the effects by varying the share of power generation technologies that contributes to electricity generation [34]. A case with an only one type of fuel, oil, has resulted in a higher risk than that obtained from oil and coal mix. The results of the analysis developed in that work showed that existing and the future EU energy portfolio mixes were not optimum, as there are other portfolios that has a higher rate of return at lower risk; i.e. the latter could be achieved by increasing the percentage of the wind energy at the electricity generation mix [34]. Also, Awerbuch concluded that renewable technologies have a significant positive effect on various portfolios and they should be included at each efficient mix [34].

Arnesano et. al. [37] have extended the work of Awerbuch with special application to Italy and considered additional factors. In that study, the life cycle cost of various technologies, regulations on carbon emissions, capacity factor, and a quantified analysis of renewables future development were added to the model. The authors of that study have integrated meteorological and geographical characteristics for a better model implementation at various locations. Carbon emission tax implemented by the EU was considered by the model; i.e. since 2013 each electric power generating facility pays for its carbon emission [37]. Assessing various scenarios, Arnesano et. al. [37] concluded that using more diversified portfolios usually results in a higher expected return associated with low risk. In addition, the hypothesis of associating renewable and nuclear technologies in the mix was tested. The results of that case showed that the latter alternative could result in efficient portfolios that has lower risk, high return, and controlled carbon emissions [37]. So, the dependency on conventional fossil fuel could be minimized by 66% [37]. Similarly, Delarue et. al. [38] have also discussed using of portfolio theory to generate a reduced cost and risk generation portfolio mix. Delarue’s model offers an important understanding of relationships’ between installed capacity, actual generated power, instantaneous power delivery, and ramp limits of conventional power plants. Also, that model has considered the variability of wind power that results from randomness of the wind energy. All of these factors were modeled and solved as a quadratic constrained problem to determine the amounts of installed and generated capacities of various technologies. The results of that work recommends that reduced cost and risk portfolios could be achieved by increasing the wind power and reducing fossil fuel percentages [38].

2.2. Exergy Based Analysis of Energy Systems

Since exergy is the thermodynamic characteristic that represents the available work that could be extracted from different energy resources, several researchers employed exergy based analysis to assess the efficiency of using various natural resources to satisfy energy demand. Bilgen et. al. [39] discussed the importance of exergy analysis to improve energy usage efficiency and alleviate some of the environmental problems, such as global warming, acid rains, and ozone layer depletion. Exergy is used to assess system's departure of a state to a reference environment; it is the most suitable relationship between the second law of thermodynamic and effects on the environment. "Exergy results from the difference in free enthalpy (Gibbs energy) between energy carriers under consideration and the common reference substance in natural environment" [39]. Exergy analysis is considered a measure of imperfections of energy systems; hence, possible ways of improvements could be identified. In that study, exergy was linked to environmental and sustainability concepts [39]. In order to solve dominant environmental problems such as global warming, a quantitative performance measure for environmental problems is needed. Fortunately, exergy function can be used to model and optimize energy conversion systems [39]. Exergy also could be used to explain ecosystems. It could be used to describe an agriculture production system, where growth and survival could be evaluated in terms of thermodynamics [39]. Therefore, eco-exergy could be used as an effective tool to enhance ecological systems management. Industrial ecology is a concept that aims to achieve sustainable production systems [39]. It integrates production processes, operations, and disposal practices. Applying exergy analysis can result in some indicators that reflect characteristics of sustainable power production systems.

Therefore, policy makers should consider exergy analysis to identify the potential opportunities to achieve sustainability[39].

Exergy analysis could also be used in forecasting energy demand, which is one of the major planning factors of nationwide scale economies. Brockway et. al. [40] applied this approach to China. China is the world’s largest energy consumer; however, there are few studies that discuss exergy and useful work in Chinese energy management system [40]. The aim of Brockway’s study was to explore the causes for the change of China’s energy demand, determine the source of exergy efficiency change, and to forecast the future energy demand. Exergy analysis was applied, as it could be used to estimate the thermodynamic quality of the energy carriers, while considering the broader energy supply chain. A key assumption in that study was that “useful work is a better ‘energy parameter’ than primary energy on which to analyze end energy use and economic activity, since it is the last thermodynamic place where energy is measured before it is exchanged for energy services” [40]. Brockway’s study [40] included an exergy time series analysis that was applied to the period of 1971-2010. During this period, the useful work was shown to have increased by 10 folds, primary energy consumption has increased by 4 folds, while the aggregate exergy efficiency conversion has increased from 5% to 12.5% [40].

Yan et. al. [41] discussed the problem of reducing the total energy cost and the exergy losses of a whole energy system supply chain. In that study energy costs and exergy losses were considered from the generation points to the consumption points. The problem addressed by Yan et. al. [41] was modeled as a multi-objective non-linear mixed-integer optimization model [41]. The formulation of that proposed model was based on the fact that “electricity exergy is 100% and the exergy of thermal energy is related to mass flow and the temperature of the energy carrier” [41]. This exergy based optimization model aimed at reducing the total energy cost and reducing exergy losses at the energy conversion step [41]. Constraints of the model were also developed; at the generation level, constraints of capacity, ramping, and fuel consumption were presented [41]. Demand side constraints were also developed considering electricity supplied from the grid [41]. Single objective function that has a weighted sum of both functions was developed [41]. The analysis of that model showed that the major exergy loss occurs during the conversion process. The model was run for various cases, and results showed that when electricity is used to cover all types of the thermal demand, high exergy losses occur. Yan et. al. [41] justified that as the high quality energy carrier (electricity) was used to satisfy the low quality demand of thermal loads.

Somma et. al. [42] applied a multi-objective optimization model that considers both economic costs and exergy assessments of distributed energy systems. Authors of that study [42] concluded that the application of exergy analysis principles in assessing distributed energy systems would improve the efficiency of exploiting primary energy resources. Similarly, Kerdan et. al. [43] highlighted that exergy oriented energy policies could improve the sustainability of the energy sector. Through the application of an exergy-based model, energy analysts would be able to define the prospective changes in the thermodynamic efficiency of the energy conversion systems due to the future energy policies and regulations [43]. Most of the power generation utilities operate with reduced efficiencies over their useful lifetime due to various reasons, such as the part-load operation upon low demand or availability of natural resources in the case of renewable [44]. Colombo et. al. [44] defined a thermoeconomic approach to assess the economic and the environmental effects of energy systems considering the inefficiencies in the operation of power generation utilities. Therefore, it could be inferred that the integration of the exergy based analysis with energy optimization models would be useful in deriving the least cost power generation mix that maximizes the thermodynamic efficiency of the whole energy conversion system.

2.3. Bottom-up energy optimization models in Developing Countries

The relevance of energy modeling frameworks in interpreting emerging and future needs of the energy sectors in developing countries, and in shaping their future optimal expansion capacities has been addressed by several studies. Pandey et al. [45] have highlighted the relevance of having efficient energy policies to avoid the socio-economic problems caused by shortage of energy supplies to the production sectors. Bazmi et al. [46] described the complexity of developing a valid energy policy, which has to consider various technical features related to power generation technologies and other economic factors. Recently, the use of *bottom-up energy optimization models* to shape energy sector policies has emerged as a robust and systematic approach to investigate the future changes in national energy sectors. Urban et al. [47] identified some of the limitations that might hinder applying bottom-up models in developing countries, highlighting the major factors that should be considered for successful application: for instance, consideration of unofficial economy, poor performance of electricity generation sector, and accurate representations of energy demand by other sectors of the economy.

Several research efforts were deployed to match the available bottom-up models to developing countries energy sectors by considering the formerly stated aspects. For instance, building on the available open sources data and geographical information systems, the least cost electrification strategy has been defined for Sub-Saharan African countries [21]. TIMES modeling tool [48] was applied to define the optimal energy generation capacity expansions in South Africa up to 2050 by considering five different demand sectors, with the aim of calculating the overall primary fossil fuels requirements and their related environmental impact. In the Asia-Pacific Economic Region, Malaysia and other 15 countries set up various MARKAL [49] models that consider the specific features of their energy sectors. Eshraghi and Ahadi [50] developed a MILP model to define the optimal choices for the energy sector in Iran, comparing the obtained results with the ones obtained by an OSeMOSYS modeling framework: both models suggested increase of investments in similar technologies. The OSeMOSYS modeling framework was similarly applied to define future energy policies in different regions, briefly described in the following.

Considering South America's available primary resources, Moura et al. [51] concluded that installing mega hydropower capacities and connecting the continent's transmission grids would reduce power generation costs and pollutants emissions. Awopone and Zobaa [52] applied the OSeMOSYS modelling tool to define the Ghana's optimum power generation mix from 2010 up to 2040, concluding that implementing pollutant emissions constraints would result in a more diversified electricity generation mix. Groissböck and Pickl [53] applied an OSeMOSYS model generator to address the evolution of Saudi Arabia's power sector assuming various scenarios for fuel prices, concluding that there is an indirect relationship between the fossil fuel prices and the amount of emissions produced. Taliotis et al. [54] support the significance of deploying energy models in countries where shifts in energy policies are expected. In particular, they developed an OSeMOSYS model to plan for replacement of oil-fired power plants by natural gas-fired power plants and renewables technologies in Cyprus assuming various scenarios and environmental constraints.

Welsch et al. [55] enhanced OSeMOSYS model generator by adding some short range operational constraints in an attempt to address the operational side of the expected energy policies. However, the results of such a model were different from the OSeMOSYS model generator version of 2011, and the authors of that study noted the uncertainties embedded in forecasting operational numerical data input for a long period ahead. Dhakouni et al. [22] assessed the potential of increasing the penetration of renewable energy resources in the Tunisian power generation mix. Based on OSeMOSYS model framework, the authors of that work concluded that higher energy independence of the country could be achieved with minor increases in the costs of the Tunisian electricity system [22].

2.4. Energy-Economy Models (Linked Models)

Bergaman [56] addressed the early trials of assessing of prospective changes in the energy supply sectors on the nationwide economy scale using Computed General Equilibrium Models (CGE)[2]. As presented in various studies, the majority of the top-down models, lack the detailed representation of the energy sectors [14,57,58]. Therefore, the significance of linking bottom-up and top-down models to assess the evolution of the energy sector on a global economy scale was addressed by several researchers. Both of the aforementioned models could be coupled via soft or hard links. In the hard-linked models, the bottom-up and Computed General Equilibrium (CGE) models are solved

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[2] Computed General Equilibrium (CGE) Models [14,61]: are non-linear mathematical models. They are based on social accounting matrices, which are derived from input-output models. CGE models assume a perfect market equilibrium. The objective of CGEs to maximize a utility function of an economy considering the capital inputs, labor, and economic growth rate.

simultaneously within a single code. Jacobsen [59] used a hard-linked model to assess the effect of the financial and technical instruments to reduce GHG emission in Denmark. In that study, authors applied a bottom-up model to assess variations in final consumption of energy commodities driven by technological changes and defined the Danish energy mix [59]. Additionally, a top-down model was used to study the relevant changes in economic policies (e.g. energy taxes). On a similar way, Bauer et al. [60] proposed REMID-R, a hard-linked model, to assess the effect of the timing of the introduction of renewables on the public welfare. PRIMS energy model [16] was deployed in several studies to address the transformation of European energy system in a detailed technological approach considering the influences of market mechanisms, community, and environmental policies. In a literature review study, Gargiulo and Gallachóir [15] presented detailed descriptions of other linked models, such as MERGE and POLES, etc. specifying the capabilities and limitations of each model generator.

In the category of soft-linked models, both of the bottom-up and top-down are solved separately and the result of one of them is utilized as an input for the other. As an illustration, Messener et al. [61] proposed a soft-link between MESSAGE (a bottom-up model) and MACRO (a computed general equilibrium model) to study the impact of the costs of energy supplies on the definition of the energy mix. Similarly, Kober et al. [62] applied a soft-linked model to assess various carbon mitigation policies. In that study, the substitution of technologies was analyzed via an energy optimization model, while a macroeconomic model was deployed to address the implications of increasing carbon taxes on decreasing consumers’ spending and diminishing GDP.

Several researchers have adopted Leontief’s Input-Output Analysis (IOA) model as the top-down models applied to derive various environmental implications induced by changes in the energy policy. Starting from a disaggregated environmentally extended IO table of UK, Daly et al. [63] calculated the direct and indirect emissions, of all production sectors, associated with prospective changes in energy generation mix. On a similar way, Heinrich et al. [64] assessed the socio-economic impacts associated with the removal of coal power plants from Germany's power generation mix. They soft-linked Germany's energy optimization and IOA models, concluding that proposed phasing out of coal technologies is not sufficient for Germany to reach its target level on GHG emissions [64]. The GHG emissions associated with the manufacturing and construction of renewable energy systems and their infrastructures were highlighted among the issues related to comprehensive assessment of energy policies. Such an issue was addressed by Ususbiaga et al. and Mcdowall et al. [65,66] through defining a disaggregated IO tables to assess the nationwide GHG emissions related to increasing the installed capacity of renewable energy systems.

It could be inferred from the review presented that soft-linked models enable a flexible and a broader spectrum of energy policy analysis, as the mathematical formulation inconsistencies between bottom-up and top-down models might hinder the integration between models in a hard-linked architecture.

2.5. Previous applications of energy modeling tools to the case of Egypt

Similar to other developing countries, the evolution of the Egyptian energy sector was addressed in both academic literature and funded consultation projects to define the optimal future energy strategy. Taliotis et al. [67] have applied OSeMOSYS to assess the evolution of the electricity generation sector in Egypt as well as 45 African countries up to

2040, assessing the effects of connecting the electricity transmission network and allowing the electricity trades with other countries. Based on the results obtained from such a model, the total installed capacity in Egypt should exceed 200 GW on 2040 [67]. In a similar way, Davidsson and Hagberg [68] applied OSeMOSYS model framework to 18 African countries, including only industrial, rural and urban electricity demand. The authors of those two studies [67,68] assumed a high level of demand aggregation, and without considering the exact demand load profile for Egypt. Moreover, in the study of Davidsson and Hageberg, wind power technologies were not included in Egypt's electricity production mix, even though Egypt actually has existing wind farms, and plans for many more; indeed Egypt's wind resources are abundant [26,68]. The TIMES model generator was applied to model Egyptian energy sector up to 2035 [69], and results have been obtained based on various scenarios, such as assuming an increase in the price of the fossil fuels, a decrease in the renewable costs, and an introduction of nuclear and coal fired power plants within the current energy mix. Based on that study, the installed capacity should be 130 GW on 2035 to meet the electricity demand, and the expected electricity generation mix would include shares of coal, wind, nuclear, and more than 40 GW of solar technologies [11]. However, access to TIMES model of Egypt, its exogenous parameters, and main assumptions is limited, because that study was performed as a private consultancy to the Egyptian government [11] and the information is classified.

Considering Egypt's nationwide economy scale, Khorshid [70] provided a representation of Egypt's energy sectors in the framework of Social Accounting Matrices (SAM)[3], with an aggregate electricity generation sector that includes all the power generation technologies.

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[3] Social Accounting Matrices (SAM) are expanded input-output tables that cover the distribution of the income in within the economy [86].

Khorshid SAM model has focused on representing the cost, pricing, and flows of energy supplies in both domestic and international markets [70]. In the available literature, there computed general equilibrium (CGE) models applied in Egypt [71,72]; unfortunately, such models lack the detailed representation of the power generation sectors, as they are aggregated with other energy and/or other production sectors [71,72].

In the present study. The proposed model will consider a detailed description of the power generation sector in Egypt, in order to overcome the limitations resulting from the previous studies, mainly related to the high level of aggregation of power generation and energy demand sectors. The majority of the available literature focuses on the developed countries; however, they feature different socio-economic formations from those of the developing countries (e.g. market mechanisms). To address this issue, a robust and simple soft-link will be developed between two open sources bottom-up and top-down models to define the total primary energy consumption and/or other environmental impacts on a nationwide economy scale. The developed methodology is modular and generic, so it is adaptable to different developing countries’ economies and it could be used to drive various economic and environmental indicators to meet the scope of the researchers’ various interests.

3. CHAPTER 3: Methods and Models

This chapter introduces the frameworks of: OSeMOSYS, a bottom-up energy optimization model and IOA, a linear top-down model, which will be used in this study. In addition, the end of this chapter describes the detailed approach of soft-linking the bottom-up and top-down models.

3.1. Bottom-Up Power Sector Modeling Using OSeMOSYS

In this study, the OSeMOSYS model generator [20,73] has been used to optimize the evolution of the power sector during a defined planning horizon. OSeMOSYS is an open-source modular linear programming optimization mathematical model that aims at defining the least cost energy generation mix while considering some techno-economic constraints. Applying OSeMOSYS to satisfy an exogenously defined temporal demand, the minimum requirements of installed capacity of each generation technology and its associated production of electricity will be determined according to a cost minimization criterion. Accordingly, the endogenous variables of direct primary energy consumption and direct emissions production due to the defined power generation mix will be determined. The functional constraints of OSeMOSYS assure that installations of new capacities will be confined to the defined upper and lower limits on the parameters of the investments, the environmental constraints, and the availability of natural resources. In this sub-section, the OSeMOSYS modeling framework will be described, identifying the logic and the major components of the model.

The framework of OSeMOSYS modeling tool

Similar to other linear programming models, OSeMOSYS modeling tool is composed of exogenous and endogenous parameters, an objective function, and functional constraints. The logic of OSeMOSYS is based on the integration of seven aspects affecting the definition of the least cost energy mix, which are called blocks in the terminology of OSeMOSYS. Specifically, those blocks are: (1) the objective of the model, (2) costs, (3) storage, (4) capacity adequacy, (5) energy balance, (6) constraints, and (7) emissions. Thanks to the modular nature of OSeMOSYS, each of those blocks could be extended to cover various energy sectors, i.e. the power sector and/or other energy sectors, such as transportation sector, by adding the related information of the various sectors. Those blocks could be explained as follows [20,73]:

1. ***the objective of the model***: the basic version of OSeMOSYS aims at defining the least cost energy mix to be employed to satisfy a temporally and spatially defined demand. In particular, the least sum of the net present value (NPV) [74] of the annual costs associated with the various feasible solutions will be selected as the global minimum value of the model.
2. ***the costs***: this block represents the total cost incurred by each technology during the whole planning period of the proposed study. Such costs will be discounted to the first year of study based on a given discount rate. The total costs are decomposed to three categories: the operating costs, the capital costs, and the salvage value (generally a negative term in the equation of the cost). The operating costs are variable and they are related to the output of each technology. The capital costs, are the investments costs associated with installation of new capacities.

The salvage value[74,75], refers to the monetary value of the installed capacity at the end of its useful life. Calculating salvage value of an installed capacity of a certain technology depends on: 1- the accounting principle at which the depreciation rate is calculated; 2- the useful lifetime over which the technology is operating [74]. Specifically, if the power plant has an operational life which is shorter than the model temporal horizon, the salvage value of it will be zero by the end of its useful lifetime until the last year of the analysis and will coincide its scrap value. On the other hand, if the useful lifetime of another power plant is greater than the model planning horizon, its salvage value will be determined based on a depreciation rate, defined by the energy analyst. It is worth to note that in some cases, the disposal of a certain asset might require additional expenses [74]. For such cases, those expenses have to be deducted from the cash inflows (selling of the asset) to obtain the net salvage value. For example, the net salvage value of a nuclear power plant is a negative value, since the required expenses associated with handling nuclear waste is higher than the scrap value of the assets of nuclear power plants.

3. ***the storage***: this block represents the storage technologies with their different capacities and operational characteristics. OSeMOSYS allows energy analysts to represent the various storage technologies, such as the pumped hydro-storage, compressed air storage, and flywheel storage in details by specifying the time periods and the rates at which energy will be stored or released. System storage can have a marked effect on reducing installed capacity, by shaving off load peaks.
4. ***the capacity adequacy****:* to assure the continuity of the electrical energy supply, the installed capacity of the various energy conversion technologies should be able to

generate the electrical energy needed to meet the instantaneous demand. OSeMOSYS accounts for the accumulation of the installed capacities over the whole planning horizon as well as the derating factors, such as the availability and capacity factors. The availability factor (a number less than 1), specifies the percentage of a year, during which a power generation technology is expected to be operating. In other words, the higher the availability factor, the less the total period at which each of the studied technologies will *not be operating,* for example due to scheduled and unscheduled maintenance, and breakdowns. Additionally, the capacity factor is attributed to exogenously defined time-slices[4], to account for time intervals during which technologies might not be operating due to the unavailability of the natural resources or operating below the rated capacity; e.g. solar and wind energy resources which are highly variable and random.

5. ***the energy adequacy**:* Energy adequacy considers the efficiency of the energy conversion technologies under different modes of operations[5]. In addition, the representation of the energy adequacy allows for estimating the total requirements of primary energy resources (renewables and non-renewables) needed to be converted to satisfy the forecasted demand.
6. ***the constraints**:* OSeMOSYS includes various functional constraints that are imposed exogenously. Among others, limitations on the availability of natural resources, upper and lower bounds on investments in some technologies, and/or targets for certain penetration of renewable technologies.

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[4] Time-slices: a set of time intervals to describe time fractions of a year. For example, a time-slice could be defined in terms of seasons, months, and the time of the day.

[5] Mode of operations: generation technologies could be working on different modes that produce different energy commodities, such as the electrical energy and the heat produced by combined cycle power plants.

7. ***the emissions accounting:*** the emission accounting in OSeMOSYS allows the energy analyst to estimate the direct emission of one or more pollutants from each generation technology under different modes of operation. Also, it allows for calculating the emission penalty according to a predefined penalty cost (monetary unit per unit of weight of the pollutant released during the energy conversion process). Furthermore, the block of emission accounting is formulated to estimate and impose upper-bound constraints on the emissions released by the energy system annually and during the whole planning horizon.

The main sets[6] of OSeMOSYS are highlighted in Table 1. Table 2 displays the main exogenous parameters, which are the inputs to the model; e.g. costs, upper and lower limits on constraints, capacity factor, etc. Whereas, Table **3** displays the endogenous parameters that will be defined by OSeMOSYS [20,73].

Table 1. Definition of the sets in OSeMOSYS model generator

Set	Description
$\boldsymbol{r}$	Region considered in the model
$\boldsymbol{t}$	Technology: represents any element that produces energy. In OSeMOSYS natural resources are also referred to as technology. In power generation, transmission and distribution are also treated as technologies. Technologies are represented as boxes in the Reference Energy System (RES), as shown in Figure 2.
$\boldsymbol{l}$	Time-slices**:** represents the time fractions of the year. This is a traditional approach in all energy model frameworks to allow temporal description of the annual demands.
$\boldsymbol{f}$	Fuel: represents the energy carriers produced form each technology. Fuels are represented by lines in RES.

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[6] Sets: are the indices to which the exogenous and endogenous parameters will attributed too.

$\boldsymbol{m}$	Mode of operation of technologies. It might happen that a specific technology(s) has more than one mode of operation: e.g. the Combined Heat and Power (CHP) plants could be operating on several modes.
$\boldsymbol{e}$	Emission streams considered in the model: e.g. carbon dioxide and Nitrogen oxide.
$\boldsymbol{y}$	Year in the temporal horizon considered by the model.

Table 2. Main exogenous parameters in OSeMOSYS model generator

Exogenous Parameter	Description
$\boldsymbol{InputActivityRatio\ [y,t,f,m,r]}$	The required number of units of fuel to produce one-unit production by the technology. It is calculated as the inverse of the efficiency in power generation technologies.
$\boldsymbol{CapitalCost\ [\ y,t,r]}$	The investment cost associated with installing new capacities (monetary unit / power unit)
$\boldsymbol{VaribaleCost\ [y,t,m,r]}$	The operating costs of producing one unit of energy by the considered technologies (monetary unit / energy unit)
$\boldsymbol{REMinimumProdcutionTarget\ [r,y]}$	The required share of renewables penetration at the annual power generation mix (%)
$\boldsymbol{TotalAnnualMaxCapicity\ [y,t.r]}$	The upper bound limit of installing new capacities (power unit)
$\boldsymbol{TotalAnnualMinCapicity\ [y,t.r]}$	The minimum amount of capacity of each technology that should be installed (power unit)
$\boldsymbol{EmissionActivityRatio\ [y,t,e,m,r]}$	The amount of emissions produced during the operation of the technology (weight unit / energy unit)
$\boldsymbol{AnnualEmissionLimit\ [y,e,r]}$	The upper limit on the level of emissions to be produced by the considered technologies in the model (weight units)

Table 3. Main endogenous parameters in OSeMOSYS

Endogenous Parameter	Description
$\boldsymbol{NewCapacity\ [r,t,y]}$	The new installed capacity (power units) of technology t in year y and in region r.

$\boldsymbol{RateOfActivity}\ [\boldsymbol{r}, \boldsymbol{l}, \boldsymbol{t}, \boldsymbol{m}, \boldsymbol{y}]$	The energy output (energy units) produced by technology t at mode m, year y, and time-slice l.
$\boldsymbol{RateOfUseByTechnology}\ [\boldsymbol{r}, \boldsymbol{l}, \boldsymbol{t}, \boldsymbol{f}, \boldsymbol{y}]$	The amount of fuel f (energy units) that is required by technology t, in region r, in year y, and in time-slice l.
$\boldsymbol{AnnualEmission}\ [\boldsymbol{y}, \boldsymbol{e}, \boldsymbol{r}]$	The total amount of emission e (weight units) produced in year y, and in region r.

In this research OSeMOSYS-Egypt, was developed by defining parameters of OSeMOSYS modelling tool according to Egypt's power sector, which are presented in the following sub-section.

3.2. Definition of Egypt's Reference Energy System

This section provides the definition and implementation of the Egyptian Reference Energy System (RES) in the OSeMOSYS-Egypt model. Moreover, the main exogenous parameters are presented here based on the analyzed energy scenario. They have been deduced from some scientific publications [68,76,77] and from grey literature, including reports by EEHC [26], World Bank [25] and IEA [1].

A *Reference Energy System* (RES) is the basic structure of all the energy modeling framework. It consists of a graphic representation of the structure of the power generation sector. It is generally composed of four tiers, comprising: *1- Primary energy supply, 2- Power generation technologies, 3- Transmission and distribution infrastructures and 4- Final demand sectors*. The RES adopted for the OSeMOSYS-Egypt model is presented in Figure 2 and is described in the following:

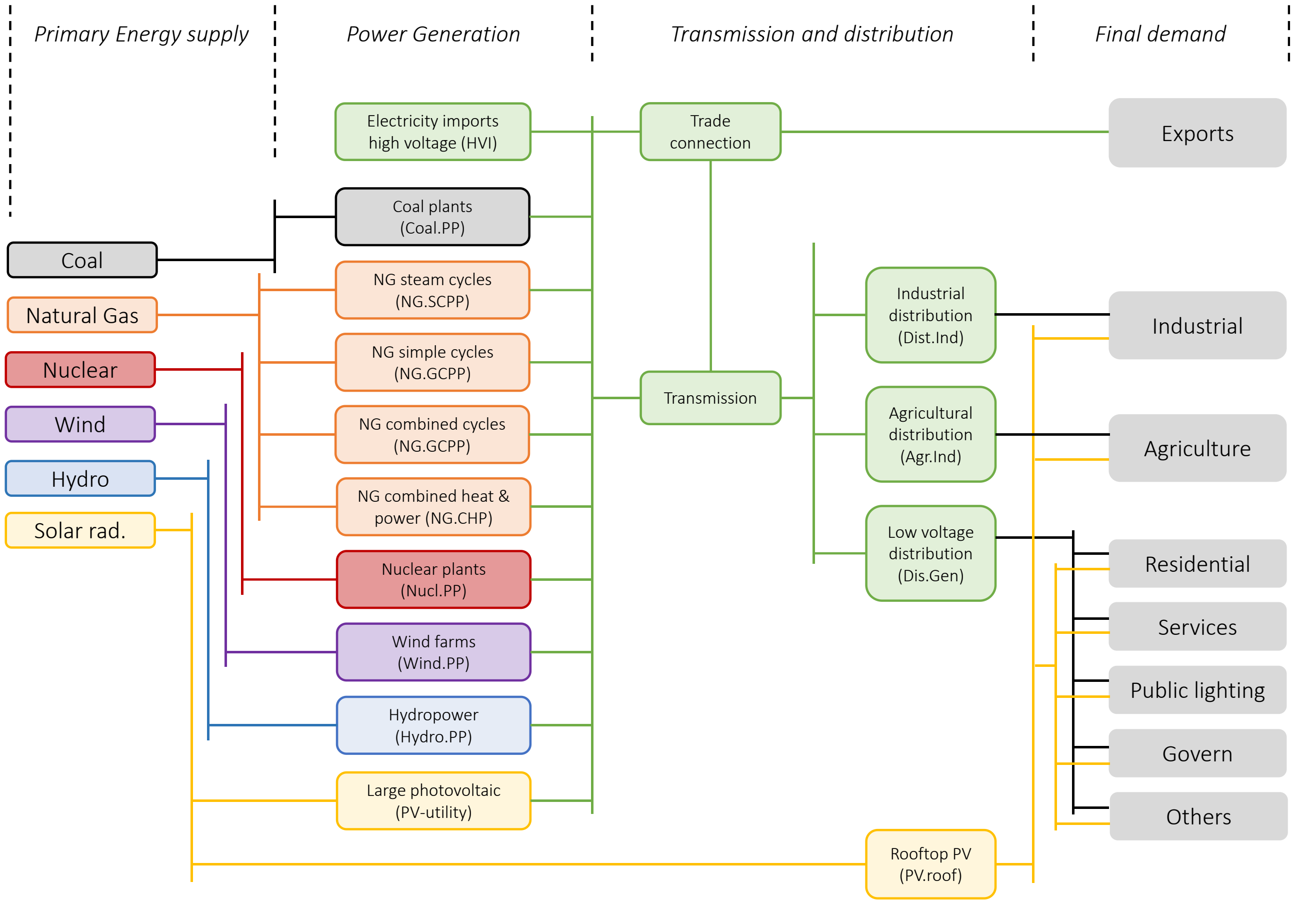

Figure 2. Egypt's Reference Energy System (RES).

Primary energy supply. It represents energy resources that contribute to electricity generation; that is, the maximum allowable resources capacities that could be exploited by each technology. Some of them have been disaggregated according to their supply origin (i.e. domestic vs imported), to enable the application of resources bounding constraints like additional transport costs or availability limits. Similarly, renewable solar and wind energy resources are categorized under different power generation technologies that might be constrained by geographical locations, such as the land resources needed for solar energy applications and suitable wind farm sits. Six different primary energy supplies are available in the Egyptian context (see Table 4): non-renewables (*Coal*, *Natural Gas* and *Nuclear* resources) and Renewables (*Wind*, *Hydro* and *Solar Radiation*).

Although there is a limited utilization of the heavy diesel in some thermal power plants, the heavy diesel is not considered among the energy resources in this study. This could be justified by the Egyptian government's short-term plan of replacing the heavy diesel with natural gas in all power plants [26]; i.e. there is a constraint of not using heavy diesel in thermal power plants in the future energy mix of Egypt.

Power generation technologies. The available power technologies convert primary energy supplies into electricity. Thirteen types of power technologies are available in the Egyptian RES (see Table 5), which are classified based on their input energy resources. *Hydroelectric plants* include all the hydropower technologies currently available in Egypt, which comprise the hydropower plants installed on the Nile stream; namely, the High dam and Aswan dam. Their primary objective, however, is the regulation of irrigation water and hence their control is not optimized for meeting energy demand. Other renewable technologies includes *photovoltaic (PV) plants* (both centralized PV plants and localized rooftop installations), and *wind farms*. Natural gas is simultaneously fed to five technologies: *steam cycles*, *simple gas cycles*, *combined cycles*, *combined heat and power cycles* and *hybrid concentrated solar power plants*. Other non-renewables include *ultra-super critical* (USC) *coal plants* (traditional coal-fired technology are not available due to the lack of domestic coal supply), and *nuclear plants*. Finally, due to the proposed connection of the national electricity grid to neighboring countries' grids, *high voltage electricity imports* are considered as a fictitious power generation technology. The main references employed in the present work for the estimation of fixed and variable costs of power technologies are Davidsson et al. [78], US EIA [79] and IRENA [80].

Transmission and distribution infrastructures. This tier defines technical features for connecting power generation with end users. In particular, transmission infrastructures receive high voltage electricity and deliver it to the distribution infrastructure at different voltages. The latter is disaggregated into three categories to enable a separate allocation of power distribution losses: *distribution to industrial demand* (Dist.Ind), *distribution to general demand* (Dist.Gen) and *distribution to agriculture demand* (Dist.Agri).

Table 4. Main features of the energy resources available in the Egyptian RES.

Energy Resource	*Acronym*
Hydropower resources	HYD
Natural Gas (domestic production)	NG-Local
Natural Gas (imports)	NG-Imports
Solar power available for Photovoltaic	SOLPV
Solar power available for CSP	SOLCSP
Wind power	WND
Coal power (imports)	Coal
Nuclear power	NUC Res

Table 5. Main features of the power technologies available in the Egyptian RES [78–81].

Power technology name	*Acronym*	*Energy efficiency [%]*	*Fixed cost [$/kW]*	*Variable cost [$/MWh]*
Hydroelectric plant	Hydro.PP	-	395	0
Photovoltaic large utility plant	PVL	-	2200	72
Photovoltaic rooftop plant	PV.roof	-	2100	86

Concentrated Solar Power	CSP.PP	-	3647	80
Wind plants	Wind.PP	-	2600	52
Steam cycle	NG.SCPP	35	900	59
Simple gas cycle	NG.GCPP	33	730	72
Combined cycle	NG.CCPP	45	1423	10
Combined heat and power	NG.CHP	85	1140	24
Hybrid CSP plant	CSPNG.PP	-	1687	59
Ultra Super Critical cycle	Coal.PP	37	3519	3
Nuclear plant	Nucl.PP	33	10778	4
High Voltage Import	HVI	-	-	-

Final demand. Electrical energy demand is classified into seven categories: *residential*, *industrial*, *commercial*, *governmental*, *public lighting*, *agriculture* and *others* (including ancillary activities).

3.3. OSeMOSYS-Egypt: setup and application

The Egyptian RES defined in the previous section has been introduced in the OSeMOSYS open-source energy modeling framework [20], together with other exogenous parameters introduced here, and hence resulting in the *OSeMOSYS-Egypt model*. The model defines the least-cost mix of power technologies that should be deployed and operated to satisfy a temporal and spatial energy demand subjected to a set of technical and economic binding constraints. Accuracy of exogenous parameters provided to the model, such as the cost of technologies and the related efficiencies, is of paramount relevance to obtain reliable results. OSeMOSYS-Egypt considers a spatial scope of a single-region economy, in a time horizon between 2008 and 2040. For the period between 2008 and 2015, the model has been calibrated by considering the data available from EEHC, while for future years until 2040 electricity demand has been derived from scenarios data.

3.3.1. Energy scenarios definition

The OSeMOSYS-Egypt model has here been adopted to analyze two different electricity demand scenarios:

IEA New Policies Scenario. This scenario has been defined by the International Energy Agency (IEA) in 2016 [1] considering the implementation of policies already defined or at least announced by world countries, and the way that such policies could be extended to consider the new intentions made by countries to reduce the global emissions as announced at COP21.

This scenario is relevant in analyzing Egypt's power sector, as the data revealed by IEA is the most common source used for the projections and analysis of energy markets [82], with a number of citations referring to this data exceeding 700. Also, it is vital to address the evolution of Egypt's power sector considering the comprehensiveness of the methods applied to define the demand growth according to this scenario. The projections of the demand on electrical energy given by IEA New Policies Scenario have been generated by, with the aid of World Energy Model (WEM) [1], a large-scale simulation tool developed by IEA. The WEM forecasts the performance of energy markets over a long planning time period. WEM [1] considers the effects of the improvements in current technologies, the growth of the power sector, end-users prices, greenhouse-gases emissions, and the trends of investments in energy sectors. The data required for the WEM [1] (e.g. energy demands, supplies, and prices) is acquired from IEA historical data, authorities in IEA member and non-member countries, and other collaborating institutions, such as IRENA.

Referring to the New Policies Scenario [1], Egypt is considered one of the Middle Eastern countries in this study, where the Compounded Average Annual Growth Rate (CAAGR) of electricity demand is 2.6% for the period between 2014 and 2040.

BMI Scenario. This scenario has been defined by *Business Monitor International* (BMI), a Fitch Group Company [83] based on market researches related to the growth in demand on energy commodities in Egypt, specifically. Hence, it provides more accurate estimates of annual growth in demand on electrical energy than those provided by the IEA New Policies Scenario, in which a generalized forecast for all Middle Eastern countries was applied. The BMI methodology is based on a regression models; precisely, the “autoregressive moving average method” [83]. This regression model considers the historical consumption of electricity, population, GDP, and industrial production. BMI incorporates data from different institutions, such as the Egyptian government, the World Bank, and publicly and privately owned companies [83].

According to the BMI forecasts [83], the aggregate increase in electricity demand is defined until 2024, ranging between 3.8% and 5%, while after 2025 up to 2040 it is assumed to be constant and equal to year 2024 (3.8%)[7]. Shares in energy consumed by each national sector are kept constant and equal to the baseline year.

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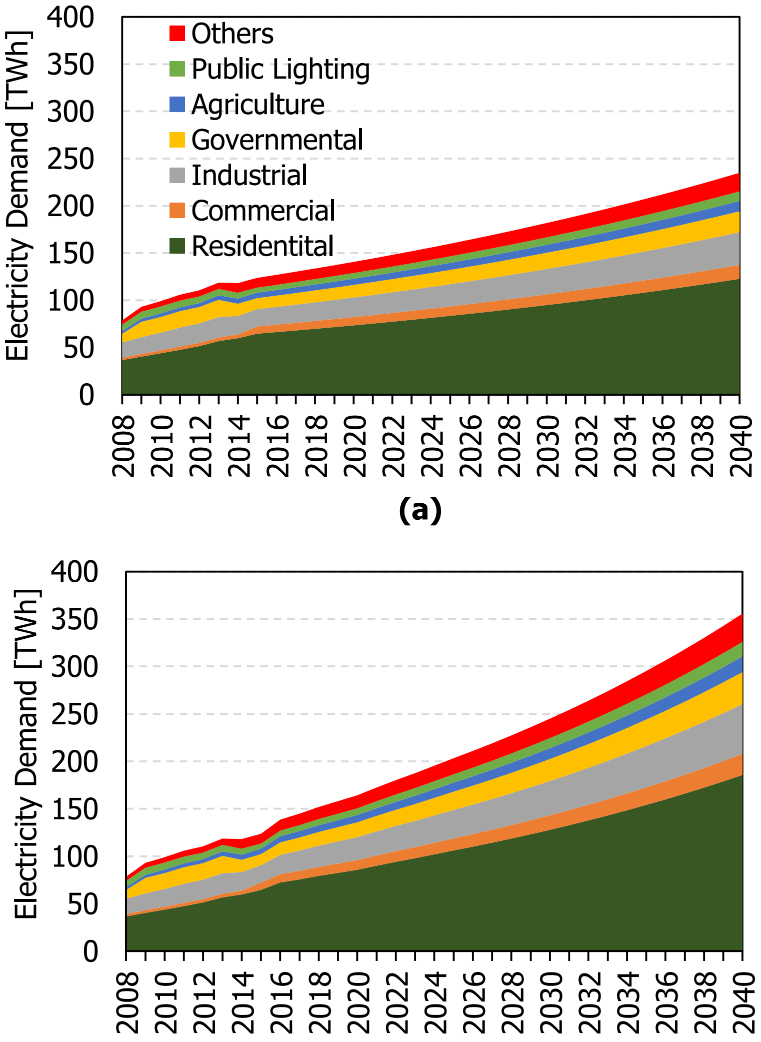
[7] Author’s own assumption due to the limitations of data availability



(a)

(b)

Figure 3. Evolution of the Egyptian electricity demand for IEA (A), data from [1,26], and BMI scenarios (B), data from [26,83].

Notice that the above introduced scenarios define several other features related to the evolution of the energy sector at large, including the prospected change in energy consumption modes of other sectors of the economy, like industry and transport. However, only future increase in electricity demand is assumed as exogenous data for the OSeMOSYS-Egypt model.

The evolution of the Egyptian electricity demand based on the two selected scenarios is represented in Figure 3: while under the BMI scenario, show in Figure 3 (subplot a) it approximately reaches 350 TWh in 2040, under the IEA scenario it equals 234 TWh, shown in of Figure 3 (subplot b). The discrepancy in Egypt’s electricity demand forecasted by the two aforementioned scenarios could be explained by the fact that in IEA scenarios Egypt’s electricity demand growth rates are given as aggregates of the Middle East countries, so this value might be affected by the level of spatial demand aggregation. For both scenarios, it can be inferred that residential and industrial demands are the major drivers for the increased demand on electricity, as displayed in Figure 3 (subplots A and B).

3.3.2. Definition of other exogenous parameters

Definition of the other fundamental exogenous inputs required to setup the OSeMOSYS-Egypt model are here described. Regarding the temporal attribute of the electricity demand, each year of the considered time horizon has been divided into a set of time-slices, and for each slice the type of electricity users have been identified. The set of time-slices has been derived by analyzing the monthly and hourly electricity load profiles provided by the Egyptian Electricity Holding Company (EEHC) [26], represented in Figure 4 (respectively in plots a and b).

As shown in Figure 4 (a), each year of the planning horizon has been divided into 5 seasons: *S1*-*S5*. For instance, the season of *S1* represents the low peak-load months from January to April. Similarly, S3 represents the high peak-load months of June, July, and August. Additionally, the electricity peak-load varies according to the hour of the day.

Therefore, each day has been divided into three hourly time intervals: namely, *D1-D3,* shown in Figure 4 (b), where the interval D3 extends from 7 p.m. to 4 a.m. next day. By coupling the monthly and hourly analysis, each year of the planning horizon has been divided into 15 times interval (*S1D1, S1D2, S1D3, S2D1… S5D3*). To illustrate, the time interval S1D2 could be defined as the sum of the hours of *D2* (from 4 a.m. to 12 p.m.) during the months of *S1.*

A comprehensive and compact picture of temporal attribute of the electrical energy demand for each time-slice is represented in Figure 5 for year 2015: the electricity demand has been divided into a number of monthly intervals, subdivided in turn into different daily intervals [26]. According to the representation revealed in Figure 4, the coupling of the defined monthly and daily intervals results in 15 columns (time slices), covering the whole year. The height of each column is proportional to the average energy demand in each of the time-slices of the year, while its width is proportional to the fraction of time (%) per year on which this energy is required. Therefore, the amount of electrical energy needed by each user type over the typical year is proportional to the sum of area of the rectangle for this user over the entire year. The demand of the residential sector occurs mainly during night hours (D3), while the largest portion of the governmental electricity demand takes place during the daytime hour intervals (D1, D2); hence the largest area for the residential sector are displayed for the slices attributed to D3, whereas the largest ones for the governmental electricity demand are displayed for the slices attributed to D1 and D2.

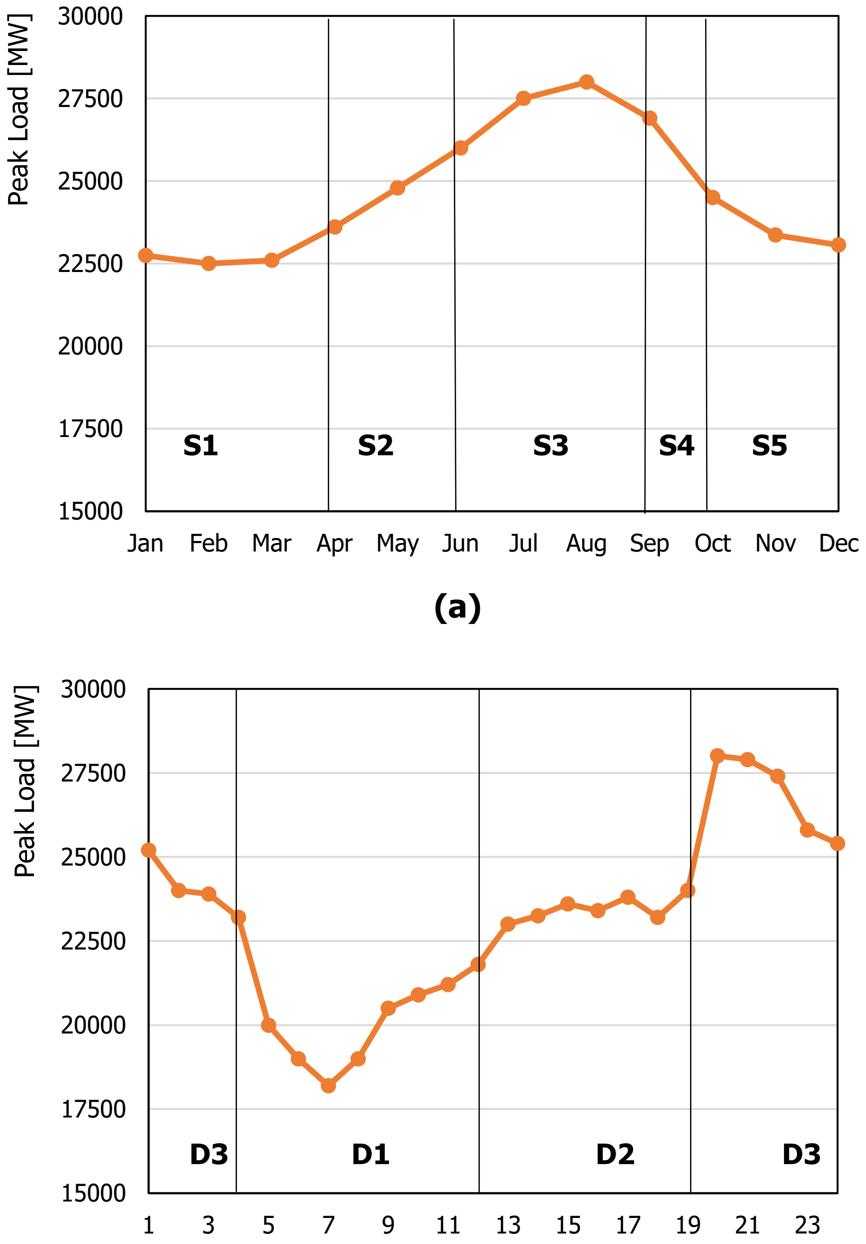


Figure 4. Egypt's peak load profile in years 2014-2015; (a) monthly and (b) hourly yearly averaged demand, data [26].

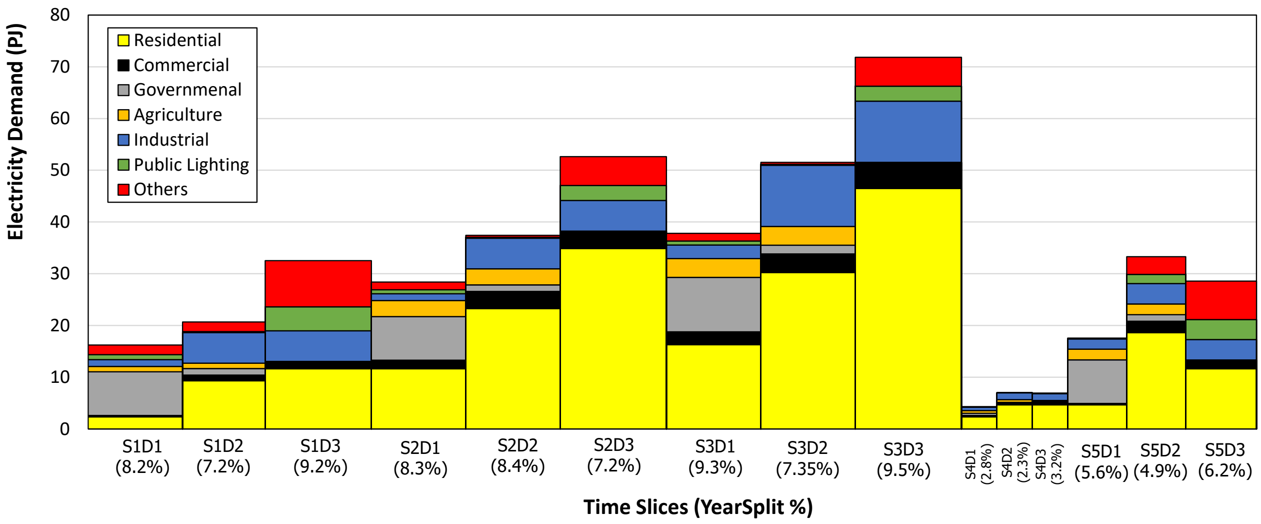


Figure 5. Sectoral Demand profiles over year time-slices for years 2014-2015, data [26].

The total energy conversion efficiency, the availability and the capacity factors of each generating technology and the related CO_2 emissions have been derived from EEHC reports [26] and from recent literature [84]. Economic cost of each technology is represented in the model by two parameters: fixed and variable costs [68]. Discount rate has been specified in the model at 22%, as it increased rapidly and significantly in Egypt during recent years, according to the *Egyptian Central Bank* data[8]; however, a sensitivity analysis of the effect of the discount rate on results was performed.

Other constraints imposed in the OSeMOSYS-Egypt model concern the upper and lower bounds for endogenous variables (i.e. installed capacities): for hydropower technologies, the maximum installed capacity is defined as 2.8 GW (corresponding to the current installed capacity), due to the lack of available additional hydro resources.

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[8] Egyptian Central Bank: http://www.cbe.org.eg/en/EconomicResearch/Statistics/Pages/MonthlyInterestRatesHistorical.aspx, accessed in 05-10-2017.

The developed bottom-up model, OSeMOSYS-Egypt is solved using the open source GNU Linear Programming Kit (GLPK) solver version 2012 [85], where the simplex algorithm is applied to define the objective function of the model; i.e. the least cost power generation mix.

3.4. Top-Down Multi-sector Modeling

Leontief's Input Output Comparative Static Analysis (IOA) has been selected and applied as the top-down modeling approach. IOA, refers to the economic analytical framework developed by Wassily Leontief in late 1930s; due to his remarkable contribution he was awarded Nobel Prize in 1973 [86]. The primary objective of IOA is to analyze the interdependence of production sectors within the boundaries of an economy. Leontief's IOA has been successfully applied for approximately 75 years as one of the most commonly applied economic analysis methodologies. The basic form of IOA is a system of linear equations that define the distribution of the output of each production sector (industry) to the other production sectors and the final demand.

As illustrated in Table 6, IOA tables are usually formulated from the historical data of the monetary transactions among the production sectors of the considered geographical area, e.g. state, country, continent, etc. Denoted by the interindustry transactions, IO tables give the information about the transactions from each production sector to itself and the other sectors. For example, part of the output of the agriculture sector is usually consumed by the sector itself, and part of the remainder is consumed by the other economic sectors of the economy, such as tourism, mining, power generation, etc. The final demand denotes the part of the output that is consumed by the households, government purchases and the exports made outside the boundaries of the studied economy. The rows denoted by value added, represent a stream of inputs (other than industrial) to the production of the economy, such as the compensation paid to the employee and the government taxes.

Table 6. Example of the structure of Input-Output tables for a country [86]

<table>
<tr><th></th><th></th><th colspan="6">To</th><th colspan="4">Final Demand</th></tr>
<tr><th></th><th></th><th>Agriculture</th><th>2</th><th>3</th><th>4</th><th>Mining</th><th>Other</th><th>Households' Expenditures</th><th>Gross Private Domestic Investment</th><th>Government Purchases of Goods and Services</th><th>Net Exports of Goods and Services</th></tr>
<tr><td rowspan="6">From</td><td>Agriculture</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mining</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Value Added</td><td>Employees</td><td colspan="6">Compensation of Employees</td><td colspan="4" rowspan="3">Gross Domestic Product</td></tr>
<tr><td>Government</td><td colspan="6">Indirect business Taxes</td></tr>
<tr><td>Business Owners and Capital</td><td colspan="6">Profit-type income and capital consumption allowances</td></tr>
</table>

In this research, the simple IOA model is applied using the open source *Full Eora 26 Multi-Regional Input Output 2015 Tables* (Eora 26) [86,87]. Hopefully, this data set suits the application of IOA in developing countries, for the following reasons: (1) it is an open-source that covers 187 countries where the production sectors are arranged in 26 sectors; (2) Eora 26 data set includes 35 environmental extensions, such as air pollution, resources extraction, water consumption, etc.

As a limitation, the original format of Eora 26 hinders its integration to the results of bottom-up model because of the high level of aggregation of the electricity generation, transmission, and distribution as well as gas and water consumption in one production sector. Therefore, to achieve the required soft-link, the sector of electricity, gas and water dataset provided by Eora 26 has been disaggregated to the level of power generation technologies. The adopted disaggregation approach is based mainly on the method developed by Lindner et al. to disaggregate the Chinse electricity generation sector [88]; it will be described subsequently. Due to the fact that input-output tables are based on the information provided by the national accounts, the data needed for applying disaggregation has been acquired from the available official national reports [26]. This approach is classified as a heuristic approach, as authors' own assumptions were applied when the required data for disaggregation were in sufficient.

The approach of the disaggregation starts with defining a balanced[9] national Eora 26 IO table for the country of study.

3.4.1. Disaggregation of IO tables

Egypt's balanced IO table has been extracted from full Eora 26 dataset, using the RStudio code [89], provided in Appendix A: The RStudio Code for Defining Egypt's Balanced IO table Using EORA 26 Dataset. The imports were treated as exogenous transactions in this study. As shown in Table 7, in the original format of Egypt's balanced IO 26 sectors, the electricity, gas, and water sector is labeled as sector 13. For an easier handling of the IO

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[9] The IO table of a national economy should be balanced; i.e. the total output of all of the production sectors (sum of the sums of the columns in monetary value) should be equal to the total outlays (the sum of sums of the rows in monetary value) [86].

table, sector 13 (electricity, gas, and water) is moved to be sector 26, the last sector at Egypt’s IO table, as presented in Table 11 of Appendix B: Egypt EORA 26 Tables. As illustrated by Figure 6, the steps of disaggregation was applied at a hierarchical approach as follows and the resulting table from each step is shown in the tables of Appendix B: Egypt EORA 26 Tables;

Table 7. Rows and columns Order of production sectors of Egypt's EORA 26 IO table

1	Agriculture
2	Fishing
3	Mining and Quarrying
4	Food & Beverages
5	Textiles and Wearing Apparel
6	Wood and Paper
7	Petroleum, Chemical and Non-Metallic Mineral Products
8	Metal Products
9	Electrical and Machinery
10	Transport Equipment
11	Other Manufacturing
12	Recycling
13	Electricity, Gas and Water
14	Construction
15	Maintenance and Repair
16	Wholesale Trade
17	Retail Trade
18	Hotels and Restaurants
19	Transport
20	Post and Telecommunications
21	Financial Intermediation and Business Activities
22	Public Administration
23	Education, Health and Other Services
24	Private Households
25	Others
26	Re-export & Re-import

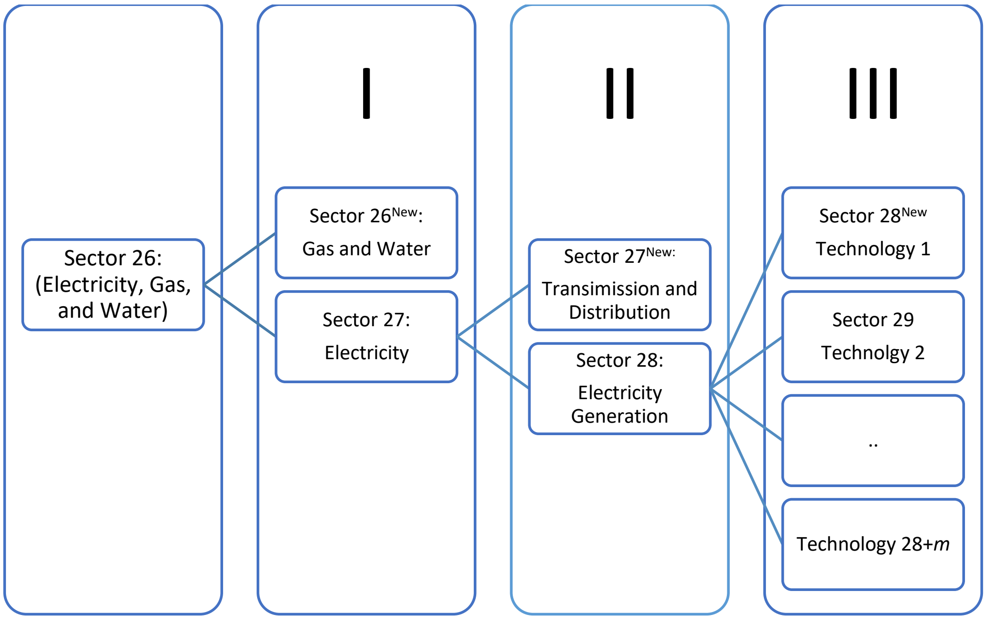

Figure 6. Presentation of the hierarchy of disaggregation approach

I. Disaggregation of the target sector into main commodities:

The original aggregated sector (electricity, gas, and water) is disaggregated into two sectors: a- gas and water sector; b- electricity sector, as presented in Table 12 of Appendix B: Egypt EORA 26 Tables. As presented in the previous studies by Marriot [90] and Lindner et. al [88] and due to the limitations of data availability, this step is performed according to the ratio of the investment in the electricity sector to the total production of the original aggregated sector (sector 26 of Table 11 (Appendix B)). In 2015, Egypt had investments in the electricity sector approximately 70% [26,87] of the total investments made in the sectors of electricity, gas and water. Hence, in Table 12 Appendix B, the new rows, sector 26^{New} (total production in monetary values the gas and water sector) and sector 27 (total production in monetary values of the electricity sector), are defined by multiplying each cell of the 26th row in Table 11 (Appendix B) by the weights of 30% and

70%, respectively. Similarly, the new columns, sector 26^{New} (total consumption of the gas and water sector from the other sectors) and sector 27 (total consumption of electricity sector from the other sectors), are defined by multiplying each cell of the 26th column in Table 11 (Appendix B) by the aforementioned weights, respectively.

Defining intra-cells, as the cells which represent the monetary transactions between the disaggregated sectors and themselves; they are defined by multiplying the original 26th sector in Table 11 (Appendix B) (electricity gas and water) aggregated value of its own consumption by the defined weights of the disaggregated rows and columns.

II. disaggregation of the new sector of electricity:

The electricity sector, the 27th sector in Table 12 (Appendix B), is furtherly disaggregated to the sectors of: a- the electricity Transmission and Distribution (TD) sector; b- the electricity generation sector. Similar to the disaggregation principle presented in the previous disaggregation step I, this disaggregation step is performed according to the ratios of investments of the electricity TD (35%) and electricity generation (65%) [26,91] to the total production of the aggregated electricity sector, the 27th sector in Table 12 (Appendix B). Therefore, as displayed Table 13 (Appendix B) IO table will include the sectors 27^{New} (electricity transmission and distribution) and 28 (electricity generation). In particular, the rows of the 27^{New} sector (total production in monetary values from the electricity TD sector) and the 28th sector (total production in monetary values from the electricity generation sector), are defined by multiplying each cell of the 27th row in Table 12 (Appendix B) by 35% and 65%, respectively. The new disaggregated columns of the

27^{New} sector (electricity TD) and 28th sector (electricity generation) as well as the intra-cells are defined by following the abovementioned procedures of the disaggregation step I.

III. disaggregation to the level of power generation technologies:

In this step the electricity generation sector, the 28th sector in Table 13 (Appendix B), is disaggregated to the level of the power generation technologies to allow for the coupling with the bottom-up energy optimization model. The disaggregated IO table of this step is displayed in Table 14 (Appendix B), and the procedure of the disaggregation of rows and columns of the IO table after the disaggregation step II (shown in Table 13 (Appendix B)) is performed as follows:

- *disaggregation of the 28th row in* Table 13 (Appendix B) *(total production of the electricity generation sector):*

It is assumed that the electricity production is delivered to the final demand sectors and the production sectors via one transmission and distribution grid to which is also connected to all of the production sectors. The disaggregated sector 28 in Table 13 (Appendix B) is furtherly disaggregated to 28^{New}+m sectors, where m+1 is the number of generating technologies, by considering the share of each technology in the total power generation mix [26], as illustrated in section 1.4. For instance, as displayed in Table 14 (Appendix B), the total electrical energy production from the hydro-power generation, the 28^{New} sector, is defined by multiplying each cell of the 28th row in Table 13 (Appendix B) by 7.2%, which represent the share of the hydro-power generation in Egypt’s 2015 power generation mix [26]. The same is applied to the other power generation technologies represented in Table 14 (Appendix B).

- *disaggregation of the 28th column in* Table 13 (Appendix B) *(the consumption of the electricity generation sector from the other sectors):*

It is worth to note that the consumption of goods and services by power plants from the various production sectors varies according to the type of the power generation plant. To illustrate, the monetary transactions from the petrochemical industry sector to wind farms is different from that is sent to fossil fuel power plants [88]. Furthermore, the data of various goods and services consumption by power plants is hardly to be recovered in the developing countries. Therefore, the author has applied the following assumptions in order to disaggregate the 28th column in Table 13 (Appendix B) to the level of the power generation technologies:

  - It has been assumed that only the fossil-fuels based production sectors; namely, sector 3, sector 7 and sector 26^{New} at the disaggregated IO Table 13 (Appendix B), have transactions with fossil-fuel based power plants and, have zero transactions, with renewable energy based power plants. Considering those three fossil-fuel based sectors, the disaggregation of 28th column in Table 13 (Appendix B) is performed according to the share of the natural gas consumption by each of the thermal power plants in the total consumption of natural gas by all of the thermal power plants in Egypt; namely, 50.7% for the steam cycle power plants, 14.7% for the simple gas cycle power plants, and 34.5% for the combined cycle power plants [26]. For example, the monetary transactions from each of sector 3, sector 7 and sector 26^{New} at the disaggregated IO Table 14 (Appendix B) to the sector 28^{New} (hydro-power generation) Table 14 (Appendix B) is zero, since hydro-power generation is considered a renewable energy based power generation technology. On the other hand, the monetary transaction from each of the sectors sector 3, sector 7 and sector 26^{New} at the disaggregated IO Table 14 (Appendix B) to the sector 29 (steam-cycle power plants) in Table 14 (Appendix B), is defined by multiplying each cell of 28th column in Table 13, by 50.7%.

- The production sectors, other than sector 3, sector 7 and sector 26^{New} at the disaggregated IO Table 14 (Appendix B), are assumed to have monetary transactions with all of the power generation technologies. The monetary transactions from such production sectors to the disaggregated power generation sectors, displayed in Table 14 (Appendix B), are defined by calculating the share of each power generation technology in the total cost of power generation in Egypt [26] based on the Levelized Cost of Energy[10] (LCOE) given by IEA [1]; namely, 0.2 % for hydro-power generation, 36.5% for the steam-cycle power generation, 23.3% for the simple-gas cycle power plants, 38.7% for the combined-cycle power plants, 1.1% for the wind farms, and 0.2% for the solar energy based power generation. For example, the column 28^{New} (hydro-power generation) in Table 14 (Appendix B) is defined by multiplying each cell of the 28th column in Table 13 by 0.2%.
- Considering the intra-cells, intersection between the power generation sectors and themselves. As shown in Table 14 (Appendix B), these cells are represented as a diagonal matrix, where each coefficient in the diagonal of the

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[10] Levelized Cost of Energy (LCOE): as defined by IEA [1], is the average cost of the electrical energy produced by a given power plant considering, the capital costs, debt serving costs, operating and maintenance costs, fuel costs, and decommissioning costs. LCOE could be also defined as the minimum average price of electrical energy produced by a power plant to recover the all of associated costs over the lifetime of the project; i.e., the lifetime of the power plants.

matrix is defined by multiplying the intra-cell of the electricity generation sector (28th sector in Table 13 (Appendix B)) by the share of each power generation technology in the electricity generation mix (represented in section 1.4) [26]. For instance, the intra-cell of sector 28^{New} (hydro-power generation) is defined by multiplying the intra-cell of the electricity generation sector (28th sector in Table 13 (Appendix B)) by 7%.

- *Disaggregation of the exogenous resources consumed and/or produced by the aggregated 26th sector (electricity, gas, and water) in Table 11 (Appendix B) to the level of electricity generation sectors, presented in Table 14 (Appendix B).*
    - *CO_2 Emissions*: it has been assumed that both the electricity TD and renewable power generation technologies have zero CO_2 emissions. Considering the fossil-fuel based power generation technologies, the disaggregation of the CO_2 to the level of power generation technologies, presented in Table 14 (Appendix B) have been defined by multiplying the aggregated value of 26th sector (electricity, gas, and water) in Table 11 (Appendix B) by the share of each power generation in the total produced CO_2 emissions; namely, 20.1% for the steam-gas cycle, 4.8% for the simple-gas cycle, and 18% for the combined-gas cycle [26,92]. The disaggregated value for CO_2 emissions produced by gas and water sector (sector 26^{New} in Table 14 (Appendix B)) is defined as the remainder of subtracting the sum of CO_2 emissions produced by fossil-fuel based power plants from the aggregated value of CO_2 emissions of sector 26th (electricity, gas , and water) in Table 11 (Appendix B).
    - Water consumption: the aggregated value of the water consumption by the 26th sector (electricity, gas, and water) in Table 11 (Appendix B) has been

disaggregated to the level of the power generation sectors, presented in Table 14 (Appendix B). Similar to the abovementioned procedure applied to disaggregate the CO_2 emissions, it is assumed that both the electricity TD and renewable power generation technologies have zero water consumption. Considering the fossil-fuel based power generation technologies, the disaggregation of the water consumption to the level of power generation technologies, presented in Table 14 (Appendix B) have been defined by multiplying the aggregated value of 26th sector (electricity, gas, and water) in Table 11 (Appendix B) by the share of each power generation in the total water consumption by power plants; namely, 45.6% for the steam-gas cycle, 5.4% for the simple-gas cycle, and 14.6% for the combined-gas cycle [26,93]. The disaggregated value for water consumed by gas and water sector (sector 26^{New} in Table 14 (Appendix B)) is defined as the remainder of subtracting the sum of water consumption by fossil-fuel based power plants from the aggregated value of water consumption of sector 26th (electricity, gas , and water) in Table 11 (Appendix B).

- Primary energy consumption: the aggregated value of the primary energy consumption of by the 26th sector (electricity, gas, and water) in Table 11 (Appendix B) has been disaggregated to the level of the power generation sectors, presented in Table 14 (Appendix B). Firstly, the disaggregated value of the gas and water sector (sector 26^{New} in Table 14 (Appendix B)) is defined by multiplying the aggregated value of 26th sector (electricity, gas, and water) in Table 11 (Appendix B) by the ratio of investment made in gas and water sector (30%) [26,87]. Secondly, it is assumed that both the electricity TD and renewable power generation technologies have zero primary energy consumption. Thirdly, considering, the disaggregation of the primary energy consumption to the level of power generation technologies, presented in Table 14 (Appendix B) is defined by multiplying the aggregated value of 28th sector (electricity generation) in Table 13 (Appendix B) by the share of each power generation in the total primary energy consumption by power plants; namely, 50.7% for the steam-gas cycle, 14.7% for the simple-gas cycle, and 34.5% for the combined-gas cycle [26].

3.4.2. Definition of Egypt's EORA 26 IO table in Hybrid Units

The Input-output analysis provided an applicable framework that could be successfully used to trace energy consumption on a nationwide economy scale. In this study, Hybrid Units IO Tables were employed [86]. Hybrid Units IO Tables are formed by using different units for the transaction of production between the various economic sectors; e.g. expressing the output of the power generation sectors in energy units, while transactions of the other sectors of the economy are represented in monetary value units [86]. In the literature, various researchers have used hybrid units' input-output tables to define the total energy consumption and CO_2 emissions of products [94]. Among others, Treloar [95] has defined the total energy requirements by the Australian residential sector using an IO table displaying hybrid units. Similarly, Machado et. al. [96] used a hybrid units IOA model to assess the total energy and CO_2 emissions associated in the international trade with Brazil.

In this research, the disaggregated IO table (in monetary values) is transformed to the form of a hybrid units' IO table, in which the transactions of the power generation sector are represented in energy units (TWh), whereas monetary value units are employed for the other sectors; this is due to the following two reasons: firstly, to obtain a consistency in the units of both linked models; i.e. the results obtained from both the bottom-up and top-down models are represented in energy units (TWh). Secondly, to overcome the uncertainty associated with forecasting the prices of electrical energy supplied to various demand sectors until the end of the planning horizon in 2040. Indeed, the prices of energy commodities are expected to change considerably in developing countries, due to the expected removal of subsidies on energy commodities in the near future [97].

In particular, the monetary flows of the disaggregated power generation sectors have been divided by the average selling price of electricity[11] [98] ($/TWh) to produce the equivalent output in energy units (TWh), as shown in Table 15 (Appendix B). Consequently, a verification assessment has been applied to assure that the total electricity output derived from the developed hybrid units IO table is equivalent to the total electricity output announced by authoritative energy institutions (e.g. IEA); in particular, in 2015 the calculated electricity production, after applying the disaggregation steps of the Egypt's IO EORA 26 table, equals to 160.4 TWh which is approximately equal to the value of 161 TWh announced by IEA [1].

3.4.3. Application of Leontief's IO model

In the context of mathematical representation, given a one economy composed of n sectors, each with s types of exogenous transactions (say, primary energy, GHG

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[11] In this study, the average price of the electricity sold to the industrial, commercial, and residential demand sector was calculated as .054 USD/kWh, data from [98].

emissions, etc.), l electricity technologies, and considering a time frame of one year, the endogenous transaction matrix $\mathbf{Z_0}(n \times n)$ can be represented as,

$$Z_0 = \begin{bmatrix} Z_{\mathrm{N}} & Z_{\mathrm{U}} \\ Z_{\mathrm{D}} & Z_{\mathrm{E}} \end{bmatrix}$$

Where, $\mathbf{Z_N}$ represents the endogenous transactions in monetary value (USD) between the non-power generation sectors (*defined as the common sectors) and themselves*, $\mathbf{Z_E}$ represents the endogenous transactions in physical units (TWh) between the power generation sectors and themselves. $\mathbf{Z_U}$ represents the endogenous flow of products in monetary values (USD) from the common sectors to the power generation sectors, and $\mathbf{Z_D}$ represents the electrical energy (in TWh) supplied to the common sectors of the economy from electrical energy production plants. According to the Leontief's analysis framework [86] , the total gross total production vector $\mathbf{x}_0(n \times 1)$ of all sectors is calculated as presented by equation (3-1),

$$\mathbf{x}_0 = \left(\mathbf{I} - \mathbf{A}_0\right)^{-1} \cdot \mathrm{y}_0 \qquad (3\text{-}1)$$

Where: $\mathbf{I}$ is the identity matrix and, $\mathbf{A}_0(n \times n)$ is hybrid technical coefficients[12] matrix that represents the links between all the national sectors, and is defined by,

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[12] Technical coefficients, also called the direct input coefficients [86], represent the input to each of the production sectors from itself and the other economic sectors to sustain the production. For example, running a thermal power plant requires inputs from the transportation sector, trade sector, etc. as well as its production of electricity to sustain its operation. Technical coefficients are calculated as follows [86]: Assuming the endogenous transaction matrix $Z = [z_{lm}]$ is the endogenous transaction from sector m to sector l, and f_m is the final demand on sector m production; total output of sector m, x_m, could be

$$\mathbf{A}_0 = \begin{bmatrix} \mathbf{A}_\mathrm{N} & \mathbf{C}_\mathrm{U} \\ \mathbf{C}_\mathrm{D} & \mathbf{A}_\mathrm{E} \end{bmatrix}$$

where, $\mathbf{A}_\mathbf{N}$ is the technical coefficients matirx of the common sectors, $\mathbf{A}_\mathbf{E}$ is the technical coefficients matrix of the electricity generation sectos, the matrices $\mathbf{C}_\mathrm{U}((n-l)\times l)$ and $\mathbf{C}_\mathrm{D}(l\times(n-l))$ are respectively the Upstream and Downstream Cutoffs technical coefficients: for each energy technology, $\mathbf{C}_\mathrm{U}$ relates the required production of each of the common sectors for the production of the electrical energy generation sectors, while $\mathbf{C}_\mathrm{D}$ represents the amount of electricity delivered to all the common sectors for each unit of production of the common sectors. $\mathbf{y}_0(n\times 1)$ is the hybrid final demand vector, representing the sum of the final demand sectors on each of the production sectors, shown in IO Table 15, and is expressed by,

$$\mathrm{y}_0 = \begin{bmatrix} \mathrm{y}_\mathrm{N} \\ \mathrm{y}_\mathrm{E} \end{bmatrix}$$

where, $\mathbf{y}_\mathrm{N}$, represents sum of the final demand sectors on each of the products of the common sectors, in USD. $\mathbf{y}_\mathrm{E}$ represents the the sum of the final demand sectors on the electrical energy in TWh.

The total exogenous transactions $\mathbf{R}_0(n\times 1)$ are calculated as presented by equation (3-2),

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represented as, $x_{m=}\sum_{i=1}^{I} z_{im} + f_m$, and $\mathrm{X} = \mathrm{Zi}$+f, in matrix form. The technical coefficient matrix A is equal to $\mathrm{A} = \mathrm{Z}\widehat{\mathrm{X}}^{-1}$.

$$\mathbf{R}_0 = \mathbf{b}_0 \cdot \hat{\mathbf{x}}_0 \qquad (3\text{-}2)$$

Where, $\mathbf{b}_0(s \times n)$ is the hybrid exogenous transactions coefficients matrix, representing the direct resources consumptions or waste emissions of each sector per unit of product, defined as,

$$\mathbf{b}_0 = \begin{bmatrix} \mathbf{b}_\mathrm{N} & \mathbf{b}_\mathrm{E} \end{bmatrix}$$

where, $\mathbf{b}_\mathrm{N}$, represents the direct resources consumptions or waste emissions by the common sectors, in physical units, $\mathbf{b}_\mathrm{E}$, represents the direct resourcs or waste emission consumed and/or produced by the electricity generation sectors in physical units (e.g. TJ, $\mathrm{tonCO_2}$, etc.).

3.5. Application of the soft-link in procedures

As formerly stated, the objective of this soft-linking bottom-up and top-down is to quantitatively assess the impacts of changes in the structure of the power generation mix on a nationwide economy scale. The procedures for this soft-linking are illustrated in Figure 7. The bottom-up model will be provided by exogenously defined techno-economic parameters (temporal demand, availability of renewable and non-renewable resources, costs of power generation by various technologies, etc.). By running the model, the least cost annual power generation mix will be defined over a given time planning horizon.

The future installed electricity production capacities and the related energy generation, endogenously computed by the bottom-up model, are then used to characterize the evolution of the energy sector in the top-down model, previously defined in section 3.4.3. The soft-link is performed according to the “ceteris paribus” principle [99], that is, the only variables introduced in the IOA model are related to (1) the electricity generation mix, (2) the increased demand for electricity and (3) the related increase in GDP induced by the electrical energy availability. Therefore, it is assumed that the technical coefficients of all the other production sectors will remain unchanged in future years, and equal to the baseline of 2015. The shock is implemented according to the following parallel steps:

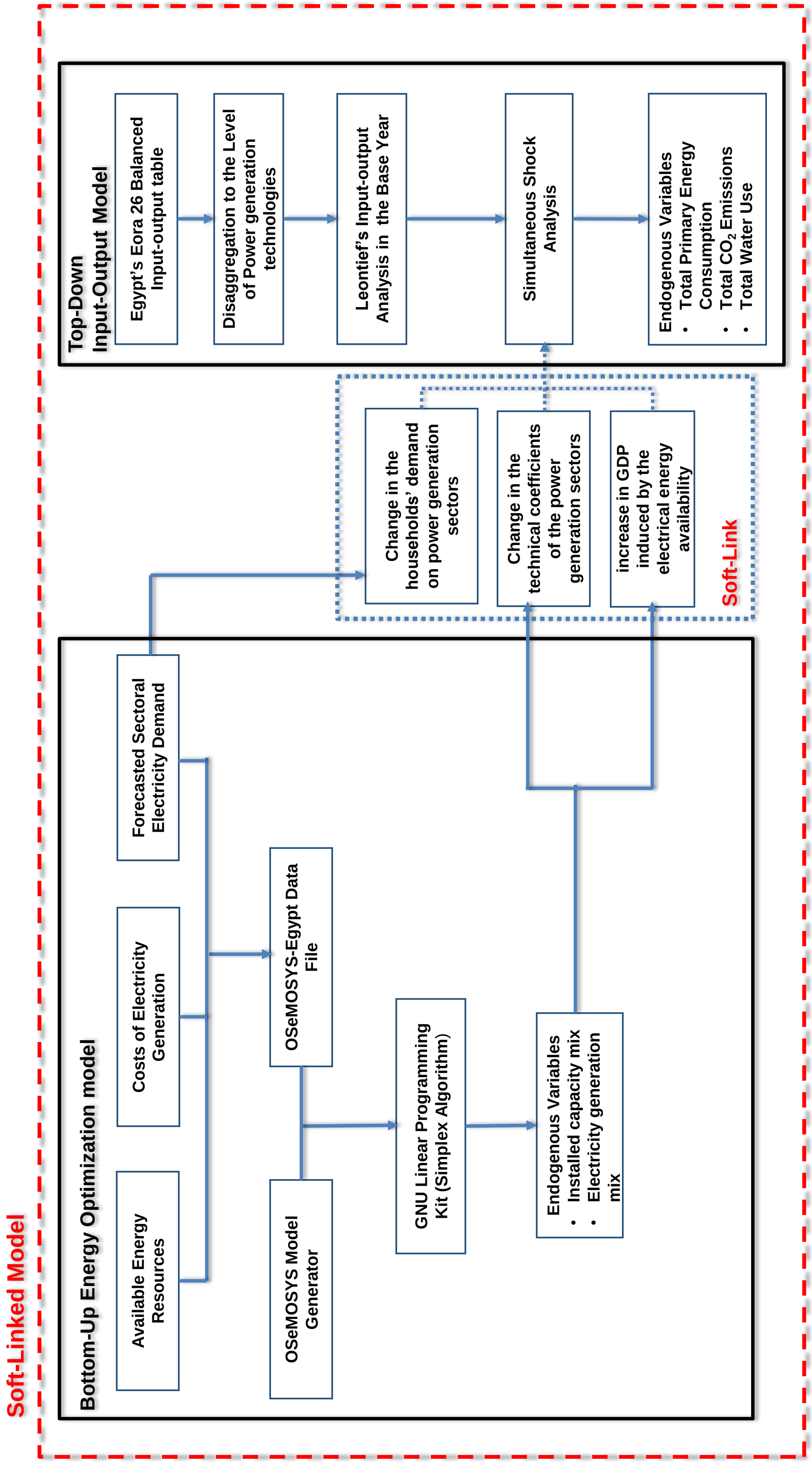

Figure 7. Block diagram of the soft-link between bottom-up and top-down models

- *Step 1. Change in the power generation mix.*

RAS method [86] is a well structured methodology that could be implemented to update the technical coefficients of the input-output tables. To successfully apply the RAS procedure to derive the technical coefficients table at the future time period designated by i, the following three information sets have to be known; namely, "(1) the total gross output of all production sectors; (2) total interindustry sales by each sector; (3) total interindustry purchases by each sector" [86] in future.

Due to the limited scope of this research, which is confined to addressing the effect of structural changes in power generation sector on the nationwide economy scale, the technical coefficients related to the rows of the electricity generation technologies (the downstream cutoff ($\mathbf{C}_{\mathrm{D}} \rightarrow \tilde{\mathbf{C}}_{\mathrm{D}}$) are *only* updated to reflect the least cost power generation mix which is defined by the bottom-up model (OSeMOSYS-Egypt): the sum of the latter coefficients for each economic sector is kept constant, while their relative shares change according to the prospected changes occurring in the electricity production mix.

In addition, to the abovementioned update of the technical coefficient of the downstream cutoff the power generation sectors, the disaggregated input-output table will be updated according the Final Demand Method [100], where the final demand is used to define the total gross output in the future year i.

- *Step 2. Change in electricity households' demand.*

The households' final demand ($\mathrm{f}_0 \subseteq \mathrm{y}_0$) is expressed by,

$$\mathrm{f}_0 = \begin{bmatrix} \mathrm{f}_{\mathrm{N}} \\ \mathrm{f}_{\mathrm{E}} \end{bmatrix}$$

where, $f_N \subseteq y_N$ represents the households'' final demand on each of the products of the common sectors, in USD. $f_E \subseteq y_E$, represents the sum of the households' final demand on the electrical energy in TWh.

The future yearly amount of electricity produced by each technology and delivered to final users is fed to the IOA model by changing households' final demand of power generation technologies ($\mathbf{f}_E \rightarrow \tilde{\mathbf{f}}_E$) according to IEA New Policies Scenario [1] which was presented in section 3.3.1.

- *Step 3. Change in national economic productivity.*

It is assumed that the increased demand for electricity by each national sector reflects the effect of an increased economic national productivity (Gross Domestic Product, GDP), and this is a reasonable assumption for developing countries according to the literature [101]; i.e. the households'' final expenditure $\mathbf{f}_N$ on the production of the common sectors will increase. Indeed, the expected increase in population and rise in the living standards will induce the consumption of all products produced with in the economy; i.e. increase in the consumption of food supplies produced by the agriculture sector, increase in the demand on the services provided by the transportation sector, etc. [4,101]. Therefore, an econometric production function was used to forecast the future growth in GDP resulting from an increased energy availability.

Equation (3-3) represents the typical logarithmic shape of the production function ($\tilde{\mathbf{f}}_N$), that links the national electricity production (EE_{prod}) with the GDP,

$$\tilde{\mathbf{f}}_{\mathrm{N}}\left(GDP, EE_{prod}\right) = \alpha \cdot \ln\left(EE_{prod}\right) - \beta \qquad (3\text{-}3)$$

where, α and β are the coefficient and constant of the logarithmic function, given by (3-3).In this case, α and β are statistically derived based on historical data from 2005-2015 [25,26], as displayed by Figure 8; and approximated to the values of 115.5 and 1039.2, respectively. The whole GDP growth rate, presented in Table 8, of each year of the planning that ends in 2040, is then divided among the national final demands of each sector by considering fixed proportions among them equal to the baseline economy.

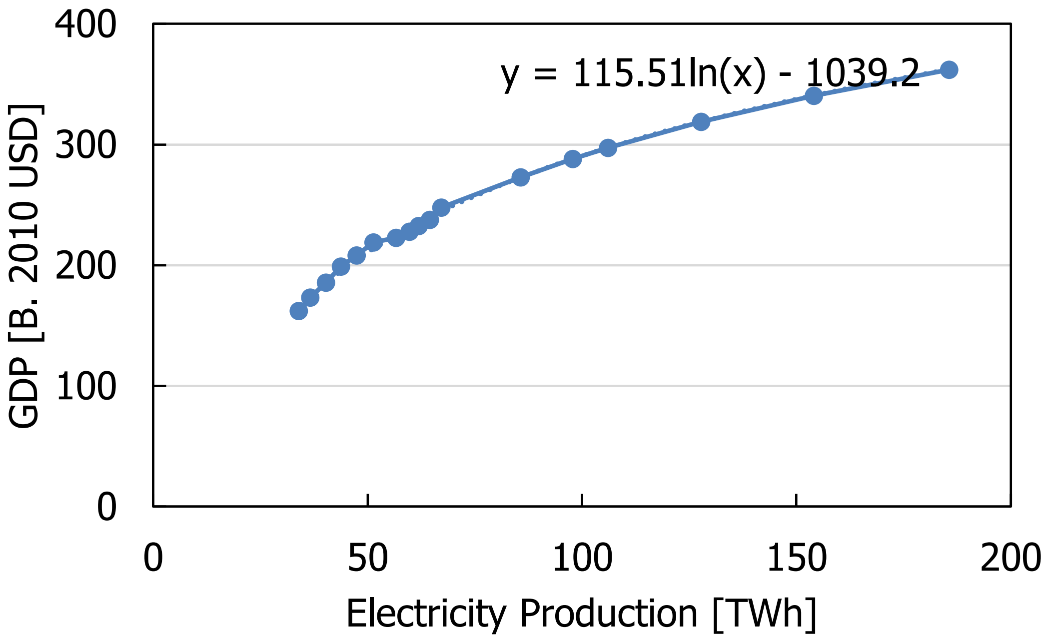

Figure 8. the derived logarithmic shape of the production function that links Egypt's national electricity production to Egypt's GDP; data generated for the period between 2005-2015 and used for the future forecast [25,26]

Table 8. Egypt's predicted GDP growth rates compared to the baseline economy in 2015

Year	*% Growth in GDP*
2020	10%
2025	20%
2030	29%
2035	37%
2040	46%

These aforementioned three shocks characterize the IOA *comparative static model* for each ith future year of the planning horizon between 2015-2040, are defined according to the following matrices,

$$\mathbf{A}_i = \begin{bmatrix} \mathbf{A}_{\mathrm{N}} & \mathbf{C}_{\mathrm{U}} \\ \tilde{\mathbf{C}}_{\mathrm{D}} & \mathbf{A}_{\mathrm{E}} \end{bmatrix} \; ; \; \mathbf{f}_i = \begin{bmatrix} \tilde{\mathbf{f}}_{\mathrm{N}} \\ \tilde{\mathbf{f}}_{\mathrm{E}} \end{bmatrix} \; ; \; \mathbf{b}_0 = \begin{bmatrix} \mathbf{b}_{\mathrm{N}} & \mathbf{b}_{E} \end{bmatrix}$$

where, $\tilde{\mathbf{C}}_{\mathrm{D}}$, $\tilde{\mathbf{f}}_{\mathrm{E}}$ and $\tilde{\mathbf{f}}_{\mathrm{N}}$ will be upated according to abovemetiond three steps. Finally, Leontief production and impact models are applied to the shocked economy in the ith year based on equation (3-2).

4. CHAPTER 4: Results and Discussion

This chapter presents and discusses the results obtained from applying the proposed soft-link illustrated in the previous chapter to the case of Egypt. In particular, the evolution of Egypt's power generation sector will be defined according to two institutional demand forecasts (IEA and BMI). In addition, the implications are derived for such an evolution on a nationwide economy scale during the planning horizon starting in 2015 and ending in 2040, and investigated by using the results of the bottom-up models as exogenous parameters to the top-down model. This chapter also explores the potential of increasing the penetration of renewables in achieving some of Egypt's environmental targets. The end of this chapter highlights the discrepancies in forecasting Egypt's total production of electricity via OSeMOSYS model generator and the proposed soft-linked model.

4.1. Bottom-Up model: verification and validation

The developed bottom-up model has been *verified* by checking the *energy balances* of the developed Egypt's RES. For example, considering the assumed losses in the transmission and distribution networks, in 2008 the sum of the electric energy produced by the power plants (394 PJ) is greater than the electric energy exiting from the transmission and distribution networks (282 PJ) by the amount of the losses estimated.

In addition, the bottom-up model has been *validated* by comparing the total electrical energy generated by various power generation technologies defined by OSeMOSYS-Egypt to the actual data of the total electrical energy generated reported in the annual reports of Egyptian Electricity Holding Company (EEHC) [26] for the period between 2009 and 2015. In particular, the annual percentage differences in the total electrical energy generated defined by OSeMOSYS-Egypt and the actual data reported by EEHC, over the aforementioned period, were in the range between 0.95% in 2009 and 5% in 2011. The latter could be justified by the shortage in the electrical energy supplies needed to satisfy the demand, due to the Egypt's 2011 socio-economic turmoil [28]; indeed, OSeMOSYS-Egypt endogenously defines the total electrical energy output to meet the exogenously defined demand parameters.

4.2. Bottom-Up model Results

This section presents the results obtained from the OSeMOSYS-Egypt model for the considered time window, and considering all the technologies enclosed in the RES: electricity generation mix, installed capacity mix, CO2 emissions and economic cost.

Electricity generation and installed capacity mixes. The proposed electrical energy generation by each technology is depicted in Figure 9 (subplots A and B). For both scenarios, the optimal generation mix includes natural gas simple and combined cycles, wind power, PV rooftop and hydroelectric power. In the IEA New Policy scenario, the energy produced by natural gas power plants will decrease in 2022, due to the Egyptian government objective of achieving the 22% of renewable sources in the electricity generation mix, supporting the penetration of renewables which is expected to reach 32% of the total production by 2040. However, even if the sudden increase in the share of renewable in the power generation mix turns out to be the optimal alternative to satisfy electricity demand, its *implementation* would probably meet practical constraints due to the short available time for commissioning and installing a large operating capacity of renewable energy power plants. Indeed, this highlights a major limitation in OSeMOSYS model generator that should be enhanced to consider the practical implementation of the proposed power generation mix. On the other hand, in the BMI scenario the increase in energy production by natural gas plants is actually constrained by the availability of natural gas supplies, which are likely to decrease according to the current forecasts [102]. Therefore, wind technology and PV rooftop have to be introduced to meet the increase in demand, leading to an increase in the share of renewable energy production from 14% up to 65% in 2040. For both scenarios, the contribution of hydropower energy is constant over the whole time window, due to the complete use of hydropower resources currently available for power generation. Figure 9 (subplots C and D) displays the installed capacity of each technology in the considered time window. In 2014, the total installed capacity reached approximately 37 GW in both scenarios. Similar to the IEA scenario, in the BMI scenario the power capacity requirements are strongly supported by the penetration of renewable sources between 2018 and 2040, mostly due to wind and photovoltaic technologies, because of the imposed constraints on the supplies of natural gas.

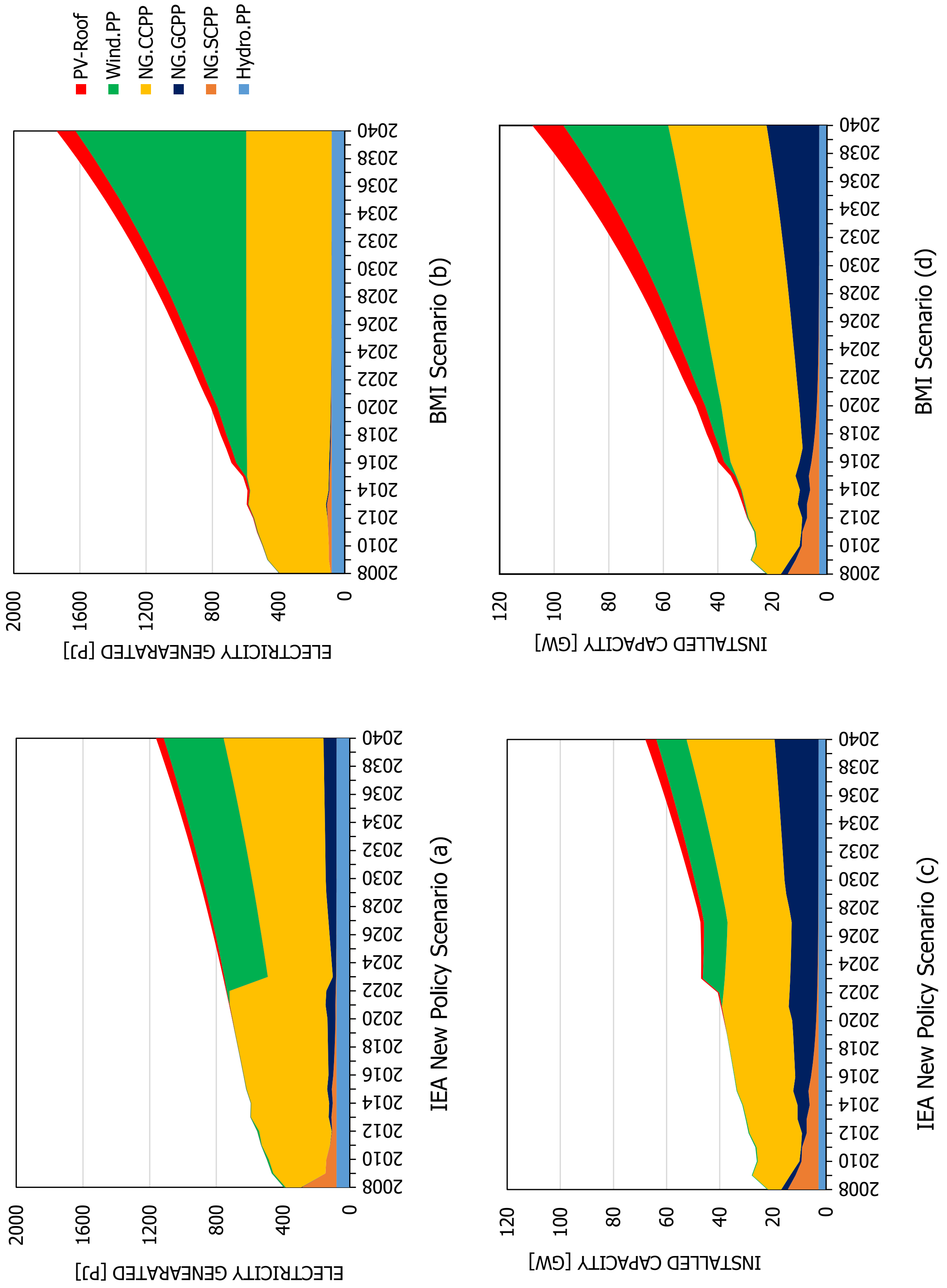

Figure 9. Electricity generation mix ((a) and (b)) and the corresponding installed capacities ((c) and (d)).

Economic cost. Figure 10 (subplot A) reports the yearly total discounted cost[13] of the two scenarios (bars, in MUSD2018/y) and the discounted cost of unit of electricity generated (black diamonds, in USD2018/MWh), evaluated for the period between 2018 and 2040. In general, the total discounted cost of BMI scenario is higher than the IEA one by 60%, mainly due to the *larger electrical energy demand forecast by BMI*, while the discounted cost per unit of energy produced is higher by approximately 20%. This is consistent with the increase in the penetration of high cost power generation technologies (i.e. wind energy and PV rooftop) in BMI scenario. For the two analyzed scenarios, the costs of electricity generation are dominated by renewable technologies; in particular, wind energy which contributes for about 43% (IEA) and 58% (BMI), and PV rooftop technology which is higher at the BMI by about four folds. Investments in natural gas combined cycles contribute with a share of 31% (IEA) and 21% (BMI) in the total economic costs. It is worth to note that in the IEA the significant contribution of renewable technologies in the cost of electricity generation could be explained by the defined constraint on the minimum requirement of renewables penetration in the power generation mix. On the other hand, in the BMI scenario the cost of electricity generation is dominated by renewable technologies because of the assumed constraint on natural gas supplies.

CO_2 emissions. Figure 10 (subplot B) presents the overall CO_2 emissions for the period between 2018 and 2040 (bars, in Mton/y) and the emissions per unit of electricity generated (black diamonds, in ton/MWh). The emissions related to the BMI scenario are

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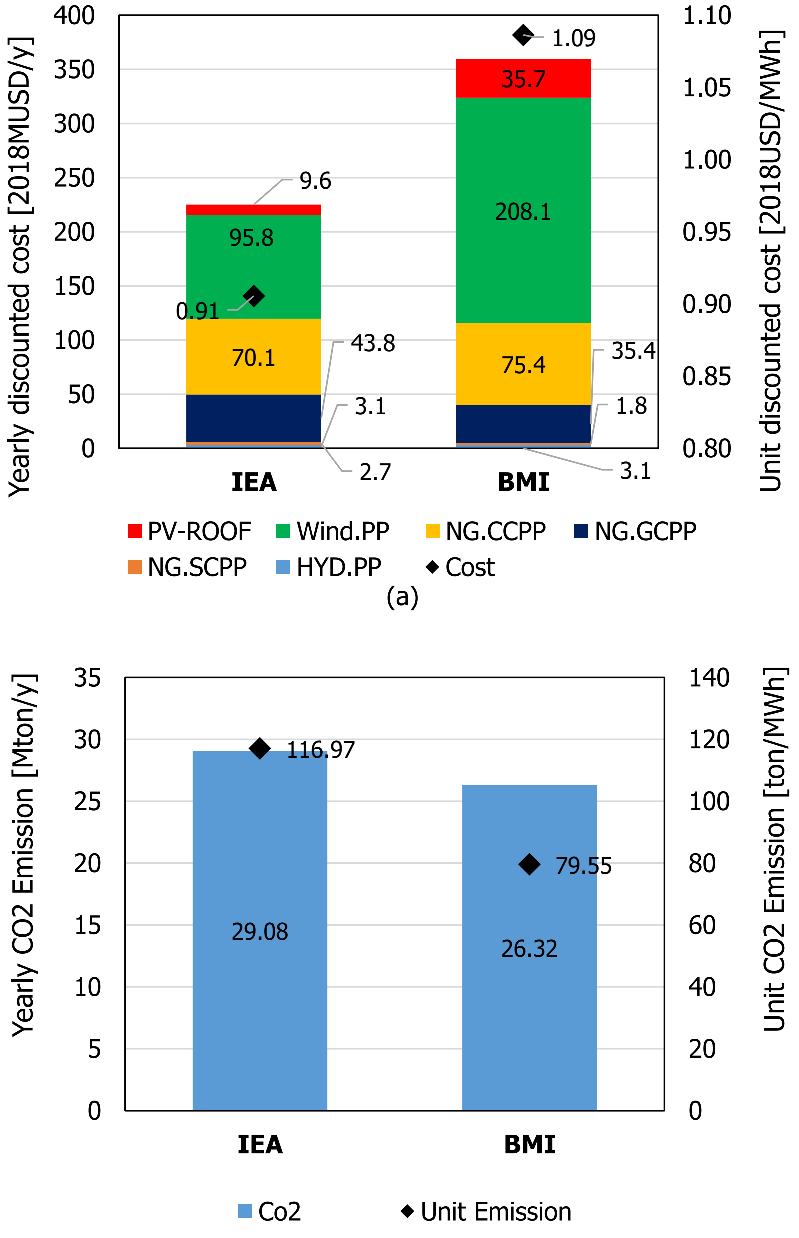
[13] yearly total discounted cost: is the sum of the of the annual costs of electricity generation discounted to 2018 and divided by the number of years of the planning horizon starting in 2018 and ending in 2040.

less than IEA scenario by about 10%, and are expected to be always below the IEA one due to the strong and rapid penetration of renewables.



(a)

(b)

Figure 10. Total technologies' annual installed capacities, the associated total discounted costs (A) and CO2 emissions (B).

4.2.1. Sensitivity analysis

A sensitivity analysis has been carried out in order to assess the robustness of the OSeMOSYS-Egypt model and the influence on final results due to changes in some crucial parameters, identified as follows (see Table 9): (1) *investment costs of renewable technologies*, (2) *renewables energy production targets*, (3) *efficiency of natural gas CCPP technology*, (4) *price of natural gas that feeds thermal power plants*, (5) *availability of the local natural gas supplies*, (6) *discount rate on capitals*, (7) *expected changes in hydropower availability* due to the *Renaissance Dam* in Ethiopia. The sensitivity analysis has been conducted on the selected parameters according to the values denoted by A, B, and C in Table 9 to analyze their separate effects on the *BMI scenario results only*. Applying the sensitivity analysis to BMI scenario is motivated by the fact that, in the opinion of the Author, this scenario better suits the future trends in energy demand by Egypt.

Table 9. Selected exogenous parameters to perform sensitivity analysis. Where a specific reference is missing, the Author has proposed reasonable values base on his own experience.

#	*Exogenous parameters*	*Values*	*Reference*
1	Decrease in the investment costs of renewable technologies (%)	A. [80]; B. 50% on 2040 (2% linear decrease starting from 2018) ; C. 70% on 2040 (3% linear decrease starting from 2018)	[80], Own assumption
2	Energy production targets by renewables (%)	A. 2022-2035: +22%; 2036-2040: +35%; B. 2022-2035: +35%; 2036-2040: +40%;	[11]

3	Increase in the efficiency of NG. CCPP (%)	A. + 5%; B. +12%	Own assumption, based on [103]
4	Year of increasing the price of NG by 40%	A. 2018; B. 2027;	Own assumption, based on [104]
5	Availability in local natural gas supplies	Unconstrained	
6a	Change in the discount rate on capitals (2%)	A. 2%	Own assumption
6b	Time changing Discount rate on capitals (%)	A. 18% in 2018 to 35% in 2040 (2% linear increase); B. 11% in 2018 to 1% in 2040 (1% linear decrease);	Own assumption
7	Reduction in Hydropower resources availability (%)	A. -16% in 2018 compared to 2017; B. -80% in 2018 compared to 2017;	[105]

Sensitivity analysis of the first four parameters, displayed in Table 9, on results are reported in Table 10. The reduction in the investment costs of renewable technologies and increase of their penetration targets in the energy mix are likely to happen in future decades. The sensitivity analysis has been here applied by considering alternative possible reductions in the investment costs of renewable technologies: A- the forecasted investment costs by IRENA [80]; B- 50% reduction in the investment cost in 2040 compared to 2017 with 2% annual decrease, and C- 70% reduction in the investment cost in 2040 compared to 2017 with 3% annual decrease (see Table 9). As reported in Table 10, neither the reduction in renewable investment costs nor increasing their penetration targets significantly affect the total cost of electricity: this could be explained by the fact that the limited resources for natural gas are always the first to be exploited in the BMI scenario, because natural gas technologies are the lowest cost alternative. In addition, as shown in Figure 9 (subplots B and D), the constrained natural gas supplies between 2018 and 2040 are not sufficient to deploy additional natural gas capacity. Therefore, wind and PV rooftop technologies contributes to the energy mix with a share of 51%, regardless of their costs and penetration targets. It can be concluded that in the BMI scenario the economic cost of electricity production, the amount of the required natural gas supplies and the share of the renewable technologies in the electricity generation mix are not sensitive to the changes in the cost of renewable technologies and to their related penetration targets.

By the end of 2018, three new natural gas combined cycle power plants of 4800 MW each will be deployed [103]. Due to their high efficiency and the related large amount of electricity production, the overall efficiency of Egypt’s natural gas combined cycles is assumed to increase by: A-5% and B-12%. This assumed increase in efficiency of the combined cycles would result in a decrease in the share of renewables in the production mix over the whole planning horizon, respectively this will result in 41% and 46%, compared to the proposed share of renewables in the electricity production mix at 51% in the BMI baseline results. Despite this, the total costs of electricity production and the consumption of natural gas have found to be non-sensitive to such change in efficiency, and this could be explained by the higher portions of the total electricity demand that are always covered by renewable technologies due to the assumed constraints on natural gas supplies.

Egyptian economy currently applies subsidies on the exploitation of natural gas reserves for power generation. However, since the annual natural gas consumption has reached its forecasted production upper limit in 2018 [102], the contribution of renewable technologies is essential to meet the electricity demand*, independently from natural gas price*. For such reason, results in Table 10 show that the change in cost of electricity production by increasing the natural gas price does not significantly affect the overall CO_2 emissions or the penetration of renewables.

Table 10. Results of the sensitivity analysis on selected parameters 1-4 over the whole planning horizon compared to BMI scenario baseline results

#	Parameters	Total discounted cost	Natural gas consumption	Renewable Energy Penetration
0	BMI baseline results	101225 MUSD2008[14]	709 BCM	51 %
1	Investment costs of renewable technologies	- 0.01 %	- 0.01 %	0 %
2	Energy production targets by renewables	+ 0.01 %	- 0.01 %	0 %
3	Efficiency of NG CCPP	- 0.02 %	- 0.01 %	-10 %; -5 %
4	Increase of NG prices	+0.01 %	+ 0.01 %	0 %

For a comprehensive assessment of the role of natural gas in the Egyptian power sector, the constraint on exploitation of natural gas local supplies has been relaxed, simulating an increase in the availability of natural gas reserves available for power generation uses that may result from the current discovery of new natural gas reserves (e.g. the Zohr oil field). The future energy mix composition is strongly affected by the assumptions of constrained or unconstrained local natural gas supplies, as can be inferred by comparing Figure 9

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[14] The sum of the annual electricity production costs discounted to 2008.

(subplots B and D) and Figure 10 with Figure 11. This is likely to cause a postposition in the penetration of renewable technologies after year 2022, when a minimum level of renewables is exogenously imposed to the model to comply with the current political intentions. As shown in Figure 11, the sudden rise of the renewables penetration in 2022, highlights the limitation of the bottom-up model in considering some practical constraints; in particular, the proposed very high and quick rise of renewables share in the electricity generation mix is hard to be realized practically in one year. For the planning period 2018-2040, the unconstrained natural gas supplies results in a decrease in the total discounted costs with respect to the base case (about 18%): this could be explained by the decrease in investments in wind energy from 58% to 39%, and the related increase in investments in natural gas simple and combined cycles by 13% and 9%, as illustrated by Figure 11 (subplot C). As a result, the unit discounted costs of energy turns out to be lower by approximately 95% compared to the baseline result. Moreover, due to the increased investments in natural gas technologies, a strong increase in natural gas consumption of about 42% is expected, causing an overall increase in CO_2 emissions by approximately 50% (Figure 11, subplot D).

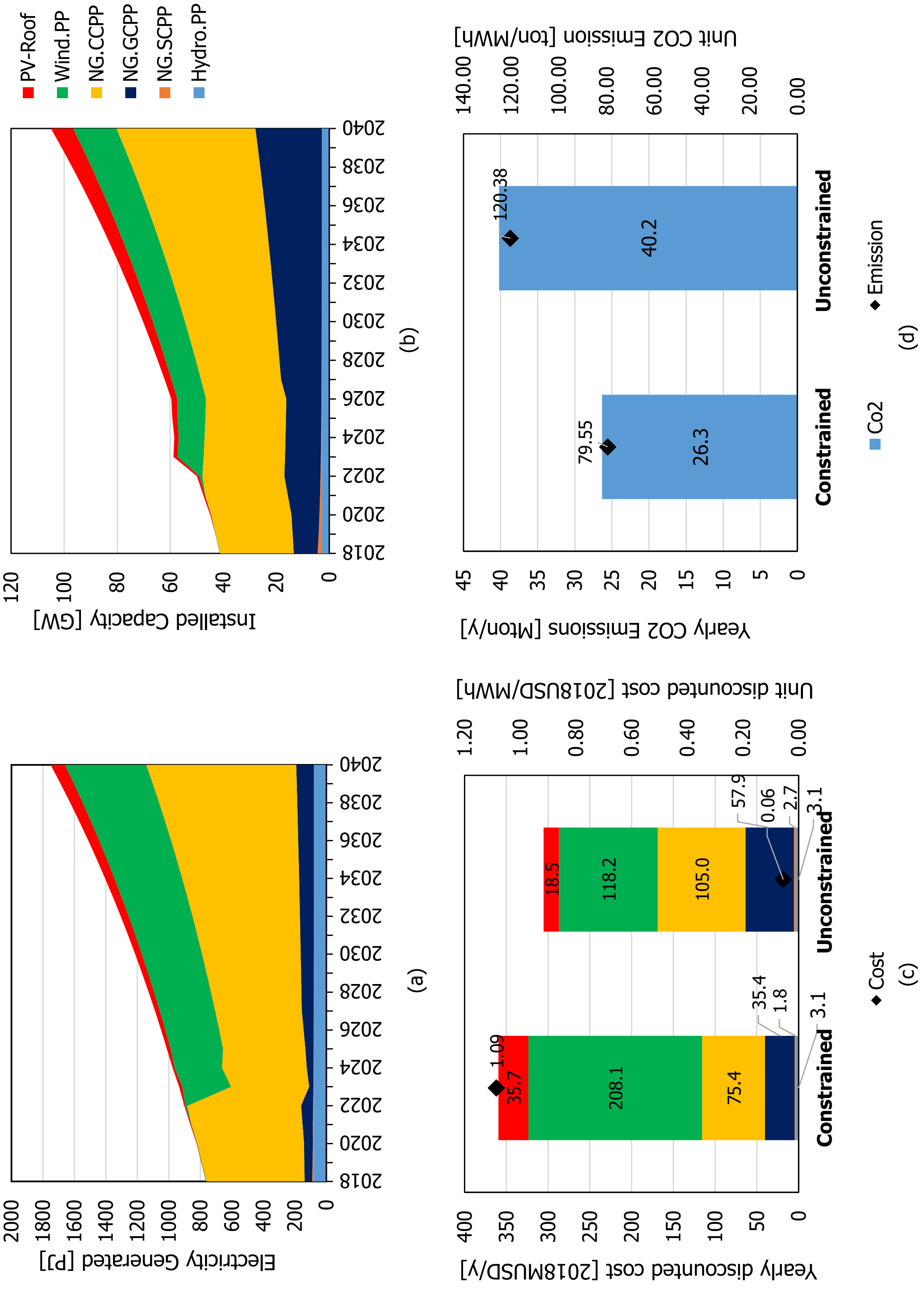

Figure 11. BMI scenario Electricity generation mix assuming unconstrained natural gas supplies.

In Egypt, values of discount rate on capitals has increased by 10% in the last 5 years, reaching 19% in 2017 [106]. In the OSeMOSYS-Egypt model, the discount rate is assumed to be fixed and equal to 22% over the whole planning period; and sensitivities (on parameters 6a and 6b in Table 9) have been applied to test the effects of possible changes in the values of discount rate on the proposed power generation mix. Since large upfront capital investments turn out to be more profitable if discount rate values are low, results obtained with discount rate of 2%, *representing extremely favorable market conditions*, are reported in Figure 12. In particular, the weight of renewables in the total discounted cost increases from about 58% in the BMI baseline scenario up to 70%. Moreover, technologies characterized by relatively low initial investment cost, such as natural gas steam cycles and simple cycles, are displaced from the optimal energy mix, leaving only natural gas combined cycles. Despite these changes, running the model with a low discount rate seems not to affect the natural gas consumption and the associated CO_2 emissions. Again, this could be explained by the fixed consumption rate of natural gas, which always comes first at an amount equals to the assumed constraint on the natural gas supplies, and independently from the type of the installed natural gas power generation technology.

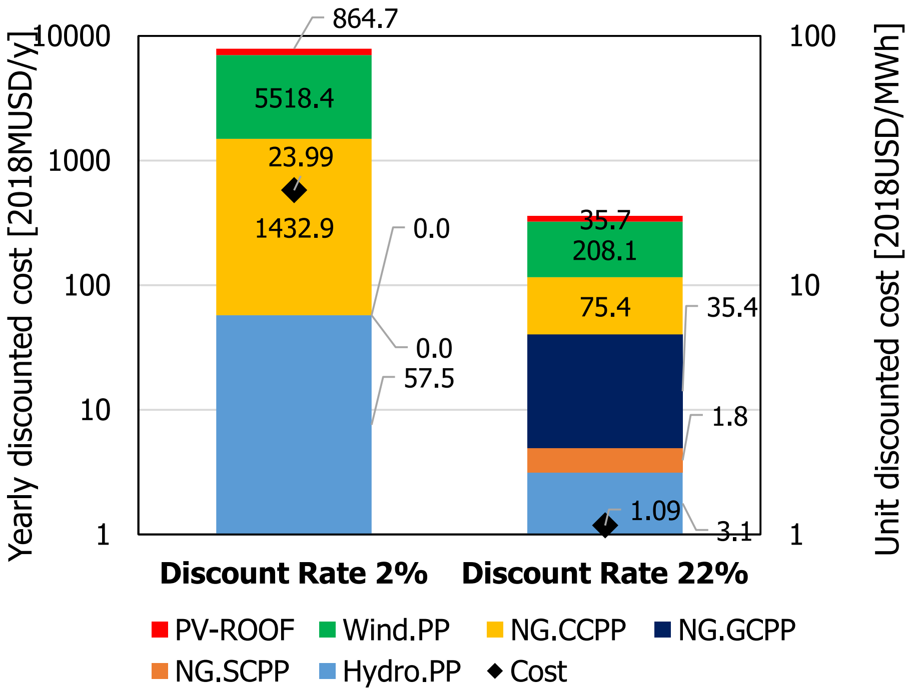

Figure 12. Electricity generation mix assuming changes in discount rate on capitals.

Based on this discussion, it is crucial for the decision makers to understand the effect of the discount rate on investments in the power sector. Egypt's Central Bank historical data shows that the common discount rate is approximately 8% [106]. To better understand the effects due to *time-dependent discount rates*, different values of annual discount rates have been introduced in the model (sensitivity 6b in Table 9), starting from the value of 19% on 2017. In particular, two cases have been assumed: A- a pessimistic market conditions where the discount rate is assumed to be 18% in 2018 with an annual increase of 2% till it reaches 35%; B- an optimistic market conditions where the discounts is assumed to be 11% in 2018 with an annual decrease of 1% till it reaches 1%. As illustrated by Figure 13 (subplots A and B), the shares of the power generation technologies in the total installed capacity vary according to the assumed discount rate values: PV rooftop installed capacity (high investment cost technology) increases as the value of the discount rate decreases (assumption b, Table 9), and the yearly discounted costs change accordingly Figure 13 (subplots C). The share of Wind energy and PV rooftop technologies in yearly total costs has increased, respectively from 56% and 7% (assumption a, Table 9) to 68% and 13% (assumption b, Table 9). It is worth to note the total installed capacity of the proposed energy mix according to (assumption b, Table 9) is higher than that of (assumption a, Table 9) by approximately 15%, as shown in Figure 13 (subplot A and B). This in increase in the total installed capacity could be explained by the strong penetration of the renewable technologies that have lower energy conversion efficiencies compared to thermal power plants; indeed, more installed capacities of renewable technologies are needed to satisfy the assumed same amount of electricity demand. In addition, the natural gas combined cycle technology has replaced the low investment technologies of natural gas steam and simple cycles, which have been displaced from proposed power generation mix, assuming the optimistic market conditions of lower discount rate values. Furthermore, considering assumption 6B in Table 9, the share of natural gas combined cycles in the total discounted costs has increased by 5% as the contribution of the combined cycle in the electricity generation mix *exceeds the sum* of the contributions of natural gas steam and simple cycles by 6.5% under the assumption 6A of the same table, causing small differences in CO2 emissions (about 6%, Figure 13 - subplot D).

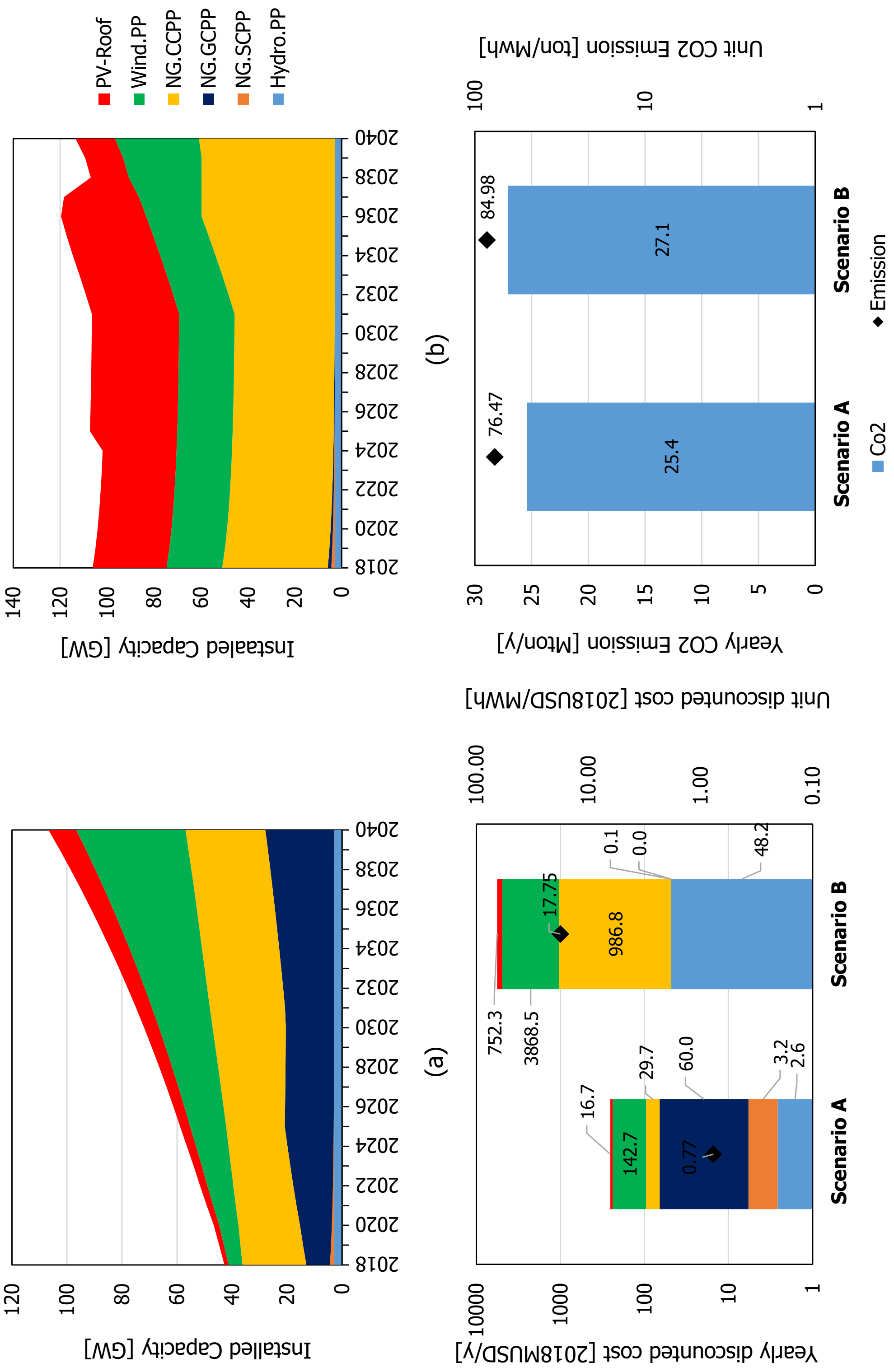

Figure 13. Share of power generating technologies in total installed capacities (a) and (b) and the rated discounted costs (c) and CO_2 emission (d), according to yearly changing discount rates.

The reduction of the hydropower resource potential available for electricity generation is likely to happen in the close future due to the construction of the Renaissance Ethiopian dam, estimated to be within 16% and 80% [105], and this may strongly affect the shape of Egyptian future energy mix. Assuming moderate reductions of hydropower potential, the expected consequences in energy production shares by technology is minimal due to the limited initial penetration of hydropower in Egypt's total installed capacity (2.8 GW). However, considering the worst-case scenario, a significant reduction of the hydropower-produced electricity by 77%, which will be mainly compensated by an increase in the electricity produced by wind technology (11%) and PV rooftop technology (11%); indeed, this could be explained by the limitation of adding new capacities of natural gas power plants (low investment cost technologies) due to the assumed constraint on natural gas supplies. Hence, the total discounted costs of electricity production for the period 2018-2040 will increase by 11% due to the increase in the share of renewables in the power generation mix, and the amount of natural gas consumption and its associated CO_2 emission will remain almost unchanged.

Results of applying the Bottom-Up energy optimization model are collected and shown in Figure 14. As shown in this figure, there are significant structural changes in the energy generation mix obtained according to the BMI scenario (Figure 14, subplot A) compared to the Business As Usual[15] (BAU) scenario (Figure 14, subplot B). Specifically, in the BMI scenario the share of the thermal power plants (natural-gas steam cycle, natural-gas open cycle and natural-gas combined cycle) is approximately constant over the period between 2018 and 2040, due to the imposed constraints of natural gas supplies, according to the

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[15] Business As Usual (BAU) scenario assumes that the shares of various power generation technologies in Egypt's power generation mix will remain unchanged until 2040.

BMI scenario data [102]. Hence, significant investments to increase the capacities of wind and PV rooftop technologies are required to meet the forecasted increase in demand. As a result, the share of the renewables in the power generation mix has increased from 8% in 2015 to approximately 70% in 2040. It is worth to note that such results will have major economic and environmental implications that are different from those of the BAU scenario (Figure 14, subplot B), where the natural gas supplies needed by thermal power plants in 2040 would exceed the levels of 2015 by three times.

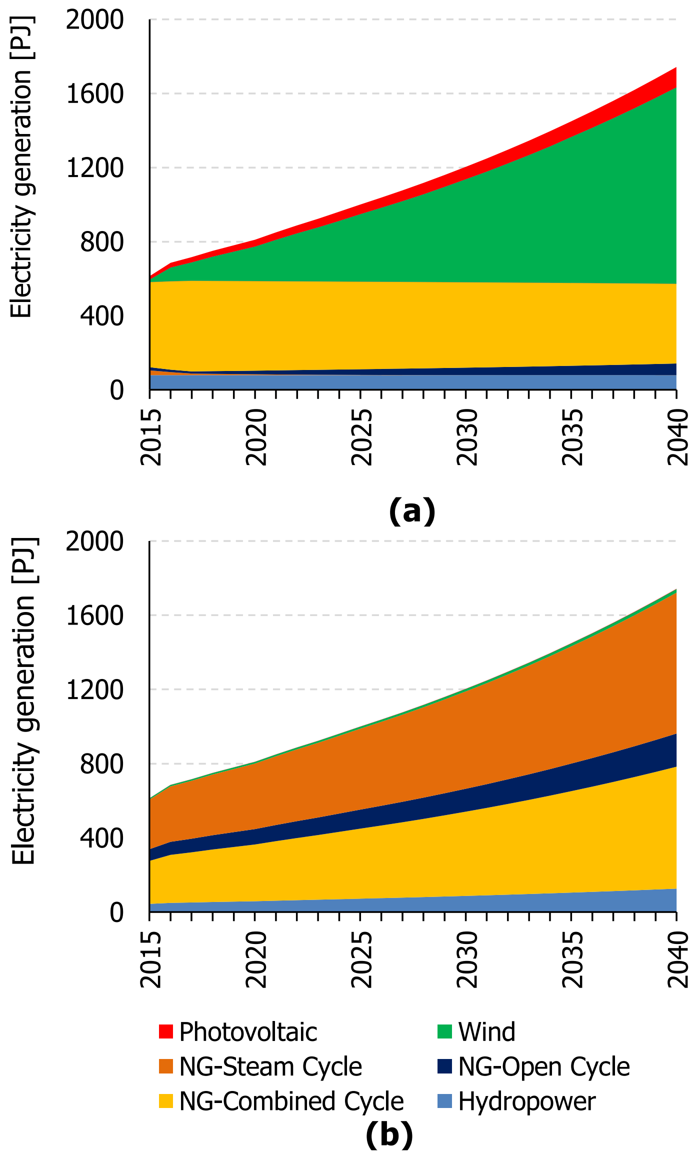


Figure 14. Electricity generation mix of the BMI scenario (a) and BAU scenario (b).

4.3. Soft-Linked Model Results

Based on the previously stated methodology of soft-linking bottom-up and top-down models, the impacts induced by the prospective structural changes in Egypt's power sector could be assessed based on various indicators, such as the consumption of primary energy, land use, etc. In this sub-section, the main results of the soft-linked model will be presented and discussed. For the sake of simplicity, in this study only the following three indicators have been analyzed, specifically: primary energy consumption, emissions of CO_2 and water consumption.

4.3.1. Primary Energy Consumption

The implications of the prospective structural changes of power generation mix on Egypt's primary energy (PE) consumption by the various production sectors have been identified by comparing the results of the soft-linked model of both the BMI and BAU scenarios, as illustrated in Figure 15 (A and B). Considering the planning horizon starting in 2015 until 2040, a 26% reduction in the total PE consumption, between the BMI scenario (430 Mtoe) and the BAU scenario (557 Mtoe), could be achieved by decarbonizing the power generation mix. As presented by the violet category in Figure 15 (a), assuming the BMI scenario, increasing the share of renewables in electricity generation by approximately 30% (results of the bottom-up model) during the first five years (2015-2020) of the planning horizon, will result in a 31% reduction in the PE consumption by the power generation sector during the same period (results of the soft-linked model). As expected, it could be inferred from the same figure that there is an indirect relationship between the share of the renewables in electricity generation mix and PE consumption of the power sector. Unfortunately, the same indirect relationship is not valid, when the whole production sectors of Egypt's economy are considered. As illustrated in Figure 15 (a), considering Egypt's nationwide economy scale for the planning horizon between 2020 and 2040, an 8% increase in the PE consumption is expected. This increase would be driven by the expected growths, induced by the assumed growth in GDP, of industrial and transportation sectors. According to the data shown in Egypt's input-out table (Table 15), both the industrial and the transportation sectors use primary energy in significant amounts; indeed, in Egypt the transportation sector is mainly based on gasoline, diesel, etc. Similarly, the fossil fuels energy commodities are used in the industrial sector to satisfy its thermal demands; i.e. process heating and/or process cooling. Specifically, the ratio of the sum of the PE consumption of the industrial and transportation sectors to the Egypt's total consumption would increase form 60% in 2015 to 75% in 2040, because no efficiency plans were assumed to reduce the primary energy consumption of the industrial and transportation sectors, due to the limited scope of this work.

With reference to Figure 15 (c), Egypt's GDP is expected to double during the assumed planning horizon between 2015 and 2040. Hopefully, adopting a policy for decarbonizing the power sector would be effective in reducing Egypt's Energy Intensity (EI) by 32% during the whole planning horizon. On contrary, referring to the BAU scenario between 2015 and 2040, illustrated by Figure 15 (d), a 3% increase in the EI is expected due to persistent increase of PE consumption by all production sectors, including the power generation which will grow assuming the same generation mix and efficiencies of technologies.

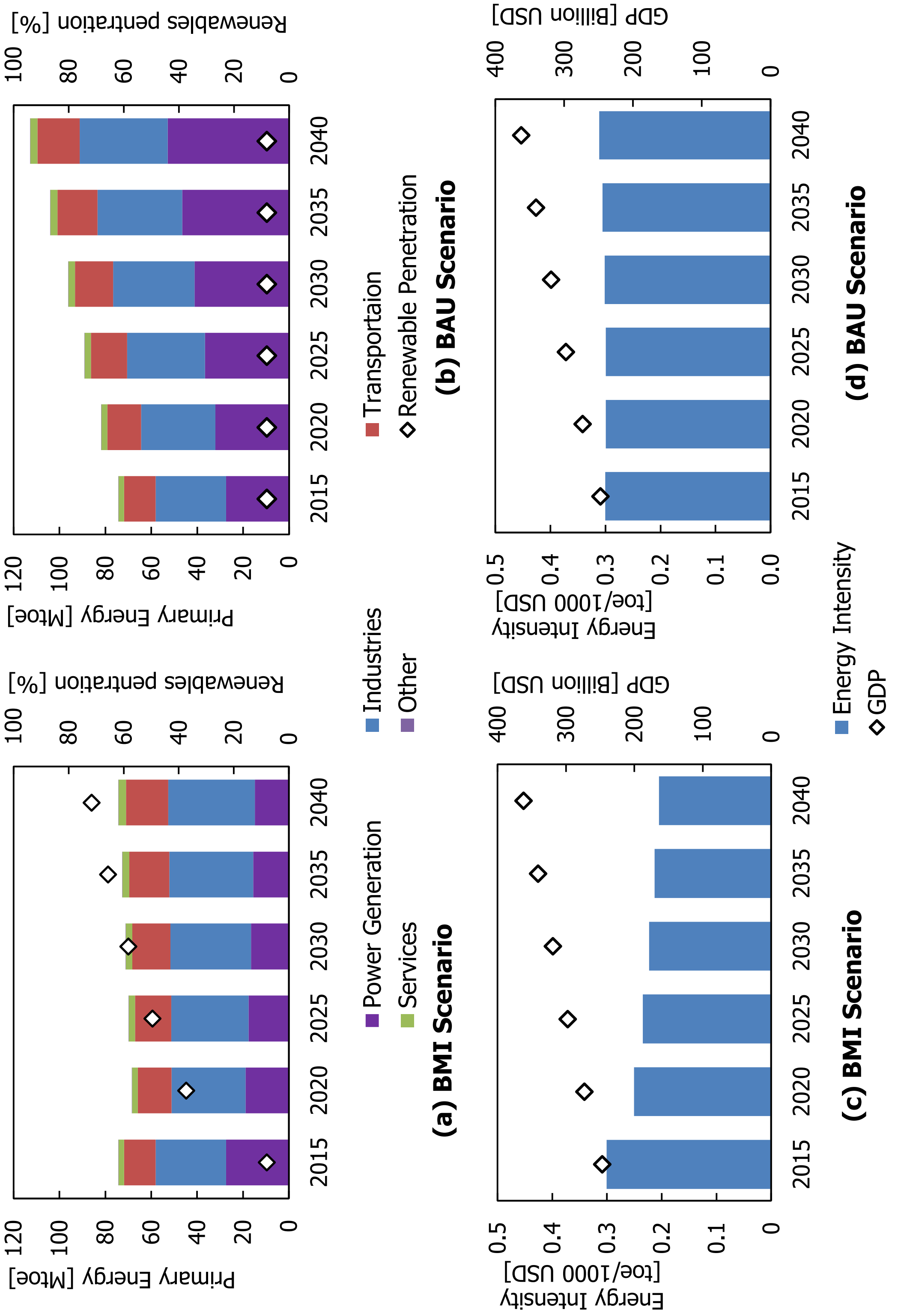


Figure 15. Egypt's primary energy consumption ((a) and (b)) and energy intensity ((c) and (d)) according to BMI and BAU scenarios

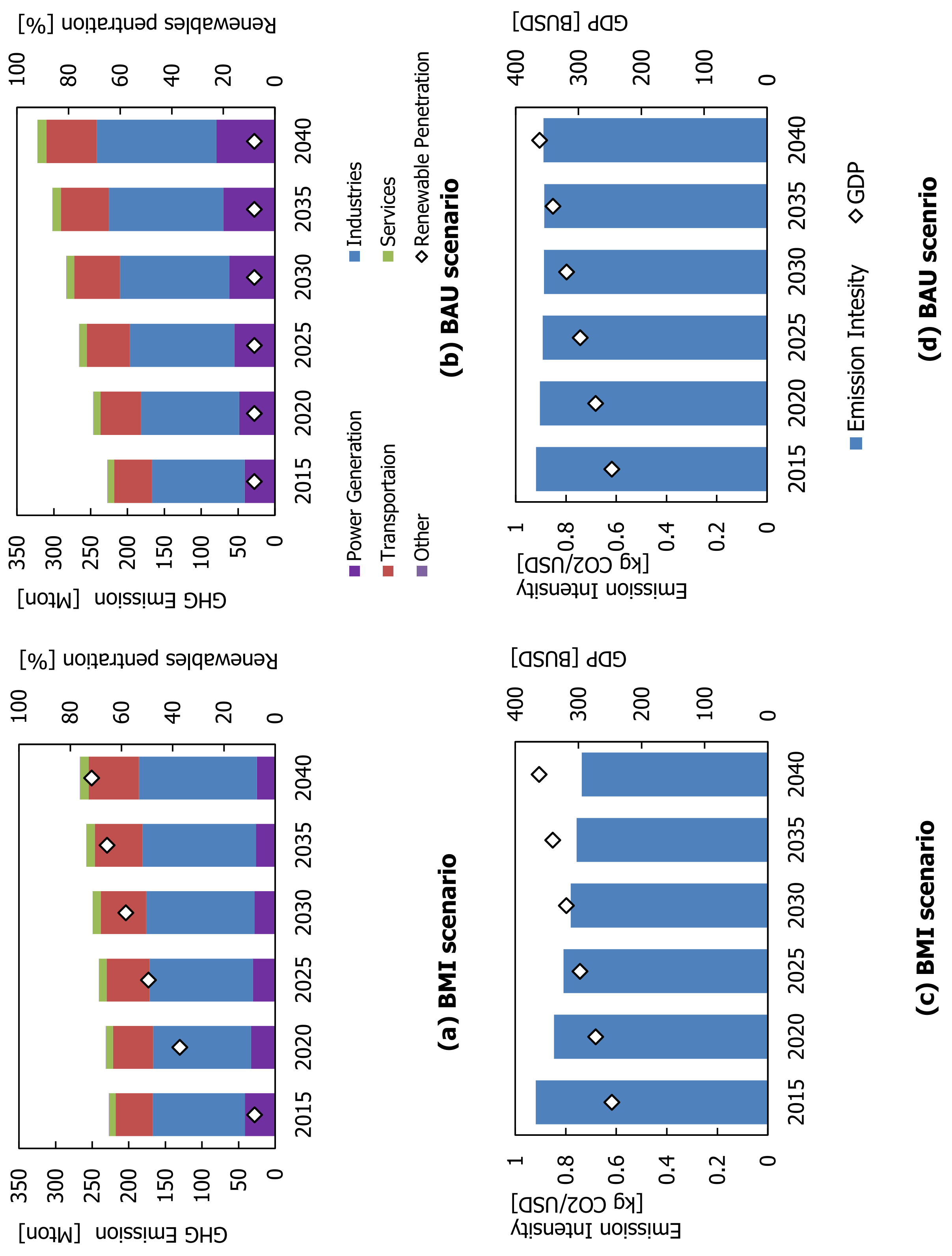
4.3.2. CO_2 Emissions

Referring to the BMI scenario, the share of renewables in the power generation mix will increase significantly, reaching 70% in 2040. In particular, the wind technologies would be dominating the electricity generation mix, replacing the natural-gas fired power plants in the power generation mix of the BAU scenario. Hence, the CO_2 emission of the power generation sector would be decreasing by 40% over the entire planning horizon (2015-2040), despite the continuous increase in electricity demand (see Figure 16 (a), violet category).

Although, the significant increase in the share of renewables at the power mix of the BMI scenario has maintained the consumption of primary energy in 2040 approximately equal to the same level of 2015, it has failed to achieve such results for the CO_2 emission production on a nationwide economy scale. As shown in Figure 16 (a), while the high share of renewables penetration is capable of decarbonizing only the power sector by 40%, the total CO_2 emissions of all production sectors have increased by 17.5%. This could be explained by the following: Firstly, the power generation sector has a limited contribution (18%) at the total production of the total CO_2 emission, in the baseline year of 2015. Secondly, the increased CO_2 emission production from the industrial, services, and transportation sectors overweigh the saving achieved by the power generation sector: leading to an increase from 227 Mt CO_2 in 2015 to 267 Mt CO_2 in 2040. Comparing BMI and BAU scenarios, shown in Figure 16 (b), the realized reduction in the total direct CO_2 emission during the entire planning period could be increased by targeting the other 82% resembled by sectors other than the power generation.

Considering the fast growing GDP in Egypt, intensity of emissions is a good environmental performance measure to assess the prospective changes in energy policy. As shown in

Figure 16 (c), decarbonizing the electricity production mix, could result in a reduction in the emission intensity by 20% between 2015 and 2020. On the contrary, as shown in Figure 16 (d) increasing the production of electricity based on a dominated fossil-fuel power generation mix, will result in a constant intensity of emissions over the whole planning horizon, due to the assumed constant technical coefficients of non-power generations production sectors.


(a) BMI scenario

(b) BAU scenario

(c) BMI scenario

(d) BAU scenrio

Figure 16 Egypt's production of CO_2 emissions ((a) and (b)) and CO_2 emissions intensity ((c) and (D)) according to BMI and BAU scenarios

4.3.3. Water Consumption

The IOA of Egypt’s economic production sectors has been extended to assess the nationwide consumption of water resources, whose availability might be reduced by 80% due to the construction of the Renaissance Dam in Ethiopia [105]. As displayed in the disaggregated Egypt’s IO table (Table 15 (Appendix B) and according to the assumptions presented in section 3.4.1, the fossil-fuel based power plants consume water to sustain their production. Thanks to the significant investments in renewable technologies, the decarbonized electricity generation mix of the BMI scenario would consume a 1.6 Billion Cubic Meters (BCM) of water less than the BAU scenario for the period between 2015 and 2040. With reference to Figure 17, the contribution of the power sectors in Egypt’s total water consumption represents minor shares of 0.5% and 0.1% in 2015 and 2040, respectively. Hence, the continuous increase in water consumption by the non-power sectors, due to the expected GDP growth, will surpass the realized savings achieved by the strong penetration of renewable technologies in the proposed power generation mix. Hence, Egypt’s total water consumption will increase by 28% over the whole planning horizon (2015-2040).

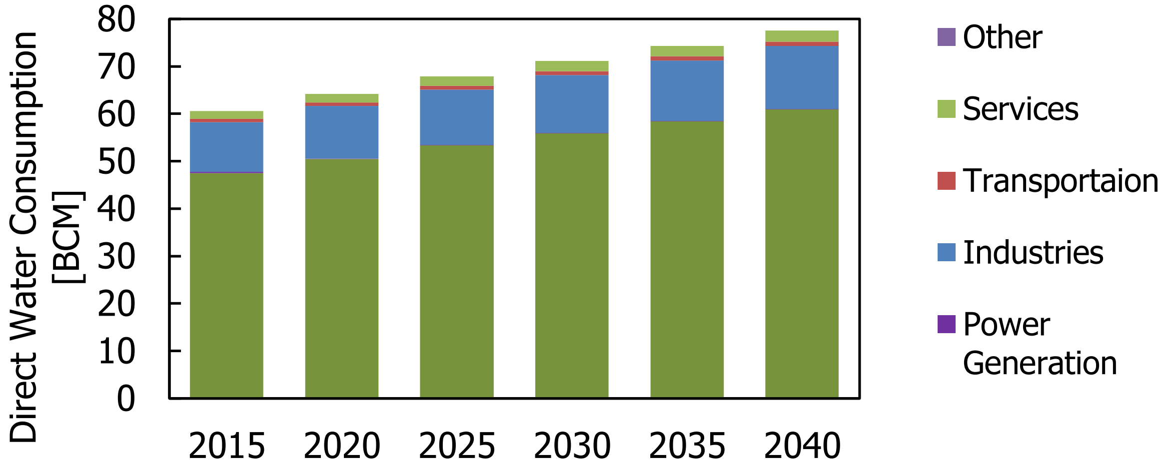


Figure 17 Egypt’s total water consumption by production sectors

4.4. Assessing the Effectiveness of Investing in Renewable Technologies

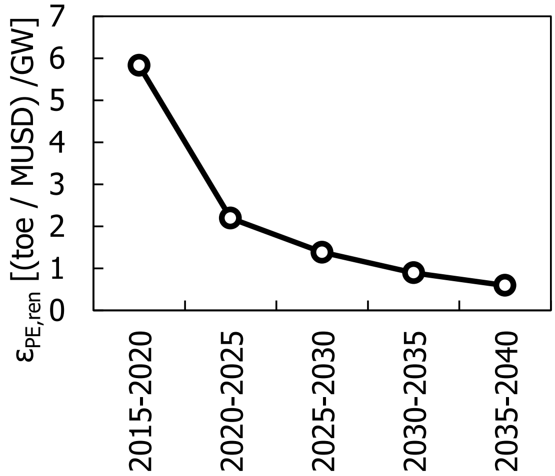
Referring to the previously stated results, shown in Figure 15 (A) and Figure 16 (A), despite the effectiveness of the persistent increase in the installed capacity of renewables in reducing the primary energy consumption and the CO_2 emissions of the electricity generation sector, the same effectiveness cannot be realized on Egypt's nationwide economy scale, where all of Egypt's production sectors are considered. This could be explained by the persistent consumption of primary energy fuels by the industrial and transportation sectors to sustain their production. Therefore, it would be useful to support policymakers with indicators that quantify the effectiveness of investing renewable power generation technologies in achieving the intended economic and environmental targets; namely, reducing the primary energy consumption and CO_2 emissions of all Egyptian production sectors.

In this study, two indicators are developed to assess the potential for decreasing Egypt's primary energy consumption and CO_2 emissions for each unit of renewables installed capacity. The first indicator, $\varepsilon_{PE,ren}$, defines the effectiveness of renewables in reducing primary energy consumption: it is presented with units of $(toe/MUSD)/GW$. As shown in equation (4-1), this indicator is evaluated as the ratio between the change in primary energy intensity $e_{PE}[toe/MUSD]$ and the change in renewables installed capacity $C_{ren}[GW]$ during the time interval between years *i* and *i+1*. Secondly,$\varepsilon_{CO2,ren}$, defines the effectiveness of renewables in reducing CO_2 emissions: it has the units of $(ton_{CO2}/MUSD)/GW$. Again, this indicator is calculated as the ratio between changes in emissions intensity $e_{CO2}[ton/MUSD]$ and the change in renewables installed capacity $C_{ren}[GW]$ during the time interval between year *i* and *i+1* (in this case the time interval is defined as 5 years), as shown in equation (4-2).

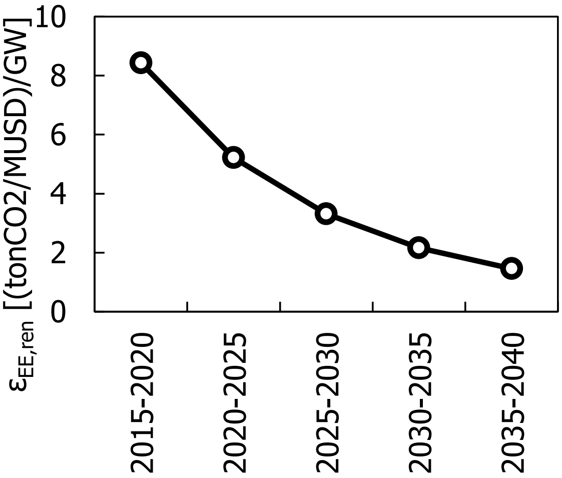
$$\varepsilon_{PE,ren,i\rightarrow i+1} = \left|\frac{e_{PE,i+1} - e_{PE,i}}{C_{ren,i+1} - C_{ren,i}}\right| \tag{4-1}$$

$$\varepsilon_{CO2,ren,i\rightarrow i+1} = \left|\frac{e_{CO2,i+1} - e_{CO2,i}}{C_{ren,i+1} - C_{ren,i}}\right| \tag{4-2}$$

The quantified effectiveness of investing in renewables throughout the entire planning horizon are presented in Figure 18. Considering the energy intensity during the first five years of the planning horizon (2015-2025), investing in renewables would be 5-6 times more effective compared to the period between 2035 and 2040, as presented in Figure 18 (A). Accordingly, during the first five years of the planning horizon, investing in renewable will have a 3-4 times higher potential for reducing CO_2 emission intensity with respect to the last five years of the planning horizon, as illustrated in Figure 18 (B). This could be justified by the significant reduction realized by the power sector during the first five years of the planning horizon. Considering the consequences of the prospective increase in the national economic production (GDP), renewables effectiveness would fade out over the planning horizon due to the growth of the other sectors: in particular, industrial and transportation sectors. The increased primary energy consumption and CO_2 emissions from those sectors will overweigh the savings realized by decarbonizing the power sector. Therefore, the deduced information from such indicators may be beneficial in supporting policymakers to define reasonable environmental targets and appropriate alternatives to achieve them: e. g, electrification of the transportation sector and gradual phasing out of high energy intensity industries, such as cement and steel industries, could be more economical alternatives for the Egyptian policymaker during the last 10 years of the planning horizon.



(a)



(b)

Figure 18 Potentials for reductions in energy intensity (a) per unit of renewables installed capacity and CO_2 emissions (b) per unit of renewables installed capacity.

4.5. Consistency of Bottom-up and Top-down Models

It is worth to note that due to the essentially different forecasts of electricity demand between the bottom-up and top-down models, there is a variation of 17% in 2020 and 36% in 2040 in the total production of the power generation sector obtained by the two models, as shown by Figure 19. Considering the bottom-up model, the sectoral electricity demands (residential, services, etc.) are *exogenous* parameters forecasted by the BMI data. On the other hand, in top-down model, the electrical energy required to support the whole economy production sectors is defined *endogenously* by applying the Leontief's input-out model and driven by the households' final demand. In addition, the latter approach assumes a causal relationship between the production of electricity and the relative increase in GDP, as discussed in section 3.5; this assumption is an accepted argument in the available literature [107].

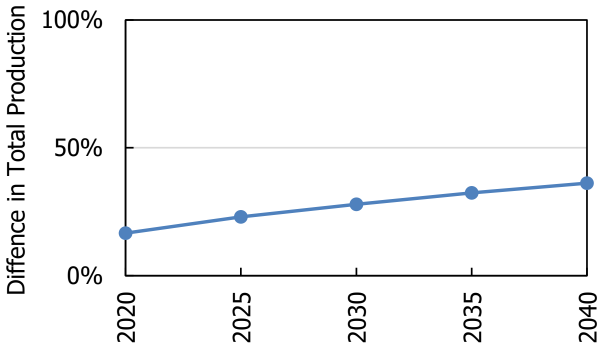


Figure 19 Percentage difference in annual electricity production between bottom-up model and top-down models

5. CHAPTER 5: Conclusions, Policy Implications, and Future Work

This research develops a decision-making supporting tool to assist in defining coherent energy policies that consider interactions between the entire production sectors of an economy. Specifically, a one-way straightforward soft-link between an open-source bottom-up energy optimization model (OSeMOSYS) and a top-down linear multi-sector model (IOA), has been formulated. Capitalizing on the capabilities of the aforementioned models, the proposed integration of them has resulted in alleviating some of their limitations. It has been shown that the proposed soft-link is useful in defining several economic and environmental implications induced by the evolution of the power sector on a nationwide economy scale. Thanks to the simplicity and generic nature of this approach, it could be extended to cover numerous indicators that might be of interest to future researches.

The developed approach has been applied to the case of Egypt, where a significant increase in demand for electricity is forecasted. Considering the planning horizon between 2015 and 2040, the OSeMOSYS-Egypt model has been developed to determine the least cost future Egyptian electricity production mix required to satisfy two different future electricity demand scenarios; namely, IEA New policies scenario and BMI scenario. Moreover, a sensitivity analysis has been conducted in order to assess the relevance of some crucial parameters in modifying the results of the model, and to test its robustness. This research adds to and extends the current literature on energy planning in developing countries by defining an Egyptian Reference Energy System (RES) based on the data published by the Egyptian Electricity Holding Company; in addition, the current and prospected primary energy supplies, power generation technologies, and the various demand categories obtained from various other references. Furthermore, the developed

RES is generic in nature, so it could be easily extended and implemented to various energy planning models.

For both the assumed scenarios, it is found that the lowest cost electricity generation mix always includes hydropower, natural gas-fired steam cycles, simple and combined cycles, wind power and PV rooftop technologies. This result mainly depends on the low economic cost of such technologies compared to the others, as well as due to the assumed constraints on the environmental impacts and polices on minimum use of renewable energy resources. Indeed, since Egypt's electricity peak load demand occurs at night hours, investing in large solar power generation utilities does not produce an economically feasible alternative.

Based on the sensitivity analysis applied to the BMI scenario, it is found that investment costs of renewables, availability of low prices natural gas and changes in prospected renewable penetration targets seem to have negligible effects on the shape of the future generation mix. Conversely, increasing the efficiency of natural gas combined cycles technology from 5% up to 12% with respect to the assumed efficiency in 2015 would impact the shape of the electricity generation mix, reducing the penetration of renewables by about 5% up to 10% over the whole planning period. Moreover, assuming unconstrained natural gas supplies results in reduction of the specific discounted costs per unit of energy produced by 95%, accompanied by 42% increase in natural gas consumption and 50% increase in the yearly total CO_2 emissions. Results of the model are also sensitive to changes in the values of discount rate on capitals: indeed, low values of discount rate cause lower capital costs technologies to be displaced from the electricity generation mix, resulting in more investments in higher capital cost technologies (i.e. natural-gas fired combined cycle, wind and PV rooftop technologies). However, despite this change in the electricity generation mix, the impact on the values of the yearly total CO_2 emissions is moderate (about 6%); this is attributed to the fixed consumption on natural gas at an amount equals to the assumed constraint on the natural gas supplies. Finally, sensitivity analysis has also been applied to quantify the effects caused by the construction of the Ethiopian Grand Renaissance Dam: despite the minimum penetration of the hydropower source in the generation mix (7%), the absolute effect caused by the dam may not be negligible. Indeed, assuming the worst-case scenario, a 77% in reduction of hydropower produced electricity would be compensated by 22% increase in the electricity production of wind and PV rooftop technologies; indeed, adding new capacities of natural gas power plants is not viable due to the assumed constraint on natural gas supplies. As a result, the total CO2 emissions level would remain almost unchanged, while the total discounted cost of electricity would be increasing by 11% between 2018 and 2040.

The results of the soft-linked model included key findings that could be beneficial in shaping Egypt’s energy policies. Although, the major increase in renewables penetration has allowed for major savings in the primary energy (PE) consumption, CO_2 emissions and the water consumption required by the power sector, it is not sufficient to achieve such savings when considering all of the non-power generation sectors. The non-power production sectors will be responsible for the prospective increase in PE consumption, CO_2 emissions and water consumption on the economy-wide scale, as no plans are assumed to reduce common sectors consumptions of primary resources and emissions of CO_2. Unfortunately, such increases in the PE consumption, CO_2 emissions, and water consumption by the common sectors, overweigh savings realized by decarbonizing the power sector, raising the question of the viability of increasing renewables penetration in the power generation mix to meet country's environmental targets.

Therefore, quantifiable performance indicators that assess the effectiveness of increasing the installed capacities of renewable technologies have been defined in this study. It is worth to note that the potential reductions in PE, CO_2 emissions, water consumption intensities fade out with time, despite the persistent increase in the installed capacities of renewable technologies. Hence, policymakers should define the optimum time plan to direct investment to increase the energy efficiencies of industrial, service, and transportation sector and/or increase the installed capacity of renewables; the latter may require associated investments in the infrastructure of electricity transmission and distribution.

Recommendations for Future Work:

The current version of the OSeMOSYS-Egypt model is able to provide a comprehensive description of the Egyptian power sector. However, the model is characterized by the following main drawbacks that could be considered as possible directions for *future improvements*:

I. Regarding the Bottom-Up model

- First of all, electricity demand has been exogenously assumed based on the literature. It is worth to note that a collaboration with local institutions is advocated by the Author in order to increase the quality and reliability of the results. In addition to this, the developed model assumes the electricity demand as perfectly rigid, hence it is not able to capture the behavior of the final users in response to a change in electricity price.

- Secondly, the technical representation of the renewable technologies in the bottom-up model should be improved to match the stochastic nature of the availability of the renewable resources. In particular, “the energy adequacy constraints” of OSeMOSYS should be enhanced to allow for an accurate representation of the capacity factors of the wind and the solar power generation utilities, which might be operating with a reduced output during specific time intervals. Similarly, it is recommended to enhance the “capacity adequacy constraints” by adding spatial constraints that specifies the land requirements for different power generation utilities; e.g. wind farms are only attractive at highly windy sites, which are somewhat limited.
- Thirdly, it is encouraged to extend the current study by considering the exergy based analysis principles in order to define the least cost power generation mix that maximizes the thermodynamic efficiency of Egypt’s power generation sector. Hence, the sustainability of the defined energy policy would be further enhanced.
- Fourthly, Egypt’s RES as well as OSeMOSYS-Egypt should be extended to consider the vast biomass resources available in Egypt. Utilizing biomass in power generation might significantly affect the cost and the environmental effects of the power generation mix in Egypt. These were not considered in the current analysis because the EEHC report did not include them, which the author believes is a deficiency.
- Fifthly, sensitivity analysis has been performed by varying each one of the considered parameters at a time: however, more interesting insights may be obtained by varying them together by applying a parametric sensitivity analysis, since some cross-effects may arise. Regarding capital discount rate, the same value of capital discount rate has been applied to all the considered energy technologies: this might not be applicable to Egypt and it may affect the quality of results and the shares of different technologies in

the power generation mix; e.g. a favorable discount rate for renewable energy technologies could have a marked influence on their share in the proposed power generation mix.

- Sixthly, the scope of the model is limited to the electrical power sector only, while great attention is currently devoted to extend the scope of energy models by including multiple energy carriers (electricity, heating, cooling, others) and multiple national sectors with more details, hence analyzing the full energy metabolism of the considered economy [108,109] by defining the sectoral demand on each of the energy carriers. For instance, the Egypt-OSeMOSYS should be extended to consider satisfying the combined industrial electrical and thermal demand by installing CHP utilities.

II. The Top-Down Model

- Regarding the top-down model, various important economic indicators are not covered in this study. For instance, it is expected that Egypt’s economic value added and the employment rate would be changed according to the potential structural changes in the power generation mix. Therefore, the proposed top-down model should be extended to cover such important economic issues related to the definition of Egypt’s energy policy. Furthermore, accurate estimates of the technical coefficients of input-output tables in each future year could be achieved by applying the RAS method.
- Lastly, Egypt’s government recently made a decision to diversify the power generation mix by installing new capacities of nuclear and coal power plants. Therefore, it is advised to update the top-down model by considering these two power generation technologies, despite them not contributing to the least cost power generation mix proposed in this study. Indeed, considering adding capacities of both coal and nuclear

power plants might affect the implications associated with evolution of the power generation mix on a nation-wide economy scale.

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Appendices

Appendix A: The RStudio Code for Defining Egypt’s Balanced IO table Using EORA 26 Dataset

```
#Egypt input-out Analysis
library(readxl)
A<-list()
Z<-list(0)
tfull<-read_excel(file.choose(),col_names = FALSE)
A1<-tfull[1:26,1:26]
A2<-tfull[27:52,1:26]
Aegy<-tfull[1405:1430,1:26]
for(j in 2:189){
  A[[j]]<-tfull[(1+(j*26)):((j+1)*26),1:26]
  Z[16][[j]]<-as.matrix(A[[j]])
}
tot<-Reduce("+", Z)
write.csv(Im, file="Zm.csv")
```

---

[16] Z: the endogenous industrial matrix.

Appendix B: Egypt EORA 26 Tables

Will Appear in the Next Page

Table 11. Egypt’s Balanced IO table 000’USD: with the 26th sector (electricity, gas and water) moved to the end

		Industries																					
		Agriculture	Fishing	Mining and Quarrying	Food & Beverages	Textiles and Wearing Apparel	Wood and Paper	Petroleum, Chemical and Non-Metallic	Metal Products	Electrical and Machinery	Transport Equipment	Other Manufacturing	Recycling	Construction	Maintenance and Repair	Wholesale Trade	Retail Trade	Hotels and Restaurants	Transport	Post and Telecommunications	Finacial Intermediation and Business	Public Administration	Education, Health and Other Services
1	Agriculture	3E+06	7E+02	3E+03	3E+06	1E+05	3E+05	3E+04	1E+03	2E+03	2E+02	3E+03	1E+03	6E+04	6E+02	7E+03	3E+04	3E+05	2E+03	3E+02	6E+04	1E+04	3E+04
2	Fishing	2E+03	1E+04	8E-01	3E+05	2E+02	2E+00	3E+02	1E+02	1E+01	7E-01	7E+03	1E+01	3E-01	2E+02	4E-01	1E+04	6E+04	2E+01	2E+00	2E+03	2E+02	4E+03
3	Mining and Quarrying	3E+04	2E+03	2E+05	1E+04	5E+03	8E+03	1E+06	9E+04	3E+03	5E+03	1E+03	3E+05	2E+05	8E+01	4E+03	3E+03	6E+03	6E+04	1E+03	2E+04	4E+04	1E+04
4	Food & Beverages	4E+05	1E+04	3E+02	1E+06	5E+04	7E+03	4E+04	2E+02	4E+02	1E+02	4E+03	8E+03	3E+02	4E+03	2E+04	2E+05	1E+06	1E+03	5E+02	7E+04	1E+05	2E+05
5	Textiles and Wearing Apparel	8E+03	1E+03	9E+02	1E+04	4E+05	8E+03	2E+04	2E+03	1E+04	1E+04	1E+04	1E+03	1E+04	3E+02	2E+04	1E+04	1E+04	3E+03	1E+03	1E+04	1E+04	3E+04
6	Wood and Paper	1E+05	3E+03	1E+04	9E+05	3E+05	1E+06	4E+05	6E+04	2E+05	5E+04	4E+05	3E+04	7E+05	1E+04	2E+05	4E+05	3E+05	8E+04	2E+05	6E+05	4E+05	4E+05
7	Petroleum, Chemical and Non-Metallic Mineral Products	6E+05	2E+04	1E+05	7E+05	1E+06	3E+05	4E+06	2E+05	8E+05	4E+05	2E+05	4E+05	2E+06	6E+03	1E+05	2E+05	2E+05	7E+05	8E+04	4E+05	6E+05	1E+06
8	Metal Products	4E+04	2E+03	5E+04	6E+05	1E+05	6E+04	4E+05	2E+06	2E+06	5E+05	3E+05	2E+05	1E+06	3E+03	7E+04	8E+04	1E+05	8E+04	3E+04	2E+05	9E+04	6E+04
9	Electrical and Machinery	5E+04	6E+03	1E+05	1E+05	1E+05	1E+05	4E+05	3E+05	4E+06	2E+06	2E+05	3E+03	1E+06	1E+04	2E+05	4E+05	1E+05	1E+05	2E+05	5E+05	7E+05	5E+05
10	Transport Equipment	1E+04	6E+03	2E+04	3E+04	7E+03	3E+03	8E+04	2E+04	3E+05	2E+06	7E+04	2E+03	2E+05	7E+03	4E+04	4E+05	1E+04	1E+05	1E+04	1E+05	5E+05	2E+04
11	Other Manufacturing	1E+04	5E+03	7E+03	7E+04	2E+05	4E+04	5E+04	2E+04	7E+04	2E+05	6E+04	5E+03	3E+05	3E+03	7E+04	1E+05	9E+04	2E+04	2E+04	1E+05	6E+04	1E+05
12	Recycling	4E+02	8E-01	9E+02	3E+03	2E+03	6E+03	2E+04	4E+04	7E+02	1E+01	6E+02	2E+04	8E+02	2E+01	8E+01	1E+03	1E+03	2E+03	8E+02	4E+03	5E+01	3E+03
13	Construction	5E+04	1E+03	2E+05	9E+04	6E+04	6E+04	2E+05	9E+04	1E+05	2E+04	2E+04	4E+02	3E+04	6E+03	1E+05	2E+05	2E+05	2E+05	1E+05	1E+06	7E+05	4E+05
14	Maintenance and Repair	1E+04	4E+02	1E+03	2E+04	2E+04	7E+03	2E+04	7E+03	2E+04	6E+03	5E+03	4E+02	3E+04	2E+02	7E+03	7E+03	2E+04	5E+03	1E+03	9E+03	5E+03	1E+04
15	Wholesale Trade	4E+05	2E+04	5E+04	1E+06	5E+05	4E+05	1E+06	4E+05	1E+06	4E+05	2E+05	3E+03	1E+06	1E+04	3E+05	4E+05	7E+05	2E+05	8E+04	4E+05	4E+05	6E+05
16	Retail Trade	3E+04	2E+03	8E+03	2E+04	7E+04	8E+03	6E+04	7E+03	4E+04	2E+04	3E+04	2E+03	5E+05	2E+03	3E+04	7E+04	2E+05	9E+04	8E+03	1E+05	1E+04	7E+04
17	Hotels and Restraurants	4E+03	6E+01	1E+03	3E+04	1E+04	2E+04	4E+04	2E+04	3E+04	5E+03	8E+03	7E+01	3E+04	1E+03	4E+04	5E+04	7E+04	4E+04	4E+04	3E+05	1E+05	2E+05
18	Transport	3E+05	8E+03	1E+05	7E+05	3E+05	2E+05	8E+05	2E+05	3E+05	1E+05	1E+05	3E+05	6E+05	2E+04	7E+05	7E+05	3E+05	4E+04	1E+05	4E+05	3E+05	5E+05
19	Post and Telecommunications	2E+04	2E+03	2E+04	8E+04	9E+04	8E+04	2E+05	7E+04	4E+05	3E+04	4E+04	2E+03	3E+05	3E+04	8E+05	1E+06	5E+05	5E+05	6E+04	1E+06	8E+05	7E+05
20	Finacial Intermediation and Business Activities	1E+06	2E+04	7E+05	2E+06	7E+05	7E+05	3E+06	9E+05	3E+06	8E+05	4E+05	5E+03	3E+06	2E+05	3E+06	4E+06	2E+06	3E+06	2E+06	3E+03	4E+06	5E+06
21	Public Administration	6E+03	1E+02	2E+03	9E+03	3E+03	4E+03	1E+04	3E+03	3E+03	1E+03	3E+03	2E+01	3E+03	3E+02	3E+03	1E+04	1E+04	7E+03	8E+03	5E+04	3E+03	3E+04
22	Education, Health and Other Services	3E+04	4E+03	5E+03	4E+04	2E+04	2E+04	6E+04	2E+04	3E+04	8E+03	8E+03	3E+02	6E+04	3E+03	6E+04	1E+05	2E+05	6E+04	2E+05	6E+05	4E+05	7E+02
23	Private Households	5E+00	3E-01	4E-01	1E+00	2E+00	3E-01	1E+00	3E-01	4E-01	3E-01	1E+00	5E+00	3E-01	2E-01	3E-01	4E-01	2E+01	2E-01	2E-01	1E+01	5E+03	1E+03
24	Others	2E+04	2E+03	5E+03	5E+04	1E+05	2E+04	5E+04	4E+04	5E+04	5E+03	7E+03	3E+03	3E+04	2E+03	9E+04	2E+04	4E+04	2E+04	1E+04	7E+04	2E+04	3E+04
25	Re-export & Re-import	9E-02	1E-01	9E-02	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01	1E-01
26	Electricity, Gas and Water	2E+05	1E+03	1E+05	4E+05	2E+05	2E+05	1E+06	3E+05	3E+05	7E+04	4E+04	2E+04	1E+05	9E+03	1E+05	4E+05	6E+05	1E+05	6E+04	4E+05	3E+05	5E+05
	Value Added																						
	Compensation of employees D.1	4E+05	6E+04	3E+05	1E+06	6E+05	1E+06	2E+06	1E+06	4E+06	1E+06	5E+05	4E+04	6E+06	3E+05	6E+06	5E+06	3E+06	3E+06	3E+06	2E+07	8E+06	2E+07
	Taxes on production D.29	3E+05	1E+04	3E+05	8E+05	5E+04	1E+05	7E+05	1E+05	2E+05	6E+04	4E+04	3E+03	5E+05	1E+05	2E+06	2E+06	8E+05	4E+05	6E+05	4E+06	2E+05	1E+06
	Subsidies on production D.39	-4E+04	-1E+03	-1E+04	-1E+05	-8E+02	-2E+03	-1E+04	-2E+03	-1E+04	-2E+03	-1E+03	-2E+01	-5E+04	-7E+03	-2E+05	-2E+05	-4E+04	-5E+04	-5E+04	-8E+05	-1E+04	-2E+05
	Net operating surplus B.2n	3E+06	2E+05	1E+06	3E+06	6E+05	1E+06	4E+06	1E+06	3E+06	1E+06	6E+05	3E+04	3E+06	2E+05	5E+06	4E+06	2E+06	2E+06	5E+06	5E+07	2E+06	1E+07
	Net mixed income B.3n	1E+06	4E+04	6E+05	1E+06	4E+05	8E+05	2E+06	8E+05	2E+06	8E+05	4E+05	7E+03	3E+06	2E+05	4E+06	4E+06	2E+06	2E+06	3E+06	2E+07	7E+06	1E+07
	Consumption of fixed capital K.1	4E+05	2E+04	2E+05	3E+05	8E+04	2E+05	6E+05	2E+05	7E+05	2E+05	8E+04	5E+03	6E+05	3E+04	5E+05	6E+05	4E+05	4E+05	8E+05	8E+06	8E+05	2E+06
	Exogenous Resources																						
	CO2 emissions (Gg) from EDGAR	3E+03	1E+02	4E+03	5E+03	2E+03	2E+03	4E+04	3E+03	6E+03	3E+03	1E+03	6E+02	5E+03	1E+02	5E+02	7E+02	6E+02	5E+04	3E+02	5E+03	8E+02	1E+03
	DEPRECATED Water use, total (m3)	5E+10	5E+08	6E+08	2E+09	6E+08	5E+08	7E+08	5E+08	5E+08	7E+08	3E+08	2E+09	7E+08	0E+00	0E+00	0E+00	7E+08	7E+08	0E+00	3E+08	0E+00	7E+08
	Primary Energy Usage (TJ)	1E+05	2E+02	2E+05	2E+04	8E+03	8E+03	3E+05	3E+04	2E+05	1E+04	4E+04	2E+04	2E+04	5E+02	1E+04	2E+04	1E+04	6E+05	6E+03	1E+04	2E+04	2E+04

Table 11. Egypt's Balanced IO table 000'USD: with the 26th sector (electricity, gas and water) moved to the end

					Final Demand						
	Private Households	Others	Re-export & Re-import	Electricity, Gas and Water	Household final consumption P.3h	Non-profit institutions serving households P.3n	Government final consumption P.3g	Gross fixed capital formation P.51	Changes in inventories P.52	Acquisitions less disposals of valuables P.53	Exports
Agriculture	7E+01	9E+01	7E+01	5E+02	2E+06	5E+03	2E+03	2E+04	4E+04	5E-01	3E+06
Fishing	3E+01	6E-01	3E+02	3E-01	9E+04	1E+02	1E+03	5E-01	3E+03	5E-01	3E+04
Mining and Quarrying	5E+01	7E+02	3E+02	5E+05	2E+05	5E+01	2E+03	6E+03	4E+04	5E-01	3E+06
Food & Beverages	5E+03	2E+02	1E+02	5E+02	1E+07	5E+04	3E-01	4E-01	6E+04	4E-01	2E+06
Textiles and Wearing Apparel	2E+02	4E+02	3E+02	1E+03	2E+06	6E+03	2E+02	7E+04	8E+03	5E-01	4E+06
Wood and Paper	1E+04	2E+04	2E+02	2E+04	1E+06	3E+03	7E+03	2E+04	1E+04	4E-01	2E+05
Petroleum, Chemical and Non-Metallic Mineral Products	1E+04	3E+04	1E+02	1E+05	6E+06	3E+04	2E+04	6E+04	2E+04	4E-01	5E+06
Metal Products	3E+03	8E+03	2E+02	1E+04	2E+05	9E+02	6E+03	2E+05	4E+04	4E-01	1E+06
Electrical and Machinery	1E+04	1E+04	1E+02	6E+04	4E+06	9E+03	4E+05	7E+06	1E+05	4E-01	1E+06
Transport Equipment	5E+03	2E+03	2E+02	2E+03	4E+06	2E+04	3E+05	2E+06	2E+05	4E-01	8E+04
Other Manufacturing	2E+03	3E+03	3E+02	8E+03	1E+06	8E+03	5E+04	5E+05	2E+04	4E-01	5E+05
Recycling	1E+00	3E-01	7E+02	9E+03	9E+05	7E+03	6E+03	4E-01	5E+04	3E+05	5E+04
Construction	8E+03	9E+03	1E+02	3E+05	2E+05	1E+03	1E+06	2E+07	2E-02	4E-01	7E+04
Maintenance and Repair	1E+02	3E+02	4E+02	1E+03	8E+05	4E+03	2E+03	5E+04	7E+02	4E-01	2E+04
Wholesale Trade	8E+03	1E+04	1E+02	6E+04	1E+07	5E+04	9E+04	2E+06	5E+04	4E-01	3E+05
Retail Trade	5E+02	2E+03	1E+02	3E+03	2E+07	1E+05	5E+03	6E+05	2E-02	4E-01	4E+04
Hotels and Restraurants	2E+03	2E+03	9E+01	3E+04	2E+07	6E+04	2E+01	4E-01	2E-02	4E-01	4E+05
Transport	5E+03	2E+04	2E+02	3E+05	7E+06	2E+04	5E+04	3E+05	7E+03	4E-01	1E+06
Post and Telecommunications	3E+04	6E+04	3E+02	6E+04	8E+06	4E+04	4E+04	1E+06	5E+02	4E-01	3E+05
Finacial Intermediation and Business Activities	2E+05	3E+05	6E+01	7E+05	7E+07	3E+05	4E+05	4E+06	1E+05	4E-01	2E+03
Public Administration	8E+03	1E+05	1E+02	3E+02	1E+06	6E+03	2E+07	9E+06	2E-02	4E-01	7E+04
Education, Health and Other Services	1E+04	2E+04	7E+01	3E+04	4E+07	2E+05	9E+06	1E+06	5E+01	4E-01	3E+05
Private Households	1E-01	4E+01	1E+02	2E-01	8E+05	6E+03	1E+04	4E-01	2E-02	4E-01	1E+04
Others	2E+03	4E-01	4E+02	1E+04	9E+05	7E+03	3E-01	4E-01	2E-02	4E-01	2E+03
Re-export & Re-import	1E-01	1E-01	4E-01	1E-01	2E-01	2E-01	2E-01	2E-01	9E-03	2E-01	4E+04
Electricity, Gas and Water	4E+03	1E+04	1E+02	4E+04	5E+06	2E+04	3E-01	5E-01	2E+01	5E-01	7E+03
Value Added											
Compensation of employees D.1	2E+05	1E+05	5E+00	1E+06							
Taxes on production D.29	3E+03	2E+04	5E+00	9E+05							
Subsidies on production D.39	-1E+02	-2E+03	-1E-01	-3E+04							
Net operating surplus B.2n	6E+04	5E+05	5E+00	4E+06							
Net mixed income B.3n	2E+05	2E+05	5E+00	2E+06							
Consumption of fixed capital K.1	8E+03	8E+04	5E+00	8E+05							
Exogenous Resources											
CO2 emissions (Gg) from EDGAR	1E+02	1E+02	0E+00	9E+04							
DEPRECATED Water use, total (m3)	0E+00	0E+00	0E+00	4E+08							
Primary Energy Usage (TJ)	5E+02	1E+03	0E+00	1E+06							

Table 12. Egypt's IO table 000'USD: dissaggregation step I

		Industries																		
		Agriculture	Fishing	Mining and Quarrying	Food & Beverages	Textiles and Wearing Apparel	Wood and Paper	Petroleum, Chemical and Non-Metallic Mineral Products	Metal Products	Electrical and Machinery	Transport Equipment	Other Manufacturing	Recycling	Construction	Maintenance and Repair	Wholesale Trade	Retail Trade	Hotels and Restraurants	Transport	Post and Telecommunications
1	Agriculture	3.E+06	7.E+02	3.E+03	3.E+06	1.E+05	3.E+05	3.E+04	1.E+03	2.E+03	2.E+02	3.E+03	1.E+03	6.E+04	6.E+02	7.E+03	3.E+04	3.E+05	2.E+03	3.E+02
2	Fishing	2.E+03	1.E+04	8.E-01	3.E+05	2.E+02	2.E+00	3.E+02	1.E+02	1.E+01	7.E-01	7.E+03	1.E+01	3.E-01	2.E+02	4.E-01	1.E+04	6.E+04	2.E+01	2.E+00
3	Mining and Quarrying	3.E+04	2.E+03	2.E+05	1.E+04	5.E+03	8.E+03	1.E+06	9.E+04	3.E+03	5.E+03	1.E+03	3.E+05	2.E+05	8.E+01	4.E+03	3.E+03	6.E+03	6.E+04	1.E+03
4	Food & Beverages	4.E+05	1.E+04	3.E+02	1.E+06	5.E+04	7.E+03	4.E+04	2.E+02	4.E+02	1.E+02	4.E+03	8.E+03	3.E+02	4.E+03	2.E+04	2.E+05	1.E+06	1.E+03	5.E+02
5	Textiles and Wearing Apparel	8.E+03	1.E+03	9.E+02	1.E+04	4.E+05	8.E+03	2.E+04	2.E+03	1.E+04	1.E+04	1.E+04	1.E+03	1.E+04	3.E+02	2.E+04	1.E+04	1.E+04	3.E+03	1.E+03
6	Wood and Paper	1.E+05	3.E+03	1.E+04	9.E+05	3.E+05	1.E+06	4.E+05	6.E+04	2.E+05	5.E+04	4.E+05	3.E+04	7.E+05	1.E+04	2.E+05	4.E+05	3.E+05	8.E+04	2.E+05
7	Petroleum, Chemical and Non-Metallic Mineral Products	6.E+05	2.E+04	1.E+05	7.E+05	1.E+06	3.E+05	4.E+06	2.E+05	8.E+05	4.E+05	2.E+05	4.E+05	2.E+06	6.E+03	1.E+05	2.E+05	2.E+05	7.E+05	8.E+04
8	Metal Products	4.E+04	2.E+03	5.E+04	6.E+05	1.E+05	6.E+04	4.E+05	2.E+06	2.E+06	5.E+05	3.E+05	2.E+05	1.E+06	3.E+03	7.E+04	8.E+04	1.E+05	8.E+04	3.E+04
9	Electrical and Machinery	5.E+04	6.E+03	1.E+05	1.E+05	1.E+05	1.E+05	4.E+05	3.E+05	4.E+06	2.E+06	2.E+05	3.E+03	1.E+06	1.E+04	2.E+05	4.E+05	1.E+05	1.E+05	2.E+05
10	Transport Equipment	1.E+04	6.E+03	2.E+04	3.E+04	7.E+03	3.E+03	8.E+04	2.E+04	3.E+05	2.E+06	7.E+04	2.E+03	2.E+05	7.E+03	4.E+04	4.E+05	1.E+04	1.E+05	1.E+04
11	Other Manufacturing	1.E+04	5.E+03	7.E+03	7.E+04	2.E+05	4.E+04	5.E+04	2.E+04	7.E+04	2.E+05	6.E+04	5.E+03	3.E+05	3.E+03	7.E+04	1.E+05	9.E+04	2.E+04	2.E+04
12	Recycling	4.E+02	8.E-01	9.E+02	3.E+03	2.E+03	6.E+03	2.E+04	4.E+04	7.E+02	1.E+01	6.E+02	2.E+04	8.E+02	2.E+01	8.E+01	1.E+03	1.E+03	2.E+03	8.E+02
13	Construction	5.E+04	1.E+03	2.E+05	9.E+04	6.E+04	6.E+04	2.E+05	9.E+04	1.E+05	2.E+04	2.E+04	4.E+02	3.E+04	6.E+03	1.E+05	2.E+05	2.E+05	2.E+05	1.E+05
14	Maintenance and Repair	1.E+04	4.E+02	1.E+03	2.E+04	2.E+04	7.E+03	2.E+04	7.E+03	2.E+04	6.E+03	5.E+03	4.E+02	3.E+04	2.E+02	7.E+03	7.E+03	2.E+04	5.E+03	1.E+03
15	Wholesale Trade	4.E+05	2.E+04	5.E+04	1.E+06	5.E+05	4.E+05	1.E+06	4.E+05	1.E+06	4.E+05	2.E+05	3.E+03	1.E+06	1.E+04	3.E+05	4.E+05	7.E+05	2.E+05	8.E+04
16	Retail Trade	3.E+04	2.E+03	8.E+03	2.E+04	7.E+04	8.E+03	6.E+04	7.E+03	4.E+04	2.E+04	3.E+04	2.E+03	5.E+05	2.E+03	3.E+04	7.E+04	2.E+05	9.E+04	8.E+03
17	Hotels and Restraurants	4.E+03	6.E+01	1.E+03	3.E+04	1.E+04	2.E+04	4.E+04	2.E+04	3.E+04	5.E+03	8.E+03	7.E+01	3.E+04	1.E+03	4.E+04	5.E+04	7.E+04	4.E+04	4.E+04
18	Transport	3.E+05	8.E+03	1.E+05	7.E+05	3.E+05	2.E+05	8.E+05	2.E+05	3.E+05	1.E+05	1.E+05	3.E+05	6.E+05	2.E+04	7.E+05	7.E+05	3.E+05	4.E+04	1.E+05
19	Post and Telecommunications	2.E+04	2.E+03	2.E+04	8.E+04	9.E+04	8.E+04	2.E+05	7.E+04	4.E+05	3.E+04	4.E+04	2.E+03	3.E+05	3.E+04	8.E+05	1.E+06	5.E+05	5.E+05	6.E+04
20	Finacial Intermediation and Business Activities	1.E+06	2.E+04	7.E+05	2.E+06	7.E+05	7.E+05	3.E+06	9.E+05	3.E+06	8.E+05	4.E+05	5.E+03	3.E+06	2.E+05	3.E+06	4.E+06	2.E+06	3.E+06	2.E+06
21	Public Administration	6.E+03	1.E+02	2.E+03	9.E+03	3.E+03	4.E+03	1.E+04	3.E+03	3.E+03	1.E+03	3.E+03	2.E+01	3.E+03	3.E+02	3.E+03	1.E+04	1.E+04	7.E+03	8.E+03
22	Education, Health and Other Services	3.E+04	4.E+03	5.E+03	4.E+04	2.E+04	2.E+04	6.E+04	2.E+04	3.E+04	8.E+03	8.E+03	3.E+02	6.E+04	3.E+03	6.E+04	1.E+05	2.E+05	6.E+04	2.E+05
23	Private Households	5.E+00	3.E-01	4.E-01	1.E+00	2.E+00	3.E-01	1.E+00	3.E-01	4.E-01	3.E-01	1.E+00	5.E+00	3.E-01	2.E-01	3.E-01	4.E-01	2.E+01	2.E-01	2.E-01
24	Others	2.E+04	2.E+03	5.E+03	5.E+04	1.E+05	2.E+04	5.E+04	4.E+04	5.E+04	5.E+03	7.E+03	3.E+03	3.E+04	2.E+03	9.E+04	2.E+04	4.E+04	2.E+04	1.E+04
25	Re-export & Re-import	9.E-02	1.E-01	9.E-02	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01
26^{New}	Gas and Water	6.E+04	3.E+02	4.E+04	1.E+05	7.E+04	7.E+04	3.E+05	9.E+04	8.E+04	2.E+04	1.E+04	5.E+03	3.E+04	3.E+03	4.E+04	1.E+05	2.E+05	4.E+04	2.E+04
27	Electricity	1.E+05	8.E+02	1.E+05	3.E+05	2.E+05	2.E+05	7.E+05	2.E+05	2.E+05	5.E+04	3.E+04	1.E+04	8.E+04	6.E+03	8.E+04	3.E+05	4.E+05	9.E+04	4.E+04
	Value Added																			
	Compensation of employees D.1	4.E+05	6.E+04	3.E+05	1.E+06	6.E+05	1.E+06	2.E+06	1.E+06	4.E+06	1.E+06	5.E+05	4.E+04	6.E+06	3.E+05	6.E+06	5.E+06	3.E+06	3.E+06	3.E+06
	Taxes on production D.29	3.E+05	1.E+04	3.E+05	8.E+05	5.E+04	1.E+05	7.E+05	1.E+05	2.E+05	6.E+04	4.E+04	3.E+03	5.E+05	1.E+05	2.E+06	2.E+06	8.E+05	4.E+05	6.E+05
	Subsidies on production D.39	-4.E+04	-1.E+03	-1.E+04	-1.E+05	-8.E+02	-2.E+03	-1.E+04	-2.E+03	-1.E+04	-2.E+03	-1.E+03	-2.E+01	-5.E+04	-7.E+03	-2.E+05	-2.E+05	-4.E+04	-5.E+04	-5.E+04
	Net operating surplus B.2n	3.E+06	2.E+05	1.E+06	3.E+06	6.E+05	1.E+06	4.E+06	1.E+06	3.E+06	1.E+06	6.E+05	3.E+04	3.E+06	2.E+05	5.E+06	4.E+06	2.E+06	2.E+06	5.E+06
	Net mixed income B.3n	1.E+06	4.E+04	6.E+05	1.E+06	4.E+05	8.E+05	2.E+06	8.E+05	2.E+06	8.E+05	4.E+05	7.E+03	3.E+06	2.E+05	4.E+06	4.E+06	2.E+06	2.E+06	3.E+06
	Consumption of fixed capital K.1	4.E+05	2.E+04	2.E+05	3.E+05	8.E+04	2.E+05	6.E+05	2.E+05	7.E+05	2.E+05	8.E+04	5.E+03	6.E+05	3.E+04	5.E+05	6.E+05	4.E+05	4.E+05	8.E+05
	Exogenous Resources																			
	CO2 emissions (Gg) from EDGAR	3.E+03	1.E+02	4.E+03	5.E+03	2.E+03	2.E+03	4.E+04	3.E+03	6.E+03	3.E+03	1.E+03	6.E+02	5.E+03	1.E+02	5.E+02	7.E+02	6.E+02	5.E+04	3.E+02
	DEPRECATED Water use, total (m3)	5.E+10	5.E+08	6.E+08	2.E+09	6.E+08	5.E+08	7.E+08	5.E+08	5.E+08	7.E+08	3.E+08	2.E+09	7.E+08	0.E+00	0.E+00	0.E+00	7.E+08	7.E+08	0.E+00
	Primary Energy Usage (TJ)	1.E+05	2.E+02	2.E+05	2.E+04	8.E+03	8.E+03	3.E+05	3.E+04	2.E+05	1.E+04	4.E+04	2.E+04	2.E+04	5.E+02	1.E+04	2.E+04	1.E+04	6.E+05	6.E+03

Table 12. Egypt's IO table 000'USD: dissaggregation step I

								Industries		Final Demand						
		Finacial Intermediation and Business Activities	Public Administration	Education, Health and Other Services	Private Households	Others	Re-export & Re-import	Gas and Water	Electricity	Household final consumption P.3h	Non-profit institutions serving households P.3n	Government final consumption P.3g	Gross fixed capital formation P.51	Changes in inventories P.52	Acquisitions less disposals of valuables P.53	Exports
1	Agriculture	6.E+04	1.E+04	3.E+04	7.E+01	9.E+01	7.E+01	1.E+02	3.E+02	2.E+06	5.E+03	2.E+03	2.E+04	4.E+04	5.E-01	3.E+06
2	Fishing	2.E+03	2.E+02	4.E+03	3.E+01	6.E-01	3.E+02	8.E-02	2.E-01	9.E+04	1.E+02	1.E+03	5.E-01	3.E+03	5.E-01	3.E+04
3	Mining and Quarrying	2.E+04	4.E+04	1.E+04	5.E+01	7.E+02	3.E+02	2.E+05	4.E+05	2.E+05	5.E+01	2.E+03	6.E+03	4.E+04	5.E-01	3.E+06
4	Food & Beverages	7.E+04	1.E+05	2.E+05	5.E+03	2.E+02	1.E+02	1.E+02	3.E+02	1.E+07	5.E+04	3.E-01	4.E-01	6.E+04	4.E-01	2.E+06
5	Textiles and Wearing Apparel	1.E+04	1.E+04	3.E+04	2.E+02	4.E+02	3.E+02	3.E+02	8.E+02	2.E+06	6.E+03	2.E+02	7.E+04	8.E+03	5.E-01	4.E+06
6	Wood and Paper	6.E+05	4.E+05	4.E+05	1.E+04	2.E+04	2.E+02	4.E+03	1.E+04	1.E+06	3.E+03	7.E+03	2.E+04	1.E+04	4.E-01	2.E+05
7	Petroleum, Chemical and Non-Metallic Mineral Products	4.E+05	6.E+05	1.E+06	1.E+04	3.E+04	1.E+02	3.E+04	7.E+04	6.E+06	3.E+04	2.E+04	6.E+04	2.E+04	4.E-01	5.E+06
8	Metal Products	2.E+05	9.E+04	6.E+04	3.E+03	8.E+03	2.E+02	3.E+03	8.E+03	2.E+05	9.E+02	6.E+03	2.E+05	4.E+04	4.E-01	1.E+06
9	Electrical and Machinery	5.E+05	7.E+05	5.E+05	1.E+04	1.E+04	1.E+02	2.E+04	4.E+04	4.E+06	9.E+03	4.E+05	7.E+06	1.E+05	4.E-01	1.E+06
10	Transport Equipment	1.E+05	5.E+05	2.E+04	5.E+03	2.E+03	2.E+02	6.E+02	1.E+03	4.E+06	2.E+04	3.E+05	2.E+06	2.E+05	4.E-01	8.E+04
11	Other Manufacturing	1.E+05	6.E+04	1.E+05	2.E+03	3.E+03	3.E+02	2.E+03	6.E+03	1.E+06	8.E+03	5.E+04	5.E+05	2.E+04	4.E-01	5.E+05
12	Recycling	4.E+03	5.E+01	3.E+03	1.E+00	3.E-01	7.E+02	3.E+03	7.E+03	9.E+05	7.E+03	6.E+03	4.E-01	5.E+04	3.E+05	5.E+04
13	Construction	1.E+06	7.E+05	4.E+05	8.E+03	9.E+03	1.E+02	8.E+04	2.E+05	2.E+05	1.E+03	1.E+06	2.E+07	2.E-02	4.E-01	7.E+04
14	Maintenance and Repair	9.E+03	5.E+03	1.E+04	1.E+02	3.E+02	4.E+02	3.E+02	7.E+02	8.E+05	4.E+03	2.E+03	5.E+04	7.E+02	4.E-01	2.E+04
15	Wholesale Trade	4.E+05	4.E+05	6.E+05	8.E+03	1.E+04	1.E+02	2.E+04	4.E+04	1.E+07	5.E+04	9.E+04	2.E+06	5.E+04	4.E-01	3.E+05
16	Retail Trade	1.E+05	1.E+04	7.E+04	5.E+02	2.E+03	1.E+02	8.E+02	2.E+03	2.E+07	1.E+05	5.E+03	6.E+05	2.E-02	4.E-01	4.E+04
17	Hotels and Restraurants	3.E+05	1.E+05	2.E+05	2.E+03	2.E+03	9.E+01	9.E+03	2.E+04	2.E+07	6.E+04	2.E+01	4.E-01	2.E-02	4.E-01	4.E+05
18	Transport	4.E+05	3.E+05	5.E+05	5.E+03	2.E+04	2.E+02	9.E+04	2.E+05	7.E+06	2.E+04	5.E+04	3.E+05	7.E+03	4.E-01	1.E+06
19	Post and Telecommunications	1.E+06	8.E+05	7.E+05	3.E+04	6.E+04	3.E+02	2.E+04	4.E+04	8.E+06	4.E+04	4.E+04	1.E+06	5.E+02	4.E-01	3.E+05
20	Finacial Intermediation and Business Activities	3.E+03	4.E+06	5.E+06	2.E+05	3.E+05	6.E+01	2.E+05	5.E+05	7.E+07	3.E+05	4.E+05	4.E+06	1.E+05	4.E-01	2.E+03
21	Public Administration	5.E+04	3.E+03	3.E+04	8.E+03	1.E+05	1.E+02	8.E+01	2.E+02	1.E+06	6.E+03	2.E+07	9.E+06	2.E-02	4.E-01	7.E+04
22	Education, Health and Other Services	6.E+05	4.E+05	7.E+02	1.E+04	2.E+04	7.E+01	8.E+03	2.E+04	4.E+07	2.E+05	9.E+06	1.E+06	5.E+01	4.E-01	3.E+05
23	Private Households	1.E+01	5.E+03	1.E+03	1.E-01	4.E+01	1.E+02	6.E-02	1.E-01	8.E+05	6.E+03	1.E+04	4.E-01	2.E-02	4.E-01	1.E+04
24	Others	7.E+04	2.E+04	3.E+04	2.E+03	4.E-01	4.E+02	4.E+03	1.E+04	9.E+05	7.E+03	3.E-01	4.E-01	2.E-02	4.E-01	2.E+03
25	Re-export & Re-import	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	4.E-01	3.E-02	7.E-02	2.E-01	2.E-01	2.E-01	2.E-01	9.E-03	2.E-01	4.E+04
26^{New}	Gas and Water	1.E+05	1.E+05	2.E+05	1.E+03	3.E+03	4.E+01	2.E+04	8.E+03	2.E+06	6.E+03	1.E-01	1.E-01	5.E+00	1.E-01	2.E+03
27	Electricity	3.E+05	2.E+05	4.E+05	3.E+03	7.E+03	9.E+01	8.E+03	3.E+03	4.E+06	2.E+04	2.E-01	3.E-01	1.E+01	3.E-01	5.E+03
	Value Added															
	Compensation of employees D.1	2.E+07	8.E+06	2.E+07	2.E+05	1.E+05	5.E+00	3.E+05	8.E+05							
	Taxes on production D.29	4.E+06	2.E+05	1.E+06	3.E+03	2.E+04	5.E+00	3.E+05	6.E+05							
	Subsidies on production D.39	-8.E+05	-1.E+04	-2.E+05	-1.E+02	-2.E+03	-1.E-01	-8.E+03	-2.E+04							
	Net operating surplus B.2n	5.E+07	2.E+06	1.E+07	6.E+04	5.E+05	5.E+00	1.E+06	3.E+06							
	Net mixed income B.3n	2.E+07	7.E+06	1.E+07	2.E+05	2.E+05	5.E+00	5.E+05	1.E+06							
	Consumption of fixed capital K.1	8.E+06	8.E+05	2.E+06	8.E+03	8.E+04	5.E+00	2.E+05	6.E+05							
	Exogenous Resources															
	CO2 emissions (Gg) from EDGAR	5.E+03	8.E+02	1.E+03	1.E+02	1.E+02	0.E+00									
	DEPRECATED Water use, total (m3)	3.E+08	0.E+00	7.E+08	0.E+00	0.E+00	0.E+00									
	Primary Energy Usage (TJ)	1.E+04	2.E+04	2.E+04	5.E+02	1.E+03	0.E+00									

Table 13. Egypt's IO table 000'USD: disaggregation step II

		Industries																		
		Agriculture	Fishing	Mining and Quarrying	Food & Beverages	Textiles and Wearing Apparel	Wood and Paper	Petroleum, Chemical and Non-Metallic Mineral Products	Metal Products	Electrical and Machinery	Transport Equipment	Other Manufacturing	Recycling	Construction	Maintenance and Repair	Wholesale Trade	Retail Trade	Hotels and Restaurants	Transport	Post and Telecommunications
1	Agriculture	3.E+06	7.E+02	3.E+03	3.E+06	1.E+05	3.E+05	3.E+04	1.E+03	2.E+03	2.E+02	3.E+03	1.E+03	6.E+04	6.E+02	7.E+03	3.E+04	3.E+05	2.E+03	3.E+02
2	Fishing	2.E+03	1.E+04	8.E-01	3.E+05	2.E+02	2.E+00	3.E+02	1.E+02	1.E+01	7.E-01	7.E+03	1.E+01	3.E-01	2.E+02	4.E-01	1.E+04	6.E+04	2.E+01	2.E+00
3	Mining and Quarrying	3.E+04	2.E+03	2.E+05	1.E+04	5.E+03	8.E+03	1.E+06	9.E+04	3.E+03	5.E+03	1.E+03	3.E+05	2.E+05	8.E+01	4.E+03	3.E+03	6.E+03	6.E+04	1.E+03
4	Food & Beverages	4.E+05	1.E+04	3.E+02	1.E+06	5.E+04	7.E+03	4.E+04	2.E+02	4.E+02	1.E+02	4.E+03	8.E+03	3.E+02	4.E+03	2.E+04	2.E+05	1.E+06	1.E+03	5.E+02
5	Textiles and Wearing Apparel	8.E+03	1.E+03	9.E+02	1.E+04	4.E+05	8.E+03	2.E+04	2.E+03	1.E+04	1.E+04	1.E+04	1.E+03	1.E+04	3.E+02	2.E+04	1.E+04	1.E+04	3.E+03	1.E+03
6	Wood and Paper	1.E+05	3.E+03	1.E+04	9.E+05	3.E+05	1.E+06	4.E+05	6.E+04	2.E+05	5.E+04	4.E+05	3.E+04	7.E+05	1.E+04	2.E+05	4.E+05	3.E+05	8.E+04	2.E+05
7	Petroleum, Chemical and Non-Metallic Mineral Products	6.E+05	2.E+04	1.E+05	7.E+05	1.E+06	3.E+05	4.E+06	2.E+05	8.E+05	4.E+05	2.E+05	4.E+05	2.E+06	6.E+03	1.E+05	2.E+05	2.E+05	7.E+05	8.E+04
8	Metal Products	4.E+04	2.E+03	5.E+04	6.E+05	1.E+05	6.E+04	4.E+05	2.E+06	2.E+06	5.E+05	3.E+05	2.E+05	1.E+06	3.E+03	7.E+04	8.E+04	1.E+05	8.E+04	3.E+04
9	Electrical and Machinery	5.E+04	6.E+03	1.E+05	1.E+05	1.E+05	1.E+05	4.E+05	3.E+05	4.E+06	2.E+06	2.E+05	3.E+03	1.E+06	1.E+04	2.E+05	4.E+05	1.E+05	1.E+05	2.E+05
10	Transport Equipment	1.E+04	6.E+03	2.E+04	3.E+04	7.E+03	3.E+03	8.E+04	2.E+04	3.E+05	2.E+06	7.E+04	2.E+03	2.E+05	7.E+03	4.E+04	4.E+05	1.E+04	1.E+05	1.E+04
11	Other Manufacturing	1.E+04	5.E+03	7.E+03	7.E+04	2.E+05	4.E+04	5.E+04	2.E+04	7.E+04	2.E+05	6.E+04	5.E+03	3.E+05	3.E+03	7.E+04	1.E+05	9.E+04	2.E+04	2.E+04
12	Recycling	4.E+02	8.E-01	9.E+02	3.E+03	2.E+03	6.E+03	2.E+04	4.E+04	7.E+02	1.E+01	6.E+02	2.E+04	8.E+02	2.E+01	8.E+01	1.E+03	1.E+03	2.E+03	8.E+02
13	Construction	5.E+04	1.E+03	2.E+05	9.E+04	6.E+04	6.E+04	2.E+05	9.E+04	1.E+05	2.E+04	2.E+04	4.E+02	3.E+04	6.E+03	1.E+05	2.E+05	2.E+05	2.E+05	1.E+05
14	Maintenance and Repair	1.E+04	4.E+02	1.E+03	2.E+04	2.E+04	7.E+03	2.E+04	7.E+03	2.E+04	6.E+03	5.E+03	4.E+02	3.E+04	2.E+02	7.E+03	7.E+03	2.E+04	5.E+03	1.E+03
15	Wholesale Trade	4.E+05	2.E+04	5.E+04	1.E+06	5.E+05	4.E+05	1.E+06	4.E+05	1.E+06	4.E+05	2.E+05	3.E+03	1.E+06	1.E+04	3.E+05	4.E+05	7.E+05	2.E+05	8.E+04
16	Retail Trade	3.E+04	2.E+03	8.E+03	2.E+04	7.E+04	8.E+03	6.E+04	7.E+03	4.E+04	2.E+04	3.E+04	2.E+03	5.E+05	2.E+03	3.E+04	7.E+04	2.E+05	9.E+04	8.E+03
17	Hotels and Restraurants	4.E+03	6.E+01	1.E+03	3.E+04	1.E+04	2.E+04	4.E+04	2.E+04	3.E+04	5.E+03	8.E+03	7.E+01	3.E+04	1.E+03	4.E+04	5.E+04	7.E+04	4.E+04	4.E+04
18	Transport	3.E+05	8.E+03	1.E+05	7.E+05	3.E+05	2.E+05	8.E+05	2.E+05	3.E+05	1.E+05	1.E+05	3.E+05	6.E+05	2.E+04	7.E+05	7.E+05	3.E+05	4.E+04	1.E+05
19	Post and Telecommunications	2.E+04	2.E+03	2.E+04	8.E+04	9.E+04	8.E+04	2.E+05	7.E+04	4.E+05	3.E+04	4.E+04	2.E+03	3.E+05	3.E+04	8.E+05	1.E+06	5.E+05	5.E+05	6.E+04
20	Finacial Intermediation and Business Activities	1.E+06	2.E+04	7.E+05	2.E+06	7.E+05	7.E+05	3.E+06	9.E+05	3.E+06	8.E+05	4.E+05	5.E+03	3.E+06	2.E+05	3.E+06	4.E+06	2.E+06	3.E+06	2.E+06
21	Public Administration	6.E+03	1.E+02	2.E+03	9.E+03	3.E+03	4.E+03	1.E+04	3.E+03	3.E+03	1.E+03	3.E+03	2.E+01	3.E+03	3.E+02	3.E+03	1.E+04	1.E+04	7.E+03	8.E+03
22	Education, Health and Other Services	3.E+04	4.E+03	5.E+03	4.E+04	2.E+04	2.E+04	6.E+04	2.E+04	3.E+04	8.E+03	8.E+03	3.E+02	6.E+04	3.E+03	6.E+04	1.E+05	2.E+05	6.E+04	2.E+05
23	Private Households	5.E+00	3.E-01	4.E-01	1.E+00	2.E+00	3.E-01	1.E+00	3.E-01	4.E-01	3.E-01	1.E+00	5.E+00	3.E-01	2.E-01	3.E-01	4.E-01	2.E+01	2.E-01	2.E-01
24	Others	2.E+04	2.E+03	5.E+03	5.E+04	1.E+05	2.E+04	5.E+04	4.E+04	5.E+04	5.E+03	7.E+03	3.E+03	3.E+04	2.E+03	9.E+04	2.E+04	4.E+04	2.E+04	1.E+04
25	Re-export & Re-import	9.E-02	1.E-01	9.E-02	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01
26^{New}	Gas and Water	6.E+04	3.E+02	4.E+04	1.E+05	7.E+04	7.E+04	3.E+05	9.E+04	8.E+04	2.E+04	1.E+04	5.E+03	3.E+04	3.E+03	4.E+04	1.E+05	2.E+05	4.E+04	2.E+04
27^{New}	Electricity TD	5.E+04	3.E+02	3.E+04	1.E+05	6.E+04	6.E+04	2.E+05	8.E+04	6.E+04	2.E+04	9.E+03	4.E+03	3.E+04	2.E+03	3.E+04	1.E+05	1.E+05	3.E+04	2.E+04
28	Electricity Generation	9.E+04	5.E+02	6.E+04	2.E+05	1.E+05	1.E+05	4.E+05	1.E+05	1.E+05	3.E+04	2.E+04	8.E+03	5.E+04	4.E+03	5.E+04	2.E+05	3.E+05	6.E+04	3.E+04
	Value Added																			
	Compensation of employees D.1	4.E+05	6.E+04	3.E+05	1.E+06	6.E+05	1.E+06	2.E+06	1.E+06	4.E+06	1.E+06	5.E+05	4.E+04	6.E+06	3.E+05	6.E+06	5.E+06	3.E+06	3.E+06	3.E+06
	Taxes on production D.29	3.E+05	1.E+04	3.E+05	8.E+05	5.E+04	1.E+05	7.E+05	1.E+05	2.E+05	6.E+04	4.E+04	3.E+03	5.E+05	1.E+05	2.E+06	2.E+06	8.E+05	4.E+05	6.E+05
	Subsidies on production D.39	-4.E+04	-1.E+03	-1.E+04	-1.E+05	-8.E+02	-2.E+03	-1.E+04	#######	-1.E+04	-2.E+03	-1.E+03	-2.E+01	-5.E+04	-7.E+03	-2.E+05	-2.E+05	-4.E+04	-5.E+04	-5.E+04
	Net operating surplus B.2n	3.E+06	2.E+05	1.E+06	3.E+06	6.E+05	1.E+06	4.E+06	1.E+06	3.E+06	1.E+06	6.E+05	3.E+04	3.E+06	2.E+05	5.E+06	4.E+06	2.E+06	2.E+06	5.E+06
	Net mixed income B.3n	1.E+06	4.E+04	6.E+05	1.E+06	4.E+05	8.E+05	2.E+06	8.E+05	2.E+06	8.E+05	4.E+05	7.E+03	3.E+06	2.E+05	4.E+06	4.E+06	2.E+06	2.E+06	3.E+06
	Consumption of fixed capital K.1	4.E+05	2.E+04	2.E+05	3.E+05	8.E+04	2.E+05	6.E+05	2.E+05	7.E+05	2.E+05	8.E+04	5.E+03	6.E+05	3.E+04	5.E+05	6.E+05	4.E+05	4.E+05	8.E+05
	Exogenous Resources																			
	CO2 emissions (Gg) from EDGAR	3.E+03	1.E+02	4.E+03	5.E+03	2.E+03	2.E+03	4.E+04	3.E+03	6.E+03	3.E+03	1.E+03	6.E+02	5.E+03	1.E+02	5.E+02	7.E+02	6.E+02	5.E+04	3.E+02
	DEPRECATED Water use, total (m3)	5.E+10	5.E+08	6.E+08	2.E+09	6.E+08	5.E+08	7.E+08	5.E+08	5.E+08	7.E+08	3.E+08	2.E+09	7.E+08	0.E+00	0.E+00	0.E+00	7.E+08	7.E+08	0.E+00
	Primary Energy Usage (TJ)	1.E+05	2.E+02	2.E+05	2.E+04	8.E+03	8.E+03	3.E+05	3.E+04	2.E+05	1.E+04	4.E+04	2.E+04	2.E+04	5.E+02	1.E+04	2.E+04	1.E+04	6.E+05	6.E+03

Table 13. Egypt's IO table 000'USD: disaggregation step II

								Industries	Industries		Final Demand						
		Finacial Intermediation and Business Activities	Public Administration	Education, Health and Other Services	Private Households	Others	Re-export & Re-import	Gas and Water	Elec. T&D	Elec. Gen	Household final consumption P.3h	Non-profit institutions serving households P.3n	Government final consumption P.3g	Gross fixed capital formation P.51	Changes in inventories P.52	Acquisitions less disposals of valuables P.53	Exports
1	Agriculture	6.E+04	1.E+04	3.E+04	7.E+01	9.E+01	7.E+01	1.E+02	1.E+02	2.E+02	2.E+06	5.E+03	2.E+03	2.E+04	4.E+04	5.E-01	3.E+06
2	Fishing	2.E+03	2.E+02	4.E+03	3.E+01	6.E-01	3.E+02	8.E-02	7.E-02	1.E-01	9.E+04	1.E+02	1.E+03	5.E-01	3.E+03	5.E-01	3.E+04
3	Mining and Quarrying	2.E+04	4.E+04	1.E+04	5.E+01	7.E+02	3.E+02	2.E+05	1.E+05	3.E+05	2.E+05	5.E+01	2.E+03	6.E+03	4.E+04	5.E-01	3.E+06
4	Food & Beverages	7.E+04	1.E+05	2.E+05	5.E+03	2.E+02	1.E+02	1.E+02	1.E+02	2.E+02	1.E+07	5.E+04	3.E-01	4.E-01	6.E+04	4.E-01	2.E+06
5	Textiles and Wearing Apparel	1.E+04	1.E+04	3.E+04	2.E+02	4.E+02	3.E+02	3.E+02	3.E+02	5.E+02	2.E+06	6.E+03	2.E+02	7.E+04	8.E+03	5.E-01	4.E+06
6	Wood and Paper	6.E+05	4.E+05	4.E+05	1.E+04	2.E+04	2.E+02	4.E+03	4.E+03	7.E+03	1.E+06	3.E+03	7.E+03	2.E+04	1.E+04	4.E-01	2.E+05
7	Petroleum, Chemical and Non-Metallic Mineral Products	4.E+05	6.E+05	1.E+06	1.E+04	3.E+04	1.E+02	3.E+04	2.E+04	5.E+04	6.E+06	3.E+04	2.E+04	6.E+04	2.E+04	4.E-01	5.E+06
8	Metal Products	2.E+05	9.E+04	6.E+04	3.E+03	8.E+03	2.E+02	3.E+03	3.E+03	5.E+03	2.E+05	9.E+02	6.E+03	2.E+05	4.E+04	4.E-01	1.E+06
9	Electrical and Machinery	5.E+05	7.E+05	5.E+05	1.E+04	1.E+04	1.E+02	2.E+04	1.E+04	3.E+04	4.E+06	9.E+03	4.E+05	7.E+06	1.E+05	4.E-01	1.E+06
10	Transport Equipment	1.E+05	5.E+05	2.E+04	5.E+03	2.E+03	2.E+02	6.E+02	5.E+02	9.E+02	4.E+06	2.E+04	3.E+05	2.E+06	2.E+05	4.E-01	8.E+04
11	Other Manufacturing	1.E+05	6.E+04	1.E+05	2.E+03	3.E+03	3.E+02	2.E+03	2.E+03	4.E+03	1.E+06	8.E+03	5.E+04	5.E+05	2.E+04	4.E-01	5.E+05
12	Recycling	4.E+03	5.E+01	3.E+03	1.E+00	3.E-01	7.E+02	3.E+03	2.E+03	4.E+03	9.E+05	7.E+03	6.E+03	4.E-01	5.E+04	3.E+05	5.E+04
13	Construction	1.E+06	7.E+05	4.E+05	8.E+03	9.E+03	1.E+02	8.E+04	7.E+04	1.E+05	2.E+05	1.E+03	1.E+06	2.E+07	2.E-02	4.E-01	7.E+04
14	Maintenance and Repair	9.E+03	5.E+03	1.E+04	1.E+02	3.E+02	4.E+02	3.E+02	3.E+02	5.E+02	8.E+05	4.E+03	2.E+03	5.E+04	7.E+02	4.E-01	2.E+04
15	Wholesale Trade	4.E+05	4.E+05	6.E+05	8.E+03	1.E+04	1.E+02	2.E+04	2.E+04	3.E+04	1.E+07	5.E+04	9.E+04	2.E+06	5.E+04	4.E-01	3.E+05
16	Retail Trade	1.E+05	1.E+04	7.E+04	5.E+02	2.E+03	1.E+02	8.E+02	7.E+02	1.E+03	2.E+07	1.E+05	5.E+03	6.E+05	2.E-02	4.E-01	4.E+04
17	Hotels and Restraurants	3.E+05	1.E+05	2.E+05	2.E+03	2.E+03	9.E+01	9.E+03	8.E+03	1.E+04	2.E+07	6.E+04	2.E+01	4.E-01	2.E-02	4.E-01	4.E+05
18	Transport	4.E+05	3.E+05	5.E+05	5.E+03	2.E+04	2.E+02	9.E+04	8.E+04	1.E+05	7.E+06	2.E+04	5.E+04	3.E+05	7.E+03	4.E-01	1.E+06
19	Post and Telecommunications	1.E+06	8.E+05	7.E+05	3.E+04	6.E+04	3.E+02	2.E+04	2.E+04	3.E+04	8.E+06	4.E+04	4.E+04	1.E+06	5.E+02	4.E-01	3.E+05
20	Finacial Intermediation and Business Activities	3.E+03	4.E+06	5.E+06	2.E+05	3.E+05	6.E+01	2.E+05	2.E+05	3.E+05	7.E+07	3.E+05	4.E+05	4.E+06	1.E+05	4.E-01	2.E+03
21	Public Administration	5.E+04	3.E+03	3.E+04	8.E+03	1.E+05	1.E+02	8.E+01	7.E+01	1.E+02	1.E+06	6.E+03	2.E+07	9.E+06	2.E-02	4.E-01	7.E+04
22	Education, Health and Other Services	6.E+05	4.E+05	7.E+02	1.E+04	2.E+04	7.E+01	8.E+03	6.E+03	1.E+04	4.E+07	2.E+05	9.E+06	1.E+06	5.E+01	4.E-01	3.E+05
23	Private Households	1.E+01	5.E+03	1.E+03	1.E-01	4.E+01	1.E+02	6.E-02	5.E-02	9.E-02	8.E+05	6.E+03	1.E+04	4.E-01	2.E-02	4.E-01	1.E+04
24	Others	7.E+04	2.E+04	3.E+04	2.E+03	4.E-01	4.E+02	4.E+03	4.E+03	7.E+03	9.E+05	7.E+03	3.E-01	4.E-01	2.E-02	4.E-01	2.E+03
25	Re-export & Re-import	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	4.E-01	3.E-02	3.E-02	5.E-02	2.E-01	2.E-01	2.E-01	2.E-01	9.E-03	2.E-01	4.E+04
26^{New}	Gas and Water	1.E+05	1.E+05	2.E+05	1.E+03	3.E+03	4.E+01	2.E+04	3.E+03	5.E+03	2.E+06	6.E+03	1.E-01	1.E-01	5.E+00	1.E-01	2.E+03
27^{New}	Electricity TD	1.E+05	8.E+04	1.E+05	9.E+02	2.E+03	3.E+01	3.E+03	4.E+02	8.E+02	1.E+06	5.E+03	8.E-02	1.E-01	5.E+00	1.E-01	2.E+03
28	Electricity Generation	2.E+05	2.E+05	3.E+05	2.E+03	4.E+03	6.E+01	5.E+03	8.E+02	1.E+03	2.E+06	1.E+04	2.E-01	2.E-01	9.E+00	2.E-01	3.E+03
	Value Added																
	Compensation of employees D.1	2.E+07	8.E+06	2.E+07	2.E+05	1.E+05	5.E+00	3.E+05	3.E+05	5.E+05							
	Taxes on production D.29	4.E+06	2.E+05	1.E+06	3.E+03	2.E+04	5.E+00	3.E+05	2.E+05	4.E+05							
	Subsidies on production D.39	-8.E+05	-1.E+04	-2.E+05	-1.E+02	-2.E+03	-1.E-01	-8.E+03	-7.E+03	-1.E+04							
	Net operating surplus B.2n	5.E+07	2.E+06	1.E+07	6.E+04	5.E+05	5.E+00	1.E+06	9.E+05	2.E+06							
	Net mixed income B.3n	2.E+07	7.E+06	1.E+07	2.E+05	2.E+05	5.E+00	5.E+05	4.E+05	8.E+05							
	Consumption of fixed capital K.1	8.E+06	8.E+05	2.E+06	8.E+03	8.E+04	5.E+00	2.E+05	2.E+05	4.E+05							
	Exogenous Resources																
	CO2 emissions (Gg) from EDGAR	5.E+03	8.E+02	1.E+03	1.E+02	1.E+02	0.E+00										
	DEPRECATED Water use, total (m3)	3.E+08	0.E+00	7.E+08	0.E+00	0.E+00	0.E+00										
	Primary Energy Usage (TJ)	1.E+04	2.E+04	2.E+04	5.E+02	1.E+03	0.E+00										

Table 14. Egypt's IO table in 000'USD: disaggregation step III

		Industries																			
		Agriculture	Fishing	Mining and Quarrying	Food & Beverages	Textiles and Wearing Apparel	Wood and Paper	Petroleum, Chemical and Non-Metallic Mineral Products	Metal Products	Electrical and Machinery	Transport Equipment	Other Manufacturing	Recycling	Construction	Maintenance and Repair	Wholesale Trade	Retail Trade	Hotels and Restaurants	Transport	Post and Telecommunications	Finacial Intermediation and Business Activities
1	Agriculture	3.E+06	7.E+02	3.E+03	3.E+06	1.E+05	3.E+05	3.E+04	1.E+03	2.E+03	2.E+02	3.E+03	1.E+03	6.E+04	6.E+02	7.E+03	3.E+04	3.E+05	2.E+03	3.E+02	6.E+04
2	Fishing	2.E+03	1.E+04	8.E-01	3.E+05	2.E+02	2.E+00	3.E+02	1.E+02	1.E+01	7.E-01	7.E+03	1.E+01	3.E-01	2.E+02	4.E-01	1.E+04	6.E+04	2.E+01	2.E+00	2.E+03
3	Mining and Quarrying	3.E+04	2.E+03	2.E+05	1.E+04	5.E+03	8.E+03	1.E+06	9.E+04	3.E+03	5.E+03	1.E+03	3.E+05	2.E+05	8.E+01	4.E+03	3.E+03	6.E+03	6.E+04	1.E+03	2.E+04
4	Food & Beverages	4.E+05	1.E+04	3.E+02	1.E+06	5.E+04	7.E+03	4.E+04	2.E+02	4.E+02	1.E+02	4.E+03	8.E+03	3.E+02	4.E+03	2.E+04	2.E+05	1.E+06	1.E+03	5.E+02	7.E+04
5	Textiles and Wearing Apparel	8.E+03	1.E+03	9.E+02	1.E+04	4.E+05	8.E+03	2.E+04	2.E+03	1.E+04	1.E+04	1.E+04	1.E+03	1.E+04	3.E+02	2.E+04	1.E+04	1.E+04	3.E+03	1.E+03	1.E+04
6	Wood and Paper	1.E+05	3.E+03	1.E+04	9.E+05	3.E+05	1.E+06	4.E+05	6.E+04	2.E+05	5.E+04	4.E+05	3.E+04	7.E+05	1.E+04	2.E+05	4.E+05	3.E+05	8.E+04	2.E+05	6.E+05
7	Petroleum, Chemical and Non-Metallic Mineral Products	6.E+05	2.E+04	1.E+05	7.E+05	1.E+06	3.E+05	4.E+06	2.E+05	8.E+05	4.E+05	2.E+05	4.E+05	2.E+06	6.E+03	1.E+05	2.E+05	2.E+05	7.E+05	8.E+04	4.E+05
8	Metal Products	4.E+04	2.E+03	5.E+04	6.E+05	1.E+05	6.E+04	4.E+05	2.E+06	2.E+06	5.E+05	3.E+05	2.E+05	1.E+06	3.E+03	7.E+04	8.E+04	1.E+05	8.E+04	3.E+04	2.E+05
9	Electrical and Machinery	5.E+04	6.E+03	1.E+05	1.E+05	1.E+05	1.E+05	4.E+05	3.E+05	4.E+06	2.E+06	2.E+05	3.E+03	1.E+06	1.E+04	2.E+05	4.E+05	1.E+05	1.E+05	2.E+05	5.E+05
10	Transport Equipment	1.E+04	6.E+03	2.E+04	3.E+04	7.E+03	3.E+03	8.E+04	2.E+04	3.E+05	2.E+06	7.E+04	2.E+03	2.E+05	7.E+03	4.E+04	4.E+05	1.E+04	1.E+05	1.E+04	1.E+05
11	Other Manufacturing	1.E+04	5.E+03	7.E+03	7.E+04	2.E+05	4.E+04	5.E+04	2.E+04	7.E+04	2.E+05	6.E+04	5.E+03	3.E+05	3.E+03	7.E+04	1.E+05	9.E+04	2.E+04	2.E+04	1.E+05
12	Recycling	4.E+02	8.E-01	9.E+02	3.E+03	2.E+03	6.E+03	2.E+04	4.E+04	7.E+02	1.E+01	6.E+02	2.E+04	8.E+02	2.E+01	8.E+01	1.E+03	1.E+03	2.E+03	8.E+02	4.E+03
13	Construction	5.E+04	1.E+03	2.E+05	9.E+04	6.E+04	6.E+04	2.E+05	9.E+04	1.E+05	2.E+04	2.E+04	4.E+02	3.E+04	6.E+03	1.E+05	2.E+05	2.E+05	2.E+05	1.E+05	1.E+06
14	Maintenance and Repair	1.E+04	4.E+02	1.E+03	2.E+04	2.E+04	7.E+03	2.E+04	7.E+03	2.E+04	6.E+03	5.E+03	4.E+02	3.E+04	2.E+02	7.E+03	7.E+03	2.E+04	5.E+03	1.E+03	9.E+03
15	Wholesale Trade	4.E+05	2.E+04	5.E+04	1.E+06	5.E+05	4.E+05	1.E+06	4.E+05	1.E+06	4.E+05	2.E+05	3.E+03	1.E+06	1.E+04	3.E+05	4.E+05	7.E+05	2.E+05	8.E+04	4.E+05
16	Retail Trade	3.E+04	2.E+03	8.E+03	2.E+04	7.E+04	8.E+03	6.E+04	7.E+03	4.E+04	2.E+04	3.E+04	2.E+03	5.E+05	2.E+03	3.E+04	7.E+04	2.E+05	9.E+04	8.E+03	1.E+05
17	Hotels and Restraurants	4.E+03	6.E+01	1.E+03	3.E+04	1.E+04	2.E+04	4.E+04	2.E+04	3.E+04	5.E+03	8.E+03	7.E+01	3.E+04	1.E+03	4.E+04	5.E+04	7.E+04	4.E+04	4.E+04	3.E+05
18	Transport	3.E+05	8.E+03	1.E+05	7.E+05	3.E+05	2.E+05	8.E+05	2.E+05	3.E+05	1.E+05	1.E+05	3.E+05	6.E+05	2.E+04	7.E+05	7.E+05	3.E+05	4.E+04	1.E+05	4.E+05
19	Post and Telecommunications	2.E+04	2.E+03	2.E+04	8.E+04	9.E+04	8.E+04	2.E+05	7.E+04	4.E+05	3.E+04	4.E+04	2.E+03	3.E+05	3.E+04	8.E+05	1.E+06	5.E+05	5.E+05	6.E+04	1.E+06
20	Finacial Intermediation and Business Activities	1.E+06	2.E+04	7.E+05	2.E+06	7.E+05	7.E+05	3.E+06	9.E+05	3.E+06	8.E+05	4.E+05	5.E+03	3.E+06	2.E+05	3.E+06	4.E+06	2.E+06	3.E+06	2.E+06	3.E+03
21	Public Administration	6.E+03	1.E+02	2.E+03	9.E+03	3.E+03	4.E+03	1.E+04	3.E+03	3.E+03	1.E+03	3.E+03	2.E+01	3.E+03	3.E+02	3.E+03	1.E+04	1.E+04	7.E+03	8.E+03	5.E+04
22	Education, Health and Other Services	3.E+04	4.E+03	5.E+03	4.E+04	2.E+04	2.E+04	6.E+04	2.E+04	3.E+04	8.E+03	8.E+03	3.E+02	6.E+04	3.E+03	6.E+04	1.E+05	2.E+05	6.E+04	2.E+05	6.E+05
23	Private Households	5.E+00	3.E-01	4.E-01	1.E+00	2.E+00	3.E-01	1.E+00	3.E-01	4.E-01	3.E-01	1.E+00	5.E+00	3.E-01	2.E-01	3.E-01	4.E-01	2.E+01	2.E-01	2.E-01	1.E+01
24	Others	2.E+04	2.E+03	5.E+03	5.E+04	1.E+05	2.E+04	5.E+04	4.E+04	5.E+04	5.E+03	7.E+03	3.E+03	3.E+04	2.E+03	9.E+04	2.E+04	4.E+04	2.E+04	1.E+04	7.E+04
25	Re-export & Re-import	9.E-02	1.E-01	9.E-02	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01
26^{New}	Gas and Water	6.E+04	3.E+02	4.E+04	1.E+05	7.E+04	7.E+04	3.E+05	9.E+04	8.E+04	2.E+04	1.E+04	5.E+03	3.E+04	3.E+03	4.E+04	1.E+05	2.E+05	4.E+04	2.E+04	1.E+05
27^{New}	Electricity T&D	5.E+04	3.E+02	3.E+04	1.E+05	6.E+04	6.E+04	2.E+05	8.E+04	6.E+04	2.E+04	9.E+03	4.E+03	3.E+04	2.E+03	3.E+04	1.E+05	1.E+05	3.E+04	2.E+04	1.E+05
28^{New}	Hydro Power Generation	7.E+03	4.E+01	5.E+03	1.E+04	8.E+03	8.E+03	3.E+04	1.E+04	9.E+03	2.E+03	1.E+03	6.E+02	4.E+03	3.E+02	4.E+03	1.E+04	2.E+04	4.E+03	2.E+03	1.E+04
29	Steam Cycle power Plants	4.E+04	2.E+02	3.E+04	8.E+04	5.E+04	5.E+04	2.E+05	6.E+04	5.E+04	1.E+04	7.E+03	4.E+03	2.E+04	2.E+03	2.E+04	9.E+04	1.E+05	2.E+04	1.E+04	8.E+04
30	Open Gas cycle power Plants	9.E+03	6.E+01	6.E+03	2.E+04	1.E+04	1.E+04	5.E+04	2.E+04	1.E+04	3.E+03	2.E+03	9.E+02	6.E+03	4.E+02	6.E+03	2.E+04	3.E+04	6.E+03	3.E+03	2.E+04
31	Combined Cycle power Plants	3.E+04	2.E+02	2.E+04	7.E+04	4.E+04	4.E+04	2.E+05	6.E+04	5.E+04	1.E+04	6.E+03	3.E+03	2.E+04	1.E+03	2.E+04	8.E+04	1.E+05	2.E+04	1.E+04	7.E+04
32	Wind	1.E+03	6.E+00	7.E+02	2.E+03	1.E+03	1.E+03	5.E+03	2.E+03	1.E+03	3.E+02	2.E+02	9.E+01	6.E+02	4.E+01	6.E+02	2.E+03	3.E+03	6.E+02	3.E+02	2.E+03
33	Solar Technologies	8.E+01	5.E-01	6.E+01	2.E+02	9.E+01	9.E+01	4.E+02	1.E+02	1.E+02	3.E+01	2.E+01	8.E+00	5.E+01	4.E+00	5.E+01	2.E+02	2.E+02	5.E+01	3.E+01	2.E+02
	Value Added																				
	Compensation of employees D.1	4.E+05	6.E+04	3.E+05	1.E+06	6.E+05	1.E+06	2.E+06	1.E+06	4.E+06	1.E+06	5.E+05	4.E+04	6.E+06	3.E+05	6.E+06	5.E+06	3.E+06	3.E+06	3.E+06	2.E+07
	Taxes on production D.29	3.E+05	1.E+04	3.E+05	8.E+05	5.E+04	1.E+05	7.E+05	1.E+05	2.E+05	6.E+04	4.E+04	3.E+03	5.E+05	1.E+05	2.E+06	2.E+06	8.E+05	4.E+05	6.E+05	4.E+06
	Subsidies on production D.39	-4.E+04	-1.E+03	-1.E+04	-1.E+05	-8.E+02	-2.E+03	-1.E+04	-2.E+03	-1.E+04	-2.E+03	-1.E+03	-2.E+01	-5.E+04	-7.E+03	-2.E+05	-2.E+05	-4.E+04	-5.E+04	-5.E+04	-8.E+05
	Net operating surplus B.2n	3.E+06	2.E+05	1.E+06	3.E+06	6.E+05	1.E+06	4.E+06	1.E+06	3.E+06	1.E+06	6.E+05	3.E+04	3.E+06	2.E+05	5.E+06	4.E+06	2.E+06	2.E+06	5.E+06	5.E+07
	Net mixed income B.3n	1.E+06	4.E+04	6.E+05	1.E+06	4.E+05	8.E+05	2.E+06	8.E+05	2.E+06	8.E+05	4.E+05	7.E+03	3.E+06	2.E+05	4.E+06	4.E+06	2.E+06	2.E+06	3.E+06	2.E+07
	Consumption of fixed capital K.1	4.E+05	2.E+04	2.E+05	3.E+05	8.E+04	2.E+05	6.E+05	2.E+05	7.E+05	2.E+05	8.E+04	5.E+03	6.E+05	3.E+04	5.E+05	6.E+05	4.E+05	4.E+05	8.E+05	8.E+06
	Exogenous Resources																				
	CO2 emissions (Gg) from EDGAR	3.E+03	1.E+02	4.E+03	5.E+03	2.E+03	2.E+03	4.E+04	3.E+03	6.E+03	3.E+03	1.E+03	6.E+02	5.E+03	1.E+02	5.E+02	7.E+02	6.E+02	5.E+04	3.E+02	5.E+03
	DEPRECATED Water use, total (m3)	5.E+10	5.E+08	6.E+08	2.E+09	6.E+08	5.E+08	7.E+08	5.E+08	5.E+08	7.E+08	3.E+08	2.E+09	7.E+08	0.E+00	0.E+00	0.E+00	7.E+08	7.E+08	0.E+00	3.E+08
	Primary Energy Usage (TJ)	1.E+05	2.E+02	2.E+05	2.E+04	8.E+03	8.E+03	3.E+05	3.E+04	2.E+05	1.E+04	4.E+04	2.E+04	2.E+04	5.E+02	1.E+04	2.E+04	1.E+04	6.E+05	6.E+03	1.E+04

Table 14. Egypt's IO table in 000'USD: disaggregation step III

							Industries	Industries	Industries						Final Demand						
		Public Administration	Education, Health and Other Services	Private Households	Others	Re-export & Re-import	Gas and Water	Elec: T&D	Hydro Power Generation	Steam Cycle power Plants	Open Gas cycle power Plants	Combined Cycle power Plants	Wind	Solar Technologies	Household final consumption P.3h	Non-profit institutions serving households P.3n	Government final consumption P.3g	Gross fixed capital formation P.51	Changes in inventories P.52	Acquisitions less disposals of valuables P.53	Exports
1	Agriculture	1.E+04	3.E+04	7.E+01	9.E+01	7.E+01	1.E+02	1.E+02	4.E-01	8.E+01	5.E+01	9.E+01	3.E+00	5.E-01	2.E+06	5.E+03	2.E+03	2.E+04	4.E+04	5.E-01	3.E+06
2	Fishing	2.E+02	4.E+03	3.E+01	6.E-01	3.E+02	8.E-02	7.E-02	2.E-04	5.E-02	3.E-02	5.E-02	2.E-03	3.E-04	9.E+04	1.E+02	1.E+03	5.E-01	3.E+03	5.E-01	3.E+04
3	Mining and Quarrying	4.E+04	1.E+04	5.E+01	7.E+02	3.E+02	2.E+05	1.E+05	0.E+00	1.E+05	4.E+04	9.E+04	0.E+00	0.E+00	2.E+05	5.E+01	2.E+03	6.E+03	4.E+04	5.E-01	3.E+06
4	Food & Beverages	1.E+05	2.E+05	5.E+03	2.E+02	1.E+02	1.E+02	1.E+02	4.E-01	8.E+01	5.E+01	9.E+01	3.E+00	6.E-01	1.E+07	5.E+04	3.E-01	4.E-01	6.E+04	4.E-01	2.E+06
5	Textiles and Wearing Apparel	1.E+04	3.E+04	2.E+02	4.E+02	3.E+02	3.E+02	3.E+02	8.E-01	2.E+02	1.E+02	2.E+02	6.E+00	1.E+00	2.E+06	6.E+03	2.E+02	7.E+04	8.E+03	5.E-01	4.E+06
6	Wood and Paper	4.E+05	4.E+05	1.E+04	2.E+04	2.E+02	4.E+03	4.E+03	1.E+01	3.E+03	2.E+03	3.E+03	8.E+01	2.E+01	1.E+06	3.E+03	7.E+03	2.E+04	1.E+04	4.E-01	2.E+05
7	Petroleum, Chemical and Non-Metallic Mineral Products	6.E+05	1.E+06	1.E+04	3.E+04	1.E+02	3.E+04	2.E+04	0.E+00	2.E+04	7.E+03	2.E+04	0.E+00	0.E+00	6.E+06	3.E+04	2.E+04	6.E+04	2.E+04	4.E-01	5.E+06
8	Metal Products	9.E+04	6.E+04	3.E+03	8.E+03	2.E+02	3.E+03	3.E+03	8.E+00	2.E+03	1.E+03	2.E+03	6.E+01	1.E+01	2.E+05	9.E+02	6.E+03	2.E+05	4.E+04	4.E-01	1.E+06
9	Electrical and Machinery	7.E+05	5.E+05	1.E+04	1.E+04	1.E+02	2.E+04	1.E+04	4.E+01	1.E+04	6.E+03	1.E+04	3.E+02	7.E+01	4.E+06	9.E+03	4.E+05	7.E+06	1.E+05	4.E-01	1.E+06
10	Transport Equipment	5.E+05	2.E+04	5.E+03	2.E+03	2.E+02	6.E+02	5.E+02	1.E+00	3.E+02	2.E+02	3.E+02	1.E+01	2.E+00	4.E+06	2.E+04	3.E+05	2.E+06	2.E+05	4.E-01	8.E+04
11	Other Manufacturing	6.E+04	1.E+05	2.E+03	3.E+03	3.E+02	2.E+03	2.E+03	6.E+00	1.E+03	9.E+02	1.E+03	4.E+01	9.E+00	1.E+06	8.E+03	5.E+04	5.E+05	2.E+04	4.E-01	5.E+05
12	Recycling	5.E+01	3.E+03	1.E+00	3.E-01	7.E+02	3.E+03	2.E+03	7.E+00	2.E+03	1.E+03	2.E+03	5.E+01	1.E+01	9.E+05	7.E+03	6.E+03	4.E-01	5.E+04	3.E+05	5.E+04
13	Construction	7.E+05	4.E+05	8.E+03	9.E+03	1.E+02	8.E+04	7.E+04	2.E+02	4.E+04	3.E+04	5.E+04	1.E+03	3.E+02	2.E+05	1.E+03	1.E+06	2.E+07	2.E-02	4.E-01	7.E+04
14	Maintenance and Repair	5.E+03	1.E+04	1.E+02	3.E+02	4.E+02	3.E+02	3.E+02	8.E-01	2.E+02	1.E+02	2.E+02	5.E+00	1.E+00	8.E+05	4.E+03	2.E+03	5.E+04	7.E+02	4.E-01	2.E+04
15	Wholesale Trade	4.E+05	6.E+05	8.E+03	1.E+04	1.E+02	2.E+04	2.E+04	4.E+01	1.E+04	7.E+03	1.E+04	3.E+02	7.E+01	1.E+07	5.E+04	9.E+04	2.E+06	5.E+04	4.E-01	3.E+05
16	Retail Trade	1.E+04	7.E+04	5.E+02	2.E+03	1.E+02	8.E+02	7.E+02	2.E+00	5.E+02	3.E+02	5.E+02	1.E+01	3.E+00	2.E+07	1.E+05	5.E+03	6.E+05	2.E-02	4.E-01	4.E+04
17	Hotels and Restraurants	1.E+05	2.E+05	2.E+03	2.E+03	9.E+01	9.E+03	8.E+03	2.E+01	5.E+03	3.E+03	5.E+03	2.E+02	3.E+01	2.E+07	6.E+04	2.E+01	4.E-01	2.E-02	4.E-01	4.E+05
18	Transport	3.E+05	5.E+05	5.E+03	2.E+04	2.E+02	9.E+04	8.E+04	2.E+02	5.E+04	3.E+04	6.E+04	2.E+03	4.E+02	7.E+06	2.E+04	5.E+04	3.E+05	7.E+03	4.E-01	1.E+06
19	Post and Telecommunications	8.E+05	7.E+05	3.E+04	6.E+04	3.E+02	2.E+04	2.E+04	5.E+01	1.E+04	7.E+03	1.E+04	3.E+02	7.E+01	8.E+06	4.E+04	4.E+04	1.E+06	5.E+02	4.E-01	3.E+05
20	Finacial Intermediation and Business Activities	4.E+06	5.E+06	2.E+05	3.E+05	6.E+01	2.E+05	2.E+05	5.E+02	1.E+05	7.E+04	1.E+05	4.E+03	8.E+02	7.E+07	3.E+05	4.E+05	4.E+06	1.E+05	4.E-01	2.E+03
21	Public Administration	3.E+03	3.E+04	8.E+03	1.E+05	1.E+02	8.E+01	7.E+01	2.E-01	5.E+01	3.E+01	5.E+01	1.E+00	3.E-01	1.E+06	6.E+03	2.E+07	9.E+06	2.E-02	4.E-01	7.E+04
22	Education, Health and Other Services	4.E+05	7.E+02	1.E+04	2.E+04	7.E+01	8.E+03	6.E+03	2.E+01	4.E+03	3.E+03	5.E+03	1.E+02	3.E+01	4.E+07	2.E+05	9.E+06	1.E+06	5.E+01	4.E-01	3.E+05
23	Private Households	5.E+03	1.E+03	1.E-01	4.E+01	1.E+02	6.E-02	5.E-02	1.E-04	3.E-02	2.E-02	4.E-02	1.E-03	2.E-04	8.E+05	6.E+03	1.E+04	4.E-01	2.E-02	4.E-01	1.E+04
24	Others	2.E+04	3.E+04	2.E+03	4.E-01	4.E+02	4.E+03	4.E+03	1.E+01	2.E+03	2.E+03	3.E+03	8.E+01	2.E+01	9.E+05	7.E+03	3.E-01	4.E-01	2.E-02	4.E-01	2.E+03
25	Re-export & Re-import	1.E-01	1.E-01	1.E-01	1.E-01	4.E-01	3.E-02	3.E-02	7.E-05	2.E-02	1.E-02	2.E-02	5.E-04	1.E-04	2.E-01	2.E-01	2.E-01	2.E-01	9.E-03	2.E-01	4.E+04
26^{New}	Gas and Water	1.E+05	2.E+05	1.E+03	3.E+03	4.E+01	2.E+04	3.E+03	0.E+00	3.E+03	8.E+02	2.E+03	0.E+00	0.E+00	2.E+06	6.E+03	1.E-01	1.E-01	5.E+00	1.E-01	2.E+03
27^{New}	Electricity T&D	8.E+04	1.E+05	9.E+02	2.E+03	3.E+01	3.E+03	4.E+02	1.E+00	3.E+02	2.E+02	3.E+02	9.E+00	2.E+00	1.E+06	5.E+03	8.E-02	1.E-01	5.E+00	1.E-01	2.E+03
28^{New}	Hydro Power Generation	1.E+04	2.E+04	1.E+02	3.E+02	4.E+00	4.E+02	6.E+01	1.E+02	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	2.E+05	7.E+02	1.E-02	2.E-02	6.E-01	2.E-02	2.E+02
29	Steam Cycle power Plants	7.E+04	1.E+05	7.E+02	2.E+03	3.E+01	2.E+03	3.E+02	0.E+00	6.E+02	0.E+00	0.E+00	0.E+00	0.E+00	1.E+06	4.E+03	7.E-02	9.E-02	4.E+00	9.E-02	1.E+03
30	Open Gas cycle power Plants	2.E+04	3.E+04	2.E+02	5.E+02	6.E+00	5.E+02	8.E+01	0.E+00	0.E+00	1.E+02	0.E+00	0.E+00	0.E+00	2.E+05	1.E+03	2.E-02	2.E-02	9.E-01	2.E-02	3.E+02
31	Combined Cycle power Plants	6.E+04	9.E+04	6.E+02	2.E+03	2.E+01	2.E+03	3.E+02	0.E+00	0.E+00	0.E+00	5.E+02	0.E+00	0.E+00	9.E+05	4.E+03	6.E-02	8.E-02	3.E+00	8.E-02	1.E+03
32	Wind	2.E+03	3.E+03	2.E+01	5.E+01	6.E-01	6.E+01	8.E+00	0.E+00	0.E+00	0.E+00	0.E+00	2.E+01	0.E+00	3.E+04	1.E+02	2.E-03	2.E-03	9.E-02	2.E-03	4.E+01
33	Solar Technologies	1.E+02	2.E+02	1.E+00	4.E+00	5.E-02	5.E+00	7.E-01	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	1.E+00	2.E+03	9.E+00	1.E-04	2.E-04	8.E-03	2.E-04	3.E+00
	Value Added																				
	Compensation of employees D.1	8.E+06	2.E+07	2.E+05	1.E+05	5.E+00	3.E+05	3.E+05	8.E+02	2.E+05	1.E+05	2.E+05	6.E+03	1.E+03							
	Taxes on production D.29	2.E+05	1.E+06	3.E+03	2.E+04	5.E+00	3.E+05	2.E+05	6.E+02	1.E+05	9.E+04	2.E+05	4.E+03	1.E+03							
	Subsidies on production D.39	-1.E+04	-2.E+05	-1.E+02	-2.E+03	-1.E-01	-8.E+03	-7.E+03	-2.E+01	-5.E+03	-3.E+03	-5.E+03	-1.E+02	-3.E+01							
	Net operating surplus B.2n	2.E+06	1.E+07	6.E+04	5.E+05	5.E+00	1.E+06	9.E+05	3.E+03	6.E+05	4.E+05	6.E+05	2.E+04	4.E+03							
	Net mixed income B.3n	7.E+06	1.E+07	2.E+05	2.E+05	5.E+00	5.E+05	4.E+05	1.E+03	3.E+05	2.E+05	3.E+05	9.E+03	2.E+03							
	Consumption of fixed capital K.1	8.E+05	2.E+06	8.E+03	8.E+04	5.E+00	2.E+05	2.E+05	6.E+02	1.E+05	9.E+04	1.E+05	4.E+03	9.E+02							
	Exogenous Resources																				
	CO2 emissions (Gg) from EDGAR	8.E+02	1.E+03	1.E+02	1.E+02	0.E+00	5.E+04	0.E+00	0.E+00	2.E+04	5.E+03	2.E+04	0.E+00	0.E+00							
	DEPRECATED Water use, total (m3)	0.E+00	7.E+08	0.E+00	0.E+00	0.E+00	1.E+08	0.E+00	0.E+00	2.E+08	2.E+07	6.E+07	0.E+00	0.E+00							
	Primary Energy Usage (TJ)	2.E+04	2.E+04	5.E+02	1.E+03	0.E+00	3.E+05	0.E+00	0.E+00	7.E+04	5.E+04	1.E+06	0.E+00	0.E+00							

Table 15. Hyprid Egypt's EORA 26 IO table in USD and electricity generation sectors sector in Physical Units (TWh)

		Industries																				
		Agriculture	Fishing	Mining and Quarrying	Food & Beverages	Textiles and Wearing Apparel	Wood and Paper	Petroleum, Chemical and Non-Metallic Mineral Products	Metal Products	Electrical and Machinery	Transport Equipment	Other Manufacturing	Recycling	Construction	Maintenance and Repair	Wholesale Trade	Retail Trade	Hotels and Restraurants	Transport	Post and Telecommunications	Finacial Intermediation and Business Activities	Public Administration
1	Agriculture	3.E+09	7.E+05	3.E+06	3.E+09	1.E+08	3.E+08	3.E+07	1.E+06	2.E+06	2.E+05	3.E+06	1.E+06	6.E+07	6.E+05	7.E+06	3.E+07	3.E+08	2.E+06	3.E+05	6.E+07	1.E+07
2	Fishing	2.E+06	1.E+07	8.E+02	3.E+08	2.E+05	2.E+03	3.E+05	1.E+05	1.E+04	7.E+02	7.E+06	1.E+04	3.E+02	2.E+05	4.E+02	1.E+07	6.E+07	2.E+04	2.E+03	2.E+06	2.E+05
3	Mining and Quarrying	3.E+07	2.E+06	2.E+08	1.E+07	5.E+06	8.E+06	1.E+09	9.E+07	3.E+06	5.E+06	1.E+06	3.E+08	2.E+08	8.E+04	4.E+06	3.E+06	6.E+06	6.E+07	1.E+06	2.E+07	4.E+07
4	Food & Beverages	4.E+08	1.E+07	3.E+05	1.E+09	5.E+07	7.E+06	4.E+07	2.E+05	4.E+05	1.E+05	4.E+06	8.E+06	3.E+05	4.E+06	2.E+07	2.E+08	1.E+09	1.E+06	5.E+05	7.E+07	1.E+08
5	Textiles and Wearing Apparel	8.E+06	1.E+06	9.E+05	1.E+07	4.E+08	8.E+06	2.E+07	2.E+06	1.E+07	1.E+07	1.E+07	1.E+06	1.E+07	3.E+05	2.E+07	1.E+07	1.E+07	3.E+06	1.E+06	1.E+07	1.E+07
6	Wood and Paper	1.E+08	3.E+06	1.E+07	9.E+08	3.E+08	1.E+09	4.E+08	6.E+07	2.E+08	5.E+07	4.E+08	3.E+07	7.E+08	1.E+07	2.E+08	4.E+08	3.E+08	8.E+07	2.E+08	6.E+08	4.E+08
7	Petroleum, Chemical and Non-Metallic Mineral Products	6.E+08	2.E+07	1.E+08	7.E+08	1.E+09	3.E+08	4.E+09	2.E+08	8.E+08	4.E+08	2.E+08	4.E+08	2.E+09	6.E+06	1.E+08	2.E+08	2.E+08	7.E+08	8.E+07	4.E+08	6.E+08
8	Metal Products	4.E+07	2.E+06	5.E+07	6.E+08	1.E+08	6.E+07	4.E+08	2.E+09	2.E+09	5.E+08	3.E+08	2.E+08	1.E+09	3.E+06	7.E+07	8.E+07	1.E+08	8.E+07	3.E+07	2.E+08	9.E+07
9	Electrical and Machinery	5.E+07	6.E+06	1.E+08	1.E+08	1.E+08	1.E+08	4.E+08	3.E+08	4.E+09	2.E+09	2.E+08	3.E+06	1.E+09	1.E+07	2.E+08	4.E+08	1.E+08	1.E+08	2.E+08	5.E+08	7.E+08
10	Transport Equipment	1.E+07	6.E+06	2.E+07	3.E+07	7.E+06	3.E+06	8.E+07	2.E+07	3.E+08	2.E+09	7.E+07	2.E+06	2.E+08	7.E+06	4.E+07	4.E+08	1.E+07	1.E+08	1.E+07	1.E+08	5.E+08
11	Other Manufacturing	1.E+07	5.E+06	7.E+06	7.E+07	2.E+08	4.E+07	5.E+07	2.E+07	7.E+07	2.E+08	6.E+07	5.E+06	3.E+08	3.E+06	7.E+07	1.E+08	9.E+07	2.E+07	2.E+07	1.E+08	6.E+07
12	Recycling	4.E+05	8.E+02	9.E+05	3.E+06	2.E+06	6.E+06	2.E+07	4.E+07	7.E+05	1.E+04	6.E+05	2.E+07	8.E+05	2.E+04	8.E+04	1.E+06	1.E+06	2.E+06	8.E+05	4.E+06	5.E+04
13	Construction	5.E+07	1.E+06	2.E+08	9.E+07	6.E+07	6.E+07	2.E+08	9.E+07	1.E+08	2.E+07	2.E+07	4.E+05	3.E+07	6.E+06	1.E+08	2.E+08	2.E+08	2.E+08	1.E+08	1.E+09	7.E+08
14	Maintenance and Repair	1.E+07	4.E+05	1.E+06	2.E+07	2.E+07	7.E+06	2.E+07	7.E+06	2.E+07	6.E+06	5.E+06	4.E+05	3.E+07	2.E+05	7.E+06	7.E+06	2.E+07	5.E+06	1.E+06	9.E+06	5.E+06
15	Wholesale Trade	4.E+08	2.E+07	5.E+07	1.E+09	5.E+08	4.E+08	1.E+09	4.E+08	1.E+09	4.E+08	2.E+08	3.E+06	1.E+09	1.E+07	3.E+08	4.E+08	7.E+08	2.E+08	8.E+07	4.E+08	4.E+08
16	Retail Trade	3.E+07	2.E+06	8.E+06	2.E+07	7.E+07	8.E+06	6.E+07	7.E+06	4.E+07	2.E+07	3.E+07	2.E+06	5.E+08	2.E+06	3.E+07	7.E+07	2.E+08	9.E+07	8.E+06	1.E+08	1.E+07
17	Hotels and Restraurants	4.E+06	6.E+04	1.E+06	3.E+07	1.E+07	2.E+07	4.E+07	2.E+07	3.E+07	5.E+06	8.E+06	7.E+04	3.E+07	1.E+06	4.E+07	5.E+07	7.E+07	4.E+07	4.E+07	3.E+08	1.E+08
18	Transport	3.E+08	8.E+06	1.E+08	7.E+08	3.E+08	2.E+08	8.E+08	2.E+08	3.E+08	1.E+08	1.E+08	3.E+08	6.E+08	2.E+07	7.E+08	7.E+08	3.E+08	4.E+07	1.E+08	4.E+08	3.E+08
19	Post and Telecommunications	2.E+07	2.E+06	2.E+07	8.E+07	9.E+07	8.E+07	2.E+08	7.E+07	4.E+08	3.E+07	4.E+07	2.E+06	3.E+08	3.E+07	8.E+08	1.E+09	5.E+08	5.E+08	6.E+07	1.E+09	8.E+08
20	Finacial Intermediation and Business Activities	1.E+09	2.E+07	7.E+08	2.E+09	7.E+08	7.E+08	3.E+09	9.E+08	3.E+09	8.E+08	4.E+08	5.E+06	3.E+09	2.E+08	3.E+09	4.E+09	2.E+09	3.E+09	2.E+09	3.E+06	4.E+09
21	Public Administration	6.E+06	1.E+05	2.E+06	9.E+06	3.E+06	4.E+06	1.E+07	3.E+06	3.E+06	1.E+06	3.E+06	2.E+04	3.E+06	3.E+05	3.E+06	1.E+07	1.E+07	7.E+06	8.E+06	5.E+07	3.E+06
22	Education, Health and Other Services	3.E+07	4.E+06	5.E+06	4.E+07	2.E+07	2.E+07	6.E+07	2.E+07	3.E+07	8.E+06	8.E+06	3.E+05	6.E+07	3.E+06	6.E+07	1.E+08	2.E+08	6.E+07	2.E+08	6.E+08	4.E+08
23	Private Households	5.E+03	3.E+02	4.E+02	1.E+03	2.E+03	3.E+02	1.E+03	3.E+02	4.E+02	3.E+02	1.E+03	5.E+03	3.E+02	2.E+02	3.E+02	4.E+02	2.E+04	2.E+02	2.E+02	1.E+04	5.E+06
24	Others	2.E+07	2.E+06	5.E+06	5.E+07	1.E+08	2.E+07	5.E+07	4.E+07	5.E+07	5.E+06	7.E+06	3.E+06	3.E+07	2.E+06	9.E+07	2.E+07	4.E+07	2.E+07	1.E+07	7.E+07	2.E+07
25	Re-export & Re-import	9.E+01	1.E+02	9.E+01	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02	1.E+02
26^{New}	Gas and Water	6.E+07	3.E+05	4.E+07	1.E+08	7.E+07	7.E+07	3.E+08	9.E+07	8.E+07	2.E+07	1.E+07	5.E+06	3.E+07	3.E+06	4.E+07	1.E+08	2.E+08	4.E+07	2.E+07	1.E+08	1.E+08
27^{New}	Electricity T&D	5.E+07	3.E+05	3.E+07	1.E+08	6.E+07	6.E+07	2.E+08	8.E+07	6.E+07	2.E+07	9.E+06	4.E+06	3.E+07	2.E+06	3.E+07	1.E+08	1.E+08	3.E+07	2.E+07	1.E+08	8.E+07
28^{New}	Hydro Power Generation	2.E-01	1.E-03	2.E-01	5.E-01	3.E-01	3.E-01	1.E+00	4.E-01	3.E-01	8.E-02	5.E-02	2.E-02	1.E-01	1.E-02	1.E-01	5.E-01	7.E-01	2.E-01	8.E-02	5.E-01	4.E-01
29	Steam Cycle power Plants	1.E+00	9.E-03	1.E+00	3.E+00	2.E+00	2.E+00	7.E+00	2.E+00	2.E+00	5.E-01	3.E-01	1.E-01	9.E-01	6.E-02	9.E-01	3.E+00	4.E+00	9.E-01	5.E-01	3.E+00	2.E+00
30	Open Gas cycle power Plants	3.E-01	2.E-03	2.E-01	7.E-01	4.E-01	4.E-01	2.E+00	6.E-01	5.E-01	1.E-01	6.E-02	3.E-02	2.E-01	2.E-02	2.E-01	8.E-01	1.E+00	2.E-01	1.E-01	7.E-01	6.E-01
31	Combined Cycle power Plants	1.E+00	8.E-03	9.E-01	3.E+00	1.E+00	1.E+00	6.E+00	2.E+00	2.E+00	4.E-01	2.E-01	1.E-01	8.E-01	6.E-02	8.E-01	3.E+00	4.E+00	8.E-01	4.E-01	2.E+00	2.E+00
32	Wind	4.E-02	2.E-04	3.E-02	8.E-02	4.E-02	4.E-02	2.E-01	6.E-02	5.E-02	1.E-02	7.E-03	3.E-03	2.E-02	2.E-03	2.E-02	8.E-02	1.E-01	2.E-02	1.E-02	7.E-02	6.E-02
33	Solar Technologies	3.E-03	2.E-05	2.E-03	6.E-03	4.E-03	3.E-03	1.E-02	5.E-03	4.E-03	1.E-03	6.E-04	3.E-04	2.E-03	1.E-04	2.E-03	7.E-03	9.E-03	2.E-03	1.E-03	6.E-03	5.E-03
	Value Added																					
	Compensation of employees D.1	4.E+08	6.E+07	3.E+08	1.E+09	6.E+08	1.E+09	2.E+09	1.E+09	4.E+09	1.E+09	5.E+08	4.E+07	6.E+09	3.E+08	6.E+09	5.E+09	3.E+09	3.E+09	3.E+09	2.E+10	8.E+09
	Taxes on production D.29	3.E+08	1.E+07	3.E+08	8.E+08	5.E+07	1.E+08	7.E+08	1.E+08	2.E+08	6.E+07	4.E+07	3.E+06	5.E+08	1.E+08	2.E+09	2.E+09	8.E+08	4.E+08	6.E+08	4.E+09	2.E+08
	Subsidies on production D.39	-4.E+07	-1.E+06	-1.E+07	-1.E+08	-8.E+05	-2.E+06	-1.E+07	-2.E+06	-1.E+07	-2.E+06	-1.E+06	-2.E+04	-5.E+07	-7.E+06	-2.E+08	-2.E+08	-4.E+07	-5.E+07	-5.E+07	-8.E+08	-1.E+07
	Net operating surplus B.2n	3.E+09	2.E+08	1.E+09	3.E+09	6.E+08	1.E+09	4.E+09	1.E+09	3.E+09	1.E+09	6.E+08	3.E+07	3.E+09	2.E+08	5.E+09	4.E+09	2.E+09	2.E+09	5.E+09	5.E+10	2.E+09
	Net mixed income B.3n	1.E+09	4.E+07	6.E+08	1.E+09	4.E+08	8.E+08	2.E+09	8.E+08	2.E+09	8.E+08	4.E+08	7.E+06	3.E+09	2.E+08	4.E+09	4.E+09	2.E+09	2.E+09	3.E+09	2.E+10	7.E+09
	Consumption of fixed capital K.1	4.E+08	2.E+07	2.E+08	3.E+08	8.E+07	2.E+08	6.E+08	2.E+08	7.E+08	2.E+08	8.E+07	5.E+06	6.E+08	3.E+07	5.E+08	6.E+08	4.E+08	4.E+08	8.E+08	8.E+09	8.E+08
	Imports	2.E+08	2.E+07	2.E+08	1.E+09	4.E+08	7.E+08	3.E+09	9.E+08	3.E+09	1.E+09	4.E+08	1.E+07	1.E+09	3.E+07	7.E+08	3.E+08	6.E+08	9.E+08	4.E+08	2.E+09	1.E+09
	Exogenous Resources																					
	CO2 emissions (Gg) from EDGAR	3.E+03	1.E+02	4.E+03	5.E+03	2.E+03	2.E+03	4.E+04	3.E+03	6.E+03	3.E+03	1.E+03	6.E+02	5.E+03	1.E+02	5.E+02	7.E+02	6.E+02	5.E+04	3.E+02	5.E+03	8.E+02
	DEPRECATED Water use, total (m3)	5.E+10	5.E+08	6.E+08	2.E+09	6.E+08	5.E+08	7.E+08	5.E+08	5.E+08	7.E+08	3.E+08	2.E+09	7.E+08	0.E+00	0.E+00	0.E+00	7.E+08	7.E+08	0.E+00	3.E+08	0.E+00
	Primary Energy Usage (TJ)	1.E+05	2.E+02	2.E+05	2.E+04	8.E+03	8.E+03	3.E+05	3.E+04	2.E+05	1.E+04	4.E+04	2.E+04	2.E+04	5.E+02	1.E+04	2.E+04	1.E+04	6.E+05	6.E+03	1.E+04	2.E+04

Table 15. Hyprid Egypt's EORA 26 IO table in USD and electricity generation sectors sector in Physical Units (TWh)

						Industries		Industries						Final Demand						
		Education, Health and Other Services	Private Households	Others	Re-export & Re-import	Gas and Water	Elec T&D	Hydro Power Generation	Steam Cycle power Plants	Open Gas cycle power Plants	Combined Cycle power Plants	Wind	Solar Technologies	Household final consumption P.3h	Non-profit institutions serving households P.3n	Government final consumption P.3g	Gross fixed capital formation P.51	Changes in inventories P.52	Acquisitions less disposals of valuables P.53	Exports
1	Agriculture	3.E+07	7.E+04	9.E+04	7.E+04	1.E+05	1.E+05	4.E+02	8.E+04	5.E+04	9.E+04	3.E+03	5.E+02	2.E+09	5.E+06	2.E+06	2.E+07	4.E+07	5.E+02	3.E+09
2	Fishing	4.E+06	3.E+04	6.E+02	3.E+05	8.E+01	7.E+01	2.E-01	5.E+01	3.E+01	5.E+01	2.E+00	3.E-01	9.E+07	1.E+05	1.E+06	5.E+02	3.E+06	5.E+02	3.E+07
3	Mining and Quarrying	1.E+07	5.E+04	7.E+05	3.E+05	2.E+08	1.E+08	0.E+00	1.E+08	4.E+07	9.E+07	0.E+00	0.E+00	2.E+08	5.E+04	2.E+06	6.E+06	4.E+07	5.E+02	3.E+09
4	Food & Beverages	2.E+08	5.E+06	2.E+05	1.E+05	1.E+05	1.E+05	4.E+02	8.E+04	5.E+04	9.E+04	3.E+03	6.E+02	1.E+10	5.E+07	3.E+02	4.E+02	6.E+07	4.E+02	2.E+09
5	Textiles and Wearing Apparel	3.E+07	2.E+05	4.E+05	3.E+05	3.E+05	3.E+05	8.E+02	2.E+05	1.E+05	2.E+05	6.E+03	1.E+03	2.E+09	6.E+06	2.E+05	7.E+07	8.E+06	5.E+02	4.E+09
6	Wood and Paper	4.E+08	1.E+07	2.E+07	2.E+05	4.E+06	4.E+06	1.E+04	3.E+06	2.E+06	3.E+06	8.E+04	2.E+04	1.E+09	3.E+06	7.E+06	2.E+07	1.E+07	4.E+02	2.E+08
7	Petroleum, Chemical and Non-Metallic Mineral Products	1.E+09	1.E+07	3.E+07	1.E+05	3.E+07	2.E+07	0.E+00	2.E+07	7.E+06	2.E+07	0.E+00	0.E+00	6.E+09	3.E+07	2.E+07	6.E+07	2.E+07	4.E+02	5.E+09
8	Metal Products	6.E+07	3.E+06	8.E+06	2.E+05	3.E+06	3.E+06	8.E+03	2.E+06	1.E+06	2.E+06	6.E+04	1.E+04	2.E+08	9.E+05	6.E+06	2.E+08	4.E+07	4.E+02	1.E+09
9	Electrical and Machinery	5.E+08	1.E+07	1.E+07	1.E+05	2.E+07	1.E+07	4.E+04	1.E+07	6.E+06	1.E+07	3.E+05	7.E+04	4.E+09	9.E+06	4.E+08	7.E+09	1.E+08	4.E+02	1.E+09
10	Transport Equipment	2.E+07	5.E+06	2.E+06	2.E+05	6.E+05	5.E+05	1.E+03	3.E+05	2.E+05	3.E+05	1.E+04	2.E+03	4.E+09	2.E+07	3.E+08	2.E+09	2.E+08	4.E+02	8.E+07
11	Other Manufacturing	1.E+08	2.E+06	3.E+06	3.E+05	2.E+06	2.E+06	6.E+03	1.E+06	9.E+05	1.E+06	4.E+04	9.E+03	1.E+09	8.E+06	5.E+07	5.E+08	2.E+07	4.E+02	5.E+08
12	Recycling	3.E+06	1.E+03	3.E+02	7.E+05	3.E+06	2.E+06	7.E+03	2.E+06	1.E+06	2.E+06	5.E+04	1.E+04	9.E+08	7.E+06	6.E+06	4.E+02	5.E+07	3.E+08	5.E+07
13	Construction	4.E+08	8.E+06	9.E+06	1.E+05	8.E+07	7.E+07	2.E+05	4.E+07	3.E+07	5.E+07	1.E+06	3.E+05	2.E+08	1.E+06	1.E+09	2.E+10	2.E+01	4.E+02	7.E+07
14	Maintenance and Repair	1.E+07	1.E+05	3.E+05	4.E+05	3.E+05	3.E+05	8.E+02	2.E+05	1.E+05	2.E+05	5.E+03	1.E+03	8.E+08	4.E+06	2.E+06	5.E+07	7.E+05	4.E+02	2.E+07
15	Wholesale Trade	6.E+08	8.E+06	1.E+07	1.E+05	2.E+07	2.E+07	4.E+04	1.E+07	7.E+06	1.E+07	3.E+05	7.E+04	1.E+10	5.E+07	9.E+07	2.E+09	5.E+07	4.E+02	3.E+08
16	Retail Trade	7.E+07	5.E+05	2.E+06	1.E+05	8.E+05	7.E+05	2.E+03	5.E+05	3.E+05	5.E+05	1.E+04	3.E+03	2.E+10	1.E+08	5.E+06	6.E+08	2.E+01	4.E+02	4.E+07
17	Hotels and Restraurants	2.E+08	2.E+06	2.E+06	9.E+04	9.E+06	8.E+06	2.E+04	5.E+06	3.E+06	5.E+06	2.E+05	3.E+04	2.E+10	6.E+07	2.E+04	4.E+02	2.E+01	4.E+02	4.E+08
18	Transport	5.E+08	5.E+06	2.E+07	2.E+05	9.E+07	8.E+07	2.E+05	5.E+07	3.E+07	6.E+07	2.E+06	4.E+05	7.E+09	2.E+07	5.E+07	3.E+08	7.E+06	4.E+02	1.E+09
19	Post and Telecommunications	7.E+08	3.E+07	6.E+07	3.E+05	2.E+07	2.E+07	5.E+04	1.E+07	7.E+06	1.E+07	3.E+05	7.E+04	8.E+09	4.E+07	4.E+07	1.E+09	5.E+05	4.E+02	3.E+08
20	Finacial Intermediation and Business Activities	5.E+09	2.E+08	3.E+08	6.E+04	2.E+08	2.E+08	5.E+05	1.E+08	7.E+07	1.E+08	4.E+06	8.E+05	7.E+10	3.E+08	4.E+08	4.E+09	1.E+08	4.E+02	2.E+06
21	Public Administration	3.E+07	8.E+06	1.E+08	1.E+05	8.E+04	7.E+04	2.E+02	5.E+04	3.E+04	5.E+04	1.E+03	3.E+02	1.E+09	6.E+06	2.E+10	9.E+09	2.E+01	4.E+02	7.E+07
22	Education, Health and Other Services	7.E+05	1.E+07	2.E+07	7.E+04	8.E+06	6.E+06	2.E+04	4.E+06	3.E+06	5.E+06	1.E+05	3.E+04	4.E+10	2.E+08	9.E+09	1.E+09	5.E+04	4.E+02	3.E+08
23	Private Households	1.E+06	1.E+02	4.E+04	1.E+05	6.E+01	5.E+01	1.E-01	3.E+01	2.E+01	4.E+01	1.E+00	2.E-01	8.E+08	6.E+06	1.E+07	4.E+02	2.E+01	4.E+02	1.E+07
24	Others	3.E+07	2.E+06	4.E+02	4.E+05	4.E+06	4.E+06	1.E+04	2.E+06	2.E+06	3.E+06	8.E+04	2.E+04	9.E+08	7.E+06	3.E+02	4.E+02	2.E+01	4.E+02	2.E+06
25	Re-export & Re-import	1.E+02	1.E+02	1.E+02	4.E+02	3.E+01	3.E+01	7.E-02	2.E+01	1.E+01	2.E+01	5.E-01	1.E-01	2.E+02	2.E+02	2.E+02	2.E+02	9.E+00	2.E+02	4.E+07
26[New]	Gas and Water	2.E+08	1.E+06	3.E+06	4.E+04	2.E+07	3.E+06	0.E+00	3.E+06	8.E+05	2.E+06	0.E+00	0.E+00	2.E+09	6.E+06	1.E+02	1.E+02	5.E+03	1.E+02	2.E+06
27[New]	Electricity T&D	1.E+08	9.E+05	2.E+06	3.E+04	3.E+06	4.E+05	1.E+03	3.E+05	2.E+05	3.E+05	9.E+03	2.E+03	1.E+09	5.E+06	8.E+01	1.E+02	5.E+03	1.E+02	2.E+06
28[New]	Hydro Power Generation	7.E-01	4.E-03	1.E-02	2.E-04	1.E-02	2.E-03	4.E-03	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	5.E+00	2.E-02	3.E-07	4.E-07	2.E-05	4.E-07	6.E-03
29	Steam Cycle power Plants	4.E+00	3.E-02	7.E-02	9.E-04	9.E-02	1.E-02	0.E+00	2.E-02	0.E+00	0.E+00	0.E+00	0.E+00	3.E+01	1.E-01	2.E-06	3.E-06	1.E-04	3.E-06	4.E-02
30	Open Gas cycle power Plants	1.E+00	6.E-03	2.E-02	2.E-04	2.E-02	3.E-03	0.E+00	0.E+00	5.E-03	0.E+00	0.E+00	0.E+00	7.E+00	3.E-02	4.E-07	6.E-07	2.E-05	6.E-07	9.E-03
31	Combined Cycle power Plants	4.E+00	2.E-02	6.E-02	8.E-04	7.E-02	1.E-02	0.E+00	0.E+00	0.E+00	2.E-02	0.E+00	0.E+00	2.E+01	1.E-01	2.E-06	2.E-06	9.E-05	2.E-06	3.E-02
32	Wind	1.E-01	7.E-04	2.E-03	2.E-05	2.E-03	3.E-04	0.E+00	0.E+00	0.E+00	0.E+00	6.E-04	0.E+00	7.E-01	3.E-03	5.E-08	6.E-08	3.E-06	6.E-08	1.E-03
33	Solar Technologies	8.E-03	6.E-05	1.E-04	2.E-06	2.E-04	3.E-05	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	5.E-05	6.E-02	2.E-04	4.E-09	5.E-09	2.E-07	5.E-09	8.E-05
	Value Added																			
	Compensation of employees D.1	2.E+10	2.E+08	1.E+08	5.E+03	3.E+08	3.E+08	8.E+05	2.E+08	1.E+08	2.E+08	6.E+06	1.E+06							
	Taxes on production D.29	1.E+09	3.E+06	2.E+07	5.E+03	3.E+08	2.E+08	6.E+05	1.E+08	9.E+07	2.E+08	4.E+06	1.E+06							
	Subsidies on production D.39	-2.E+08	-1.E+05	-2.E+06	-1.E+02	-8.E+06	-7.E+06	-2.E+04	-5.E+06	-3.E+06	-5.E+06	-1.E+05	-3.E+04							
	Net operating surplus B.2n	1.E+10	6.E+07	5.E+08	5.E+03	1.E+09	9.E+08	3.E+06	6.E+08	4.E+08	6.E+08	2.E+07	4.E+06							
	Net mixed income B.3n	1.E+10	2.E+08	2.E+08	5.E+03	5.E+08	4.E+08	1.E+06	3.E+08	2.E+08	3.E+08	9.E+06	2.E+06							
	Consumption of fixed capital K.1	2.E+09	8.E+06	8.E+07	5.E+03	2.E+08	2.E+08	6.E+05	1.E+08	9.E+07	1.E+08	4.E+06	9.E+05							
	Imports	1.E+09	2.E+07	3.E+07	1.E+07	1.E+08	1.E+08	6.E+04	1.E+08	4.E+07	8.E+07	5.E+05	1.E+05							
	Exogenous Resources																			
	CO2 emissions (Gg) from EDGAR	1.E+03	1.E+02	1.E+02	0.E+00	5.E+04	0.E+00	0.E+00	2.E+04	5.E+03	2.E+04	0.E+00	0.E+00							
	DEPRECATED Water use, total (m3)	7.E+08	0.E+00	0.E+00	0.E+00	1.E+08	0.E+00	0.E+00	2.E+08	2.E+07	6.E+07	0.E+00	0.E+00							
	Primary Energy Usage (TJ)	2.E+04	5.E+02	1.E+03	0.E+00	3.E+05	0.E+00	0.E+00	7.E+04	5.E+04	1.E+06	0.E+00	0.E+00							