The Role of Gas to Power in Supporting Large-scale Renewable Energy Integration in Morocco: Insights from Optimization through Long-term Bottom-up Modelling

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Abstract: To strengthen its energy sector, Morocco adopted at the end of 2009 an energy strategy based mainly on the increased penetration of renewable sources, the improvement of energy efficiency, and the reinforcement of regional integration. Morocco's energy strategy called for increasing the share of renewable electricity to 42% of installed capacity by 2020 and over 52% of installed renewable capacity by 2030. However, as renewable energy becomes more widespread, the national power system will face new challenges due to its intermittent nature. It is, therefore, necessary to deploy flexible resources to cope with this intermittency and improve the stability of the power system. In this work, we used a bottom-up linear optimization model to identify the best options for developing gas to power technology in Morocco. We find out that the new gas to power facilities development, and the import of liquefied natural gas (LNG), is not the optimal solution. Instead, it would be interesting for Morocco to negotiate its natural gas supply via the GME with one of its neighbours, Spain or Algeria.

1 INTRODUCTION

Today, the world's energy sector's main challenge is to ensure, while preserving the environment, sustainable energy security for emerging countries, maintaining growth and living standards for developed countries, and providing access to energy at affordable costs for less developed countries (Sarkis and Tamarkin, 2008). In this perspective, renewable energies (RES) have emerged as an appropriate solution to the challenges of security of supply, access to energy and preservation of the environment (Gasparatos, 2017).

In Morocco, the power generation sector faces the same challenges, including increasing demand for electricity at an average rate of 7% per year since 2002, a commitment to reduce greenhouse gas emissions by 32% by 2030, and heavy dependence on imported fossil fuels (98% in 2009) (Nfaoui, 2020). Thus, Morroco adopted, in 2009, a new energy strategy. This strategy was based primarily on increasing clean energy, improving energy efficiency, and strengthening regional integration.

However, a power system with a high share of renewable resources faces the problem of power quality and reliability (McPherson,2018). Although many flexible generation options exist to facilitate RES system integration, one of the main challenges is to select the most optimal alternative to meet the power system requirements. Historically, one of the most appropriate ways to address the intermittency generated by renewable energy was to develop natural gas-fired power plants (GFPPs) such as combined cycle power plants (CCGTs) (Ibrahim, 2018). However, Morocco's gas resources are not sufficient for the large-scale development of gas to power technologies. Indeed, the Tahaddart CCGT plant, developed in 2005, and the Aïn Beni Mathar integrated combined cycle solar power plant

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("ISCC"), set in 2010, take advantage of the Maghreb-Europe (GME) gas pipeline arrangement between Morocco and Algeria.

This agreement will expire towards the end of 2021. At the time of submitting this paper, there has been no announcement regarding the renewal of this agreement. Given this situation, Morocco may continue the development of the Gas to Power field through several options. These include mainly: 1) Renewal of the GME contract or negotiation of a new contract but this time with Spain to import gas from Spain through the same pipeline; 2) Making use of recently discovered deposits in the Tendrara region and seeking new deposits; or, 3) Importing Liquefied Natural Gas (LNG).

This paper intends to evaluate the optimal choice for natural gas development in Morocco under the guidelines of the National Energy Strategy The focus will be on assessing whether the choice of importing LNG or purchasing natural gas directly from Algeria or Spain through the GME is optimal. To do so, we will describe, in section 2, the optimization tool used as well as the approach followed to integrate the renewed installed capacity objectives in its equation system. In the 3rd section, we introduce our case study: the Moroccan electrical system and its characteristics. We also present the scope of our research. Finally, in the 4th section, we will discuss the results of our study and explain the upcoming research work.

2 MATERIALS AND METHODS

2.1 Tool: Open-Source Energy Modelling System

Optimizing power systems in developing countries to meet demand with available supply technologies and resources can be solved by bottom-up modelling techniques. The Open-Source Energy Modelling System (OSeMOSYS) is one of the bottom-up, dynamic, and linear optimization models applied to integrated assessment and energy planning (Dhakouani, 2019). It aims to satisfy demand by accounting for technical, economic, and environmental parameters while optimizing the total discounted cost (Howells, 2011). The developers of this model designed it around a series of "blocks" of functionality. These functionalities are related to the following aspects: costs, capacity adequacy, energy balance, renewable energies, emissions, and provisions. The parameters introduced by the analyst, the intermediate variables, and the equations and the constraints are what characterize each block (Howells et al., 2011).

Initially, the code for OSeMOSYS was written in GNU MathProg, and recently, it has been translated into GAMS (General algebraic modelling system) and Python. Our study uses the GAMS version of OSeMOSYS. OSeMOSYS allows the modeller to introduce a constraint of integration of RES in the energy system through equation (1).

$$\forall_{r,y}: \boldsymbol{REMinProductionTarget}_{r,y} \times \boldsymbol{RETotalProductionOfTargetFuelAnnual}_{r,y} \leq \boldsymbol{TotalREProductionAnnual}_{r,y} \quad (1)$$

$"r"$ and $"y"$ represent the data sets for the region and the modelling year, respectively. The *REMinProductionTarget(r,y)* parameter is the minimum renewable production target desired by the analyst. Also, the variable *RETotalProductionOfTargetFuelAnnual(r,y)* stands for the Annual Production of the fuels marked as renewable in the model, and the variable *TotalREProductionAnnual(r,y)* denotes the annual production of all technologies marked as renewable in the model. However, using this equation for the case of the Moroccan energy strategy is not viable. The objectives of the Moroccan energy strategy are expressed as renewable installed capacity and not as annual renewable energy production. A modification of the code is necessary before proceeding with the modelling.

2.2 Implementation of the Renewable Installed Capacity Constraint in OSeMOSYS

In this section, we explain the formulas for modelling the installed capacity constraints of renewable energy sources. To impose a constraint on renewable generation, we used the same method as that used by (Howells et al., 2011). Thus, we initially converted equation (1) to equation (2).

$$\forall_{r,y}: \boldsymbol{REMinCapacityTarget}_{r,y} \times TotalPowerCapacityAnnual_{r,y} \leq TotalRECapacityAnnual_{r,y} \quad (2)$$

Equation (2) is composed of 3 terms. The first one is the variable *TotalRECapacityAnnual*, which is a new variable introduced to the system. It allows identifying the total annual renewable capacity. Equation (3) determines the computing method of this variable.

$$\forall_{r,t,y}: \sum_{t} TotalCapacityAnnual_{r,t,y} \times \boldsymbol{RETagTechnology}_{r,t,y} = TotalRECapacityAnnual_{r,y} \quad (3)$$

The variable *TotalCapacityAnnual* is the existing total capacity of technology *"t"* for year *"y"*. The *RETagTechnology* parameter represents a binary parameter flagging renewable technologies. It has the value 1 for renewable technologies and 0 otherwise.

The 2nd term is the variable *TotalPowerCapacityAnnual(r,y)*. This variable accounts for the total annual capacity of the technologies generating electricity. It is derived from the *TotalCapacityAnnual* variable and the *PowerTagTechnology* parameter as shown in equation (4). The new parameter was added to allow the model to identify electricity-generating technologies and separate them from other technologies defined in the model.

$$\forall_{r,t,y}: \sum_{t} TotalCapacityAnnual_{r,t,y} \times \boldsymbol{PowerTagTechnology}_{r,t,y} = TotalPowerCapacityAnnual_{r,y} \quad (4)$$

The 3rd term is the *REMinCapacityTarget(r,y)* parameter. It has been introduced to be able to define a minimum target of renewable capacity.

3 CASE DESCRIPTION

The research framework of our study covers the period from 2010 to 2050. The periodic modelling cycle follows a five-year capacity investment decision cycle. Our analysis will be based on two distinct scenarios.

In the first scenario, we will assume that Morocco has decided to develop flexible power plants running on natural gas through the development of a gas infrastructure based on the import of LNG, development of an LNG regasification terminal and a network for the transport of the gas towards the power plants. The second scenario would be based on the hypothesis that Morocco successfully negotiated a natural gas supply contract via the GME with Algeria or Spain. The other assumptions commonly used in the two scenarios included in Table 1 are:

Table 1: Assumptions and Scenarios characteristics

Assumption categories	Scenarios	
	Scenario 1 (LNG development)	***Scenario 2 (GME contracts)***
Objectives in terms of RES	The national energy strategy targets regarding renewable installed capacity have been adopted for the years 2020 and 2030. They are 42% and 52% respectively. For the other years, a linear extrapolation has been established. This gives a 37% for 2015; 47% in 2025; 57% in 2035; 62% in 2040; 67% in 2047 and 72% in 2050.	
Candidate renewable technologies	- Onshore wind (WIND) - Photovoltaic utility (PV_UTIL)	- Concentrated Solar Power (CSP) - Hydropower plants (HYDRO_PP)
Flexible backup technologies	- Gas power plants developed before 2010 supplied through GME or Tendrara gas. - New natural gas plants to be supplied through regasification terminal. - Pumped Hydro storages (PHS)	- Old and new gas power plants fed by Gazuduc. - Pumped Hydro storages (PHS)
Discount rate	5%	
Minimum reserve margin	15% after 2015 and 20% starting from 2020.	
Emission Limits	Nan	

3.1 Energy System of Reference of Our Study

In the framework of energy modelling, a graphical network representation of all the technical activities needed to supply various forms of energy to the end-use activities is often used, known as the Reference Energy System (RES) (Hermelee, 1979). The RES adopted for our case is shown in (Figure 1).

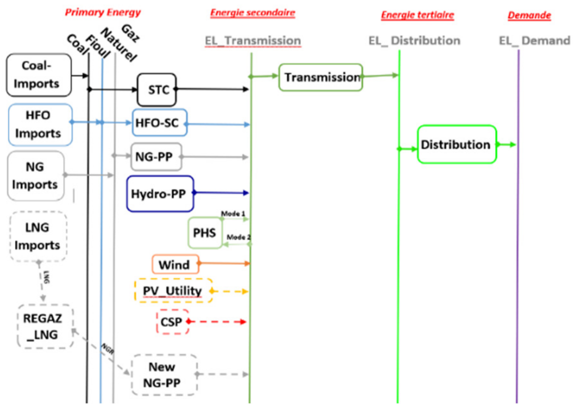

Figure 1: Electricity supply model of Morocco's or the reference energy system.

The model takes into account the Moroccan power generation fleet at the end of 2009 (http://www.one.org.ma). Table 2 presents additional information on the installed capacity of the Moroccan electricity system during this period. In the RES shown in Figure 1, the technologies and energy carriers represented in a continuous line represent the technologies in the system at the beginning of the modeling process. Technologies and energy carriers represented in split line represent proposed technologies and energy carriers to meet the demand throughout the modelling period.

For the first scenario, all the GFPPs will use only regasified LNG. Under the second scenario, all GFPPs will be supplied directly by pipeline, and there will be no LNG imports

Table 2: Installed capacity at the end of 2009 in Morocco.

Power plants	Capacity in MW
Hydraulic Power Plants	1 284
Pumped Hydro Storages	464
Steam Heat Plants (Coal Fired)	465
Steam Heat Plants (Oil Fired)	600
Coal-Fired Power Plant	1 320
CCGT/ ISCC	680
WIND	222
TOTAL	5035

3.2 Inputs and Data

Several inputs and data were adopted for the modelling of the Moroccan power system by OSeMOSYS. Firstly, and in order to simulate the seasonal and daily variability of the electricity demand, together with the intermittent availability of renewable energy sources, we divided the model years into 6-time steps (3 seasons: Winter, Intermediate and Summer, and two sub-periods: Night and Day). For demand, we are referring to the data provided by the ONEE in its various activity reports between 2010 and 2018 (http://www.one.org.ma). Concerning the electricity demand between 2020 and 2050, we relied on the analysis of the 2050 energy demand made by the Moroccan Ministry of Energy and Mines (https://www.mem.gov.ma). This type of analysis is highly dependent on the capital costs of the technologies under consideration. Similar considerations apply to fuel costs, operations and maintenance (O&M) costs and non-operating costs. These costs have been identified from several sources (https://taqamorocco.ma)(https://atb.nrel.gov)(https://energydata.info). Figures (2, 3 and 4) show the fuel costs, capital costs and fixed operating and maintenance costs of the main technologies used in the analysis.

4 RESULTS

The modelling study we conducted showed that the most economically advantageous scenario for Morocco is the 2nd one. Morocco will save more than 17 billion dollars by adopting scenario 2 (Figure 5). The 2nd scenario is also the best one regarding greenhouse gas emissions. It prevents more than 12 million tons of CO2 equivalent emissions. (Figure.6)

The comparison between the 1st and 2nd scenarios highlights the dominant role of Pumped Hydro Storage (PHS) (Figure.7). In fact, in the 1st scenario, the model considered that it was more optimal to invest in PHS to deal with the intermittent nature of RES than to invest in the construction and commissioning of new power plants fuelled by LNG.

In addition, this scenario shows that it is only after the year 2040 when the share of renewables will have exceeded 62%, that new GFPP could become interesting.

One explanation for this is that the development of GFPPs and their supply of regasified LNG requires significant investment in terms of infrastructure. Wile the implementation of PHS does not require as much capital investment.

For the second scenario (Figure 8), natural gas is used the most to cope with the intermittency of renewables in the first years of their installed capacity development. Then, as their share increases, there is a balance between PHS and CCGT/ISGC.

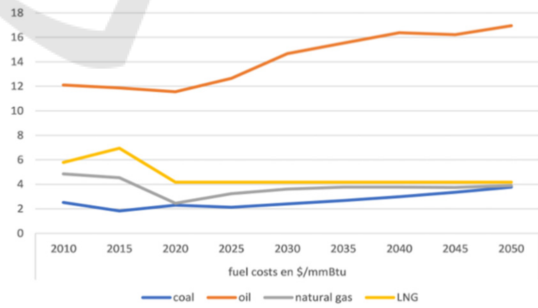

Figure 2: Energy Prices by Source (2010-2050)

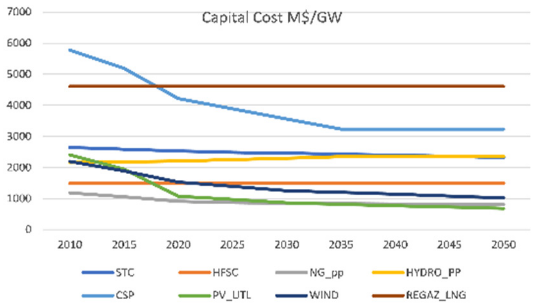

Figure 3: Capital cost of the technologies (2010-2050).

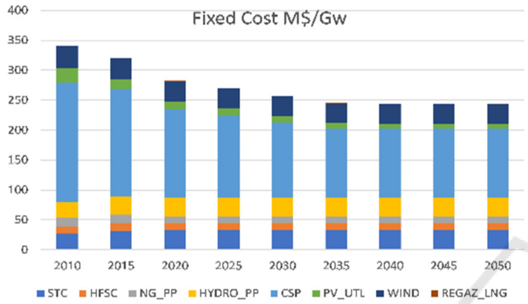

Figure 4: Fixed cost of the technologies (2010-2050).

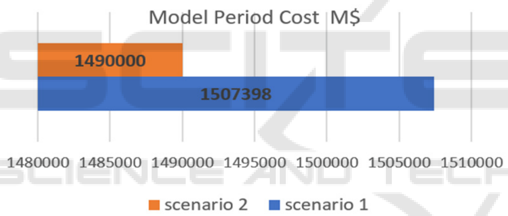

Figure 5: Total discounted cost of the scenarios.

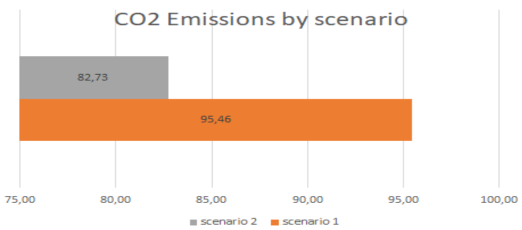

Figure 6: CO2 Emissions by scenario

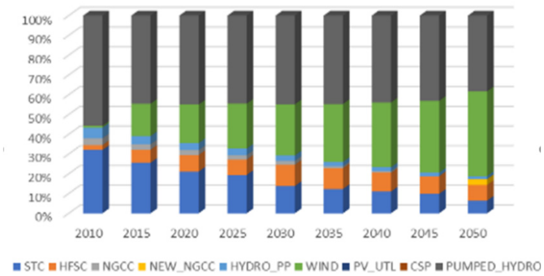

Figure 7: Share of Total Annual Capacity by Technology (Scenario 1).

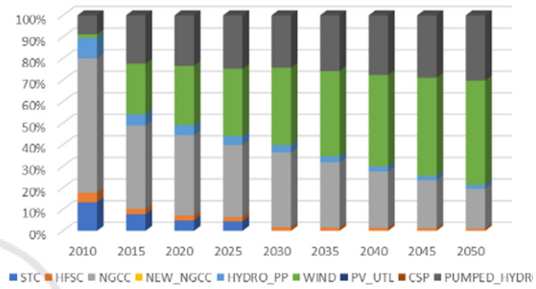

Figure 8: Share of Total Annual Capacity by Technology (Scenario 2)

5 CONCLUSION

This study has shown that the choice of importing LNG and regasifying it to supply new GFPPs for power generation is not necessarily the optimal solution to provide flexibility to renewable generation. We observe that the option of developing PHS is more interesting for Morocco, especially with its geological capacities allowing the country to have sufficient conditions for the development of PHS on a large scale. On the other hand, it would be interesting for Morocco to negotiate its natural gas supply through the GME with one of its neighbours, Spain or Algeria. It would also be interesting for Morocco to develop gas infrastructure around this pipeline, which would allow it to benefit from the Morocco-Nigeria gas pipeline project. Future research may consider evaluating the concept of floating storage and regasification units (FSRUs). FSRUs are becoming increasingly relevant as they can reduce the costs associated with gas terminal development.

6 FURTHER RESEARCH

Our future research will address other issues related to the Moroccan energy system. For that, we will proceed to a new configuration of the model. We will consider new parameters such as the exchange of electricity with neighbouring countries and the possibility of exporting electricity. We will try to build a machine learning that estimates most of the parameters needs by the model. We will also look at the storage capacities needed to support the development of renewable energies.

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