Energy 165 (2018) 198–209

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Modelling for power generation sector in Developing Countries: Case of Egypt

Yassin Yehia Rady [a, *], Matteo V. Rocco [b], M.A. Serag-Eldin [a], Emanuela Colombo [b]

[a] American University in Cairo, Department of Mechanical Engineering, AUC Avenue, 11835 New Cairo, Egypt
[b] Politecnico di Milano, Department of Energy, via Lambruschini 4, Milan, Italy

A R T I C L E I N F O

Article history:
Received 12 January 2018
Received in revised form
3 September 2018
Accepted 12 September 2018
Available online 14 September 2018

Keywords:
Energy modelling
Developing Counties
Egypt
OSeMOSYS
Energy scenarios

A B S T R A C T

In this article, the economic and environmental implications due to the projected evolution of the power sector in Egypt until 2040 are assessed and discussed. The Reference Energy System (RES) of the Egyptian power sector has been defined and implemented in the Open Source Energy Modelling System (OSeMOSYS), based on two different energy scenarios. To increase the accuracy of the analysis, the discount rate on capital investments for the energy technologies has been imposed as a time dependent exogenous variable. Moreover, the robustness of the obtained results has been tested through a sensitivity analysis on the main exogenous parameters.

It is found that Combined Cycles, Wind, and Photovoltaic rooftop systems are compatible technologies to be included in the future Egypt's power generation mix. In particular, based on the abundant Egypt's renewables resources endowments, 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 a part of the natural gas share. Moreover, the significant impact of discount rate on capitals on the final results is highlighted: low values of discount rate would skew generation mix to include higher investment cost technologies and vice versa.

1. Introduction

Security and affordability of energy supplies are aspects of paramount relevance in shaping future energy policies and countries' energy power mixes. These aspects will become increasingly important in the future, since according to 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]. Energy modelling frameworks are widely recognized as useful approaches for planning future investments towards a viable and sustainable national power sector, identifying the future energy power mix that enables to fulfill the demand of electricity at lowest cost, in compliance with technical, environmental and political constraints. Moreover, energy modelling frameworks enable 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 political instabilities in some regions [2].

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, encouraging foreign investments in sectors different than the energy one, hence resulting in positive spillover effects. The use of energy models to support policy making 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 model allows analysis of national energy sectors to forecast their future energy demand, prices, and supply, while considering the development of their related technologies [3]. For similar purposes, the DICE [4] and MERGE [5] modelling 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 (DCs), where the financial availability and the access to high-quality data are two major challenges. Despite this, the

* Corresponding author.
E-mail addresses: yrady@aucegypt.edu (Y.Y. Rady), matteovincenzo.rocco@polimi.it (M.V. Rocco), amrserag@aucegypt.edu (M.A. Serag-Eldin), emanuela.colombo@polimi.it (E. Colombo).

https://doi.org/10.1016/j.energy.2018.09.089
0360-5442/

number of energy models applications in DCs are increasing: among other modelling frameworks, Howells et al. have developed the Open Source Energy Modelling System (OSeMOSYS), defined as a partial equilibrium long-term energy planning supportive tool with a bottom-up representation of energy conversion technologies [6]. Several recent application of OSeMOSYS can be found in literature: as an example, the assessment of the evolution of Tunisian and Sub-Saharan power sectors has been recently performed based on an open-source energy optimization framework, which emerged in recent years to overcome the aforementioned limitations [7,8]. 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 [9].

1.1. Egypt's power sector

Among other DCs, the economy of Egypt is expected to grow rapidly in the next decades [10]: 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 [11,12]. This strong dependence on fossil energy supplies is mainly due to the strong subsidies on fossil energy utilities imposed so far, and it makes Egypt fragile and vulnerable to socio-economic events (like the 2011 turmoil [13]), resulting in low levels of reliability and security of supply [12]. 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, 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 [12]. 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 [12]. 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, Egypt govern considers adding 7.1 GW coal-fired capacity by 2022: however, this alternative is debatable, as Egypt does not have coal reserves. For such 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 (INDCs) in 2015 United Nations conference on climate in Paris [12,14]. In addition, the penetration Furthermore, investments are planned in the electricity trade infrastructure with neighbor countries. Egypt's transmission grid is connected to Libya, Sudan, Jordan, and Lebanon. A 3 GW trade connection is planned to link Egypt with Saudi Arabia, which has a different peak load demand profile [12].

For such reasons, the development of Egypt's power sector will be a challenging task, and energy modelling 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 [15]. Unfortunately, technical and economic data required to setup energy models can be hardly recovered, with particular references to costs of energy technologies, average efficiencies and availabilities.

1.2. Objectives of the paper

The overall objective of this research is to provide a quantitative assessment of future development scenarios for the power generation sector in Egypt. The evolution of Egyptian power generation sector is here assessed within a time period between 2018 and 2040 based on the OSeMOSYS energy modelling framework, hence developing the *OSeMOSYS-Egypt model*. The least cost power generation mix will be identified according to two different electricity demand scenarios, and compared with the energy plans announced by the Egyptian government [15]. Moreover, the robustness of the obtained results is tested 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 novelties introduced by this study are:

To enrich the current literature with a detailed analysis about Egypt's power generation sector. This analysis has led to a detailed representation of the Egypt's *Reference Energy System* (RES), considering the specific characteristics of the energy demand of disaggregated sectors, technologies, and transmission and distribution infrastructures [6,16].

To implement the developed RES in the OSeMOSYS-Egypt model, validating its analysis capabilities by considering various scenarios of electricity demand growth until 2040, by performing an in-depth sensitivity analysis, and by providing policymakers with a comprehensive representation of the achieved results.

The rest of the paper is organized as follows: section 2 provides a general literature overview related to the topic of energy modelling; section 3 provides the definition of the Reference Energy System (RES) for Egypt, a description about the energy model adopted for the analysis, including the setup of its main parameters, decision variables, objective function, and constraints. In the same section, the adopted future scenarios are introduced and described. Respectively report and discuss the obtained results and the sensitivity of the model on the most relevant exogenous parameters. Concluding remarks, recommendations, and future research interests are provided in section 6.

2. Literature review

The relevance of energy modelling frameworks in interpreting emerging and future needs of the energy sectors in DCs, and in shaping their future optimal expansion capacities has been addressed by several studies. Pandey et al. 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 [17]. Bazmi et al. 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 *Energy Planning Mathematical Optimization Models* (EPMOMs) to shape energy sector policies has emerged as a robust and systematic approach to investigate the future changes in national energy sectors [18].