AWESOME

WATER-ECOSYSTEM-FOOD

FUTURE ENERGY SCENARIOS

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Author(s): Matteo Vincenzo Rocco, Mohammad Amin Tahavori, Yassin Yahya Radi

Content of this report: Report about the future energy scenarios developed for the AWESOME project, including the analysis of evolution of the power demand based on different economic projections and different policy scenarios until 2100 across the spatial scales requested by the AWESOME models.

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Abbreviations

RES:	Reference Energy System
CP:	Current Policy
SSP:	Share Socioeconomic Pathway
IO:	Input-Output

IOT:	Input-Output Table
GDP:	Gross Domestic Production
IEA:	International Energy Agency
VRES:	Renewable Energy Source
SWI:	Shannon-Wiener Index
OSeMOSYS:	Open-Source Energy Modeling System
CGE:	Competitional General Equilibrium
WP:	Work Package
WEFE:	Water-Energy-Food-Ecosystem

EXECUTIVE SUMMARY

The Deliverable D2.4 Future Energy Scenarios reports the energy scenarios developed for the AWESOME project. The document reports the development of an open-source energy system optimization model of the energy supply chain for the spatial domain useful for the AWESOME project (i.e. including Egypt, Ethiopia, and Sudan). The model is then used to explore different pathways of future energy scenarios in terms of energy demand and infrastructure evolution and their economic and environmental impacts. The future sectoral energy demand scenarios are developed based on the Socio-economic Pathways (SSPs) and the outcomes of D2.1 (Demographic projections), using a multi-sectoral optimal resource allocation economic model. All results, material and scenarios simulated are uploaded to the project repository *AWESOME_project /Work_packages /WP2 /Energy Model/Results.*

1. INTRODUCTION

This report aims to provide the future energy scenarios for the AWESOME project within task T2.4, *Future Energy Scenarios* of Work Package 2 (WP2). WP2 focus on the generation of future climate, water, food, energy demand and regional policy scenarios in the AWESOME study area. The outputs of the WP2 serve to evaluate the impact of such scenarios on the Water Energy Food Ecosystem (WEFE) Nexus in WP3 and WP4 as represented in **Figure 1**. Particularly, the energy modelling task aims at developing an open-source energy model to represent the energy demand and supply system of Egypt, Ethiopia, and Sudan within different economic projections. Ethiopia and Egypt have the highest population and biggest economies, which makes them the highest consumers of energy in the region, as shown in **Figure 2**. Besides that, they have the highest occupied area of the Nile river basin, i.e. 11.7% and 10.5% respectively, while Sudan accounts for 63.6%[1]. Moreover, Ethiopia has recently built the Grand Renaissance Dam on the Blue Nile, great potential for hydropower production for the country. With an installed capacity of 5150 MW, the dam is expected to annually generate around 16 TWh of energy[2]. Moreover, the spatial scope of the model is in line with the crop model (T2.4) and the analysis ongoing in WP4.
In general, the strong energy dependency of the economic activities of these countries and the underdeveloped energy infrastructure within the area, makes the planning of future capacity expansion a crucial task to guarantee a better understanding of the impact of the investment decisions and energy policies.
To fulfil Task 2.4, the OSeMOSYS energy system modelling framework is used. OSeMOSYS is an open-source cost minimization modelling system for long-run integrated assessment and energy planning. The model is calibrated for a period of five years using historical data. Demographic projections obtained in D2.1 are used to derive future energy projection scenarios as the main driver of the energy model. To have a consistent and scientifically grounded demand projections, an integrated energy-economic modelling framework has been utilized to interconnect the demographic projections with the energy model. Based on the results, we then analysed the impact of every single pathway in terms of costs, environmental impacts, possible power pools between the regions, and energy security issues within the area.

This report starts with an assessment of the current energy supply and demand situation within the spatial domain of the model (section 2), then continues introducing the energy modelling framework used in this study along with the historical calibration of the model (section 3). The approach for demand projection scenarios is discussed in section 4. Section 5 is dedicated to the definition of future energy scenarios and the discussion of the outcomes. Finally, Section 6 gives some final remarks. The document ends with the references and an annex including the data used to setup and configure the model.

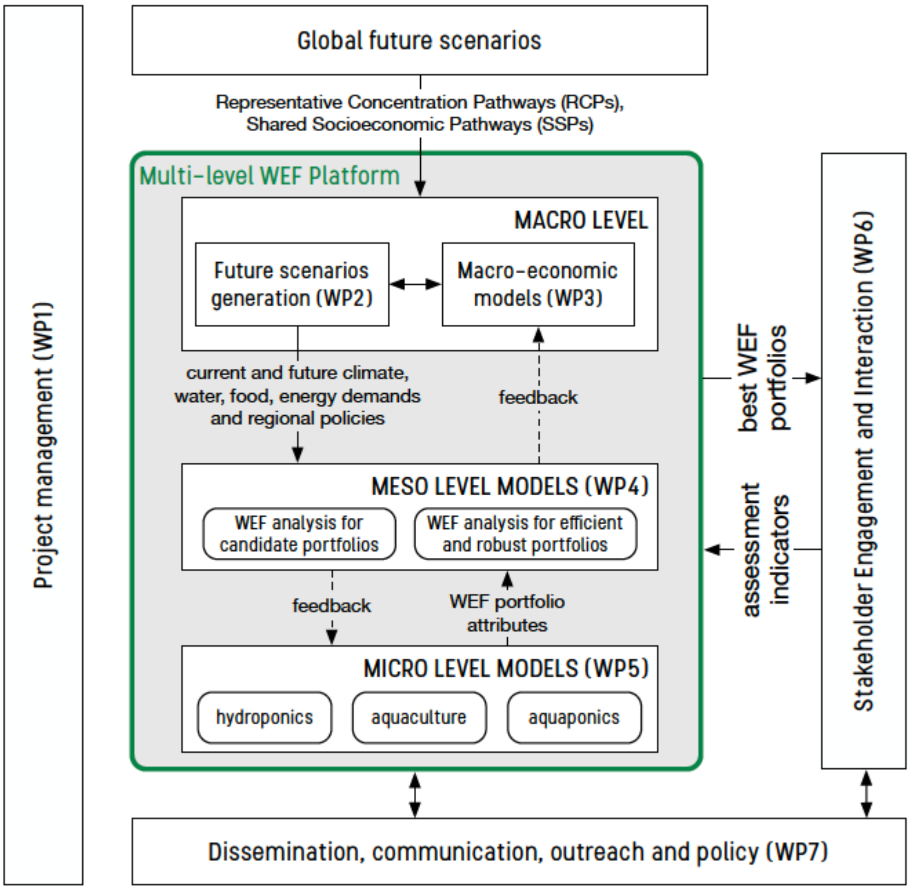


Figure 1 - AWESOME project structure

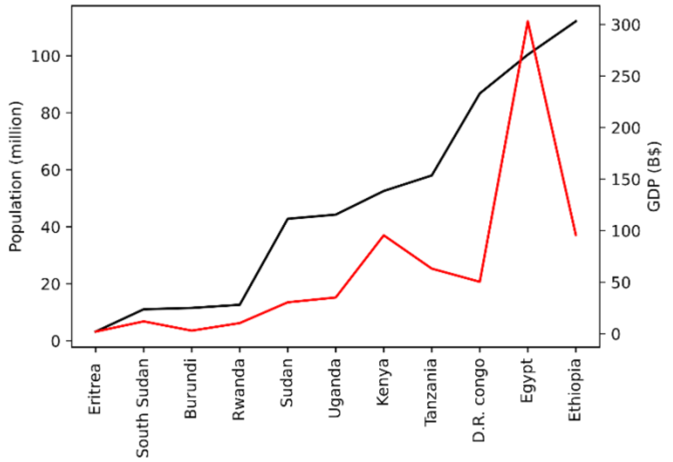


Figure 2 – GDP and population of countries within Nile River basin in 2019[3]

2. ENERGY SUPPLY AND DEMAND ASSESSMENT

2.2 ENERGY SECTOR IN AFRICA

Energy is at the base of modern life and its role is fundamental to run any economic activity. This becomes very challenging in contexts where the energy supply infrastructure is poor. Energy represents a key factor for poverty eradication and sustainable development in Africa. According to IEA World Energy Outlook 2020[4], more than 579 million people in Africa does not have access to electricity. Beside low access to electricity, Africa total energy supply highly depends on wastes and biomass as shown in **Figure 3**. Having high dependency on biomass energy resources, especially in the case of household's final demand, leads to daily exposure to noxious fumes, with adverse health impacts and social impacts, such as the burden of collecting fuelwood, falling heavily on women and children. Improvements in the energy system infrastructure in the area specially in power sector, represents the key factor to give access to clean energy to African population along with boosting economic growth in the area.

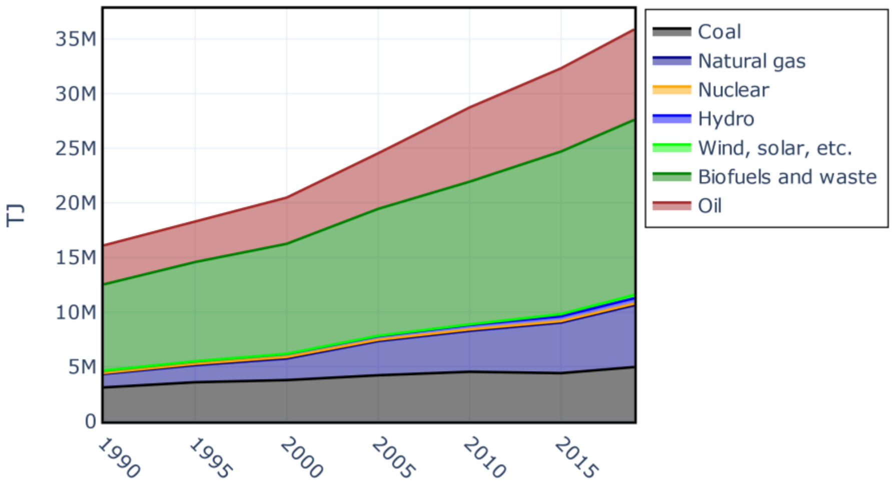


Figure 3- Total energy supply in Africa[5]

2.1.1 Egypt

Egypt is the third populated country in Africa and it is located in the north-eastern part of the continent (south Mediterranean). Compared to Ethiopia and Sudan, Egypt has an advanced energy sector infrastructure with more than 99% of the population having access to electricity[4]. Besides being one the most populated countries in the continent, Egypt has the biggest economy with 363 billion dollars of GDP in 2020[3]. Egypt's electricity production is highly dependent on fossil fuel (mainly natural gas) as shown in **Figure 4**.

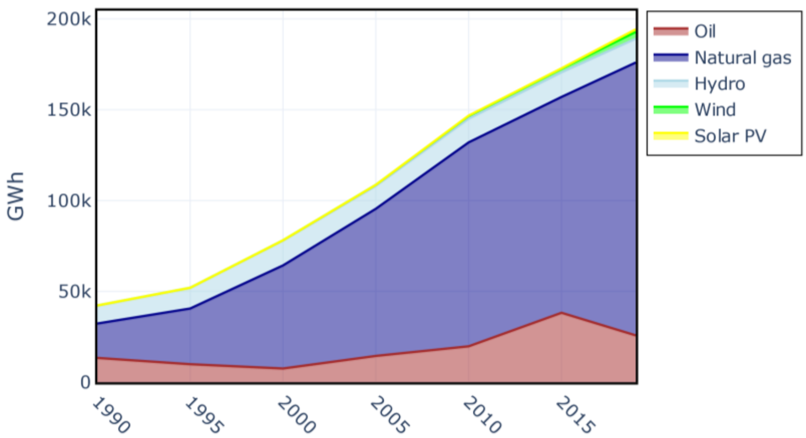


Figure 4 – Electricity generation in Egypt by source[5]

While the electricity mix highly relies on fossil fuels, the potential of renewable energy production in Egypt is relatively high. Diversification of the electricity generation mix with renewable sources could improve Egypt's energy security while giving the opportunity to increase gas exports and minimize the local environmental impacts.

2.1.2 Ethiopia

Ethiopia has currently one of the highest levels of economic growth in Africa with an average of 8% yearly growth while it still remains a low-income country[6]. In 2019 only 47% of the population had access to electricity, leaving more than 60 million people without access to it. Fast economic growth and ambitions towards 100% access to electricity, makes Ethiopia future energy sector planning one of the most important ones. Electricity generation in Ethiopia relies heavily on hydropower, as shown in **Figure 5,** which provides opportunities and threats. Very high dependency on hydro resources decreases the energy security due to low level of diversification in the energy production mix. On the other hand, it is the chance to have low-cost electricity production providing the potential for exporting electricity to other countries in the region.

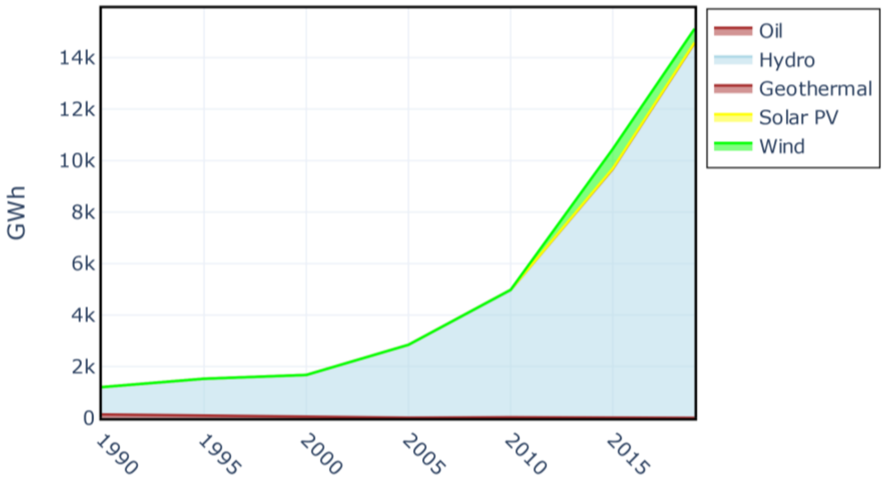


Figure 5 – Electricity generation in Ethiopia by source[5]

2.1.3 Sudan

In 2019, less than 50% of Sudan population had access to electricity. The situation is rapidly improving in the recent years[4]. Due to low economic productivity, the residential sector has the highest share of the electricity consumption, which is around 60% of the total final demand of electricity[5]. From the supply side point of view, the production mix in Sudan is highly undiversified, as it relies only on hydro and oil power production technologies as shown in **Figure 6**.

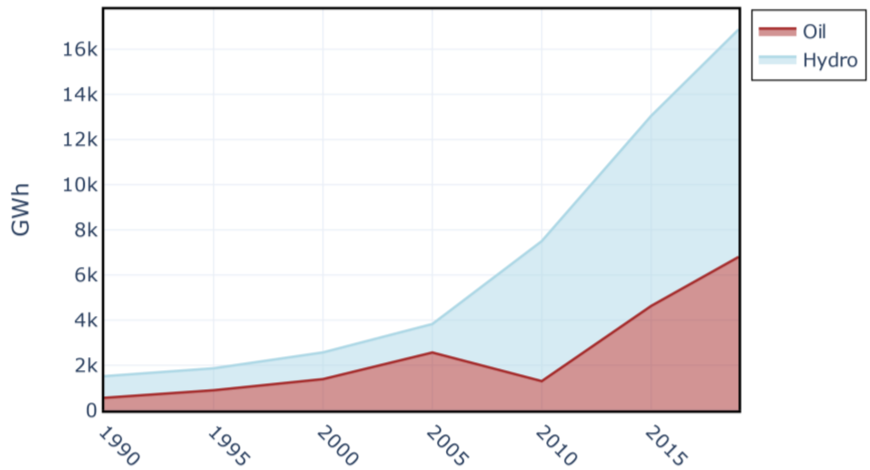


Figure 6 – Electricity generation in Sudan by source[5]

3. ENERGY MODELLING APPROACH

3.1 ENERGY MODELLING FRAMEWORK

Energy system models allow analysts to perform or form coherent scenarios of the energy supply chain from the extraction of natural resources to the final consumption of energy carriers. In the recent years, many different models have been developed trying to analyse the energy systems, using different approaches, to answer different questions, ranging from operational analysis of the energy systems to capacity expansion planning for the long term[7].

Considering the scope of the AWESOME project, different energy systems modelling frameworks may be effectively adopted, even though each of them are characterized by advantages and drawbacks. With reference to the project proposal, Calliope has been mentioned as the preferred modelling framework for the project[8]. While the latter is considered one of the most promising open-source modelling frameworks for energy system operational assessments, it is very demanding in terms of exogenous data requirements (e.g., the model has an hourly operational resolution, so; therefore, data related to hourly resources availability and hourly energy demand needs to be provided as exogenous parameters).

Because of recent developments of the AWESOME project, the scope of the project has been broadened in a way that further interaction needs to be considered within different work packages.

This motivated the team to use a different modelling approach to come along with the project needs such as future integrations with the meso-level model and the link with economic model of WP3, while also improving the quality of the interactions between the energy model and the others. As a consequence, the OSeMOSYS open-source energy modelling framework[9] is selected as the most promising approach to achieve the best quality and detail of the results in line with the project objectives. OSeMOSYS is a linear cost minimization energy system framework for long-run energy planning which calculates the least-cost, technically feasible solution that meets a given energy demands projections, while respecting a series of exogenous constraints. In essence, the exogenous parameters of the model are related to:

- The types and techno-economic characteristics of the available technologies (e.g., costs and performance parameters of different types of power plants) and available resources (e.g., availability of solar radiation, and cost of different fuels);
- Characteristics of transmission and distribution infrastructures within the given spatial domain;
- Projections of energy demands, assumed as perfectly rigid with respect to the changes in energy price;
- Other policy or technical constraints that may be required to define the scenarios (e.g., future decrease in renewable technologies investment cost, and political decision to ban a technology after a specific year).

One of the main advantages of this framework is the need of a lower detail in terms of data required to build an energy model. This peculiarity is the best choice for addressing the energy modelling for the African context.

3.2 AWESOME CASE STUDY

To pursue the scopes of Task 2.4, Egypt, Ethiopia, and Sudan are explicitly modelled in OSeMOSYS. The model focuses on the development of the power sector with rich technological detail and a high level of disaggregation of the power demand in the countries from 2015 to 2055. Regarding the time resolution of the model, every year is divided into four seasons and every day is subdivided in turn into three different time-slices[i], to consider the seasonal and intra-day variability of demand and resource availability. Such time resolution leads to a detailed definition, not only on the characterization of the power demand but also to a better description of the availability of natural

[i] Daily time-slices refers to intra-day time brackets such as day and night hours of a day.

resources such as water, sun, wind in different time-slices, which is crucial for an integrated assessment with the meso-level models (WP4).

The first step in developing a comprehensive energy system model for assessing future energy scenarios is the calibration process. The calibration of the model represents a validation step that must be performed with the aim to design more accurate results in terms of future capacity and production planning. As any other decision-making process, an energy model requires analysis of the past and present status of the energy sector. This implies that a considerable amount of historical data would be required. Although information requirements vary from one application to another, to develop an energy model for a specific context, the following information is necessary[10]:

- Energy use by various economic activities
- Energy production, transformation, and delivery to various users
- Technical and operating statistics of the plants and installations
- Financial and cost information
- Country-based macro-economic and technical parameters.

Accordingly, for 2015 to 2018, the techno-economic parameters such as capital cost, fixed cost, fuel cost, variable O&M cost, efficiencies are defined for every power production technology. The power demand of every specific category of end-user like households, industries, and agriculture sector of the regions is calibrated based on historical data, considering the shape of the consumption during the time-slices. While on the production technologies, the model needs to be calibrated with higher details. Starting with the technology availabilities, it is necessary to define the availabilities of every technology in different regions. Although for conventional power plants, the availabilities are not generally dependent on the location, non-conventional power plants availability changes considerably based on the location. Similarly, the historical capacity stock and the production of the technologies per country, should be calibrated. Despite the lack of solid data, different sources are used to structure the historical capacity evolution and production for the given time-horizon (2015-2018).

3.2.1 Temporal resolution

To be in line with other projects' modelling frameworks, the time horizon of the energy model is 2020 – 2050. The model is calibrated in the period within 2015 and 2018 (due to the lack of data for 2019), while the end of the time horizon is extended by 5 years (from 2050 to 2055) to allow the model to plan investments for capacity expansion also in the last modelling period. While the model is built based on a yearly time-step, every year is divided into different time-slices. Finer time-slices are crucial from different perspectives. Better definition of the energy consumption shape and the availability of energy resources, specifically the VRES, are the most important reasons for finer time-slices in the model. Consequently, every year is split to four different seasons. Moreover, every day is split into three time-slices as the daytime profile has a very strong impact on the power consumption share and the availability of resources. As the model estimates the maximum energy available from every production technology based on the equivalent hours (number of hours that a technology can produce power with its maximum capacity), it is crucial to define the number of hours in every time-slices. **Table 1** shows the definition of the four seasons in the model.

Table 1 – Definition of seasonal time-slices in the model

Month	Days per month	Season	Days per season
January	31	S1	90
February	28		
March	31		
April	30	S2	91
May	31		
June	30		
July	31	S3	92
August	31		
September	30		
October	31	S4	92
November	30		
December	31		

Regarding the daily time-slices, considering the share of the power load and the availability of resources in different hours of the day, three time-slices are defined, as represented in **Table 2**.

Table 2 – Definition of daily time-brackets

Daily time-slice	From-To	Number of hours
D1	04:00 - 16:00	12
D2	16:00 – 20:00	4
D3	20:00 – 04:00	8

3.2.2 Supply technologies

Power production technologies of the model should be in line with the current power generation structure of the countries and possible future technologies. Moreover, the availability of data for the model calibration is an important factor to be taken into consideration. In most of the databases, the technologies are classified without high details in terms of technical specifications. For example, the IEA database considers only one type of wind generation technology without differentiating between different types of wind generation technologies, such as on-shore and off-shore ones. As a result, highly detailed technologies may lead to a lack of appropriate data. Moreover, the aggregated definition of the technologies would lead to inappropriate definition of technologies characteristics such as costs and efficiencies. Besides the definition of power production technologies, transmissions and distributions technologies need to be modelled. The model is implemented based on the technologies listed in **Table 3**.

Table 3 – Technology resolution in the model

Technology	Acronym
Nuclear Power Plants	nuclear_pp
Oil Power Plants	oil_pp
Coal Power Plants	coal_pp
Natural Gas Power Plant	ng_pp
Concentrated Solar Power Plants	cs_pp
Wind Power Plants	wind_pp
Geothermal Power Plants	geo_pp
Hydro Power Plants	hydro_pp
On Grid Photovoltaic	pv_on
Off Grid Photovoltaic	pv_off
Biomass Power Generation	bio_pp
Uranium Extraction or Import	uran_extract
Oil Extraction or Import	oil_extract
Coal Extraction or Import	coal_extract
Natural Gas Extraction or Import	ng_extract
Transmission Technologies	transmission
Distribution Technologies	distribution

Considering the technologies listed in the table, the life cycle of the power production in a closed energy system (energy system of a single country without considering the trades) can be schemed as **Figure 7** (also called Reference Energy System (RES)).

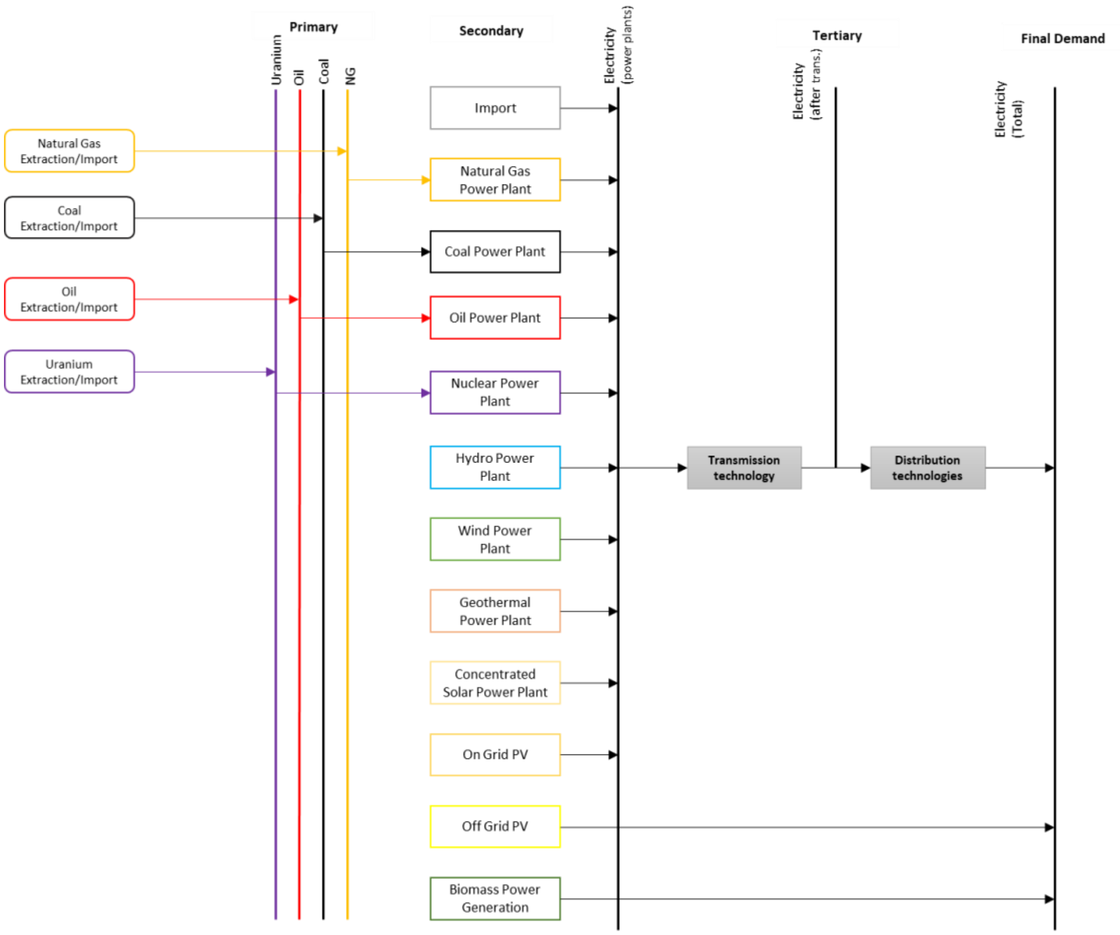


Figure 7 – Single Region RES

The term *primary* shown in the **Figure 7**, is used to designate an energy flow that is extracted from stock of natural resources or captured from a flow of resource and that has not undergone any transformation or conversion other than separation and cleaning[11]. Examples include coal, crude oil, uranium, natural gas, and other natural resources. *Secondary* energy on the other hand refers to any energy obtained from a primary source employing a transformation or a conversion process. Thus, electricity is accounted as a secondary commodity as it requires conversion technologies to be produced. The secondary commodities then should be transmitted and distributed to the end-users. The term tertiary defines the energy commodity passed by the transmission or distribution lines from the conversion technologies to the end-users.
Besides the detailed structure of the RES for a single region, the definition of trades of electricity between countries is crucial. **Figure 8** illustrates the trade connections between the regions of the

model and shows clearly that the flow of electricity exports and imports will occur through the transmission lines of every single region within the energy model.

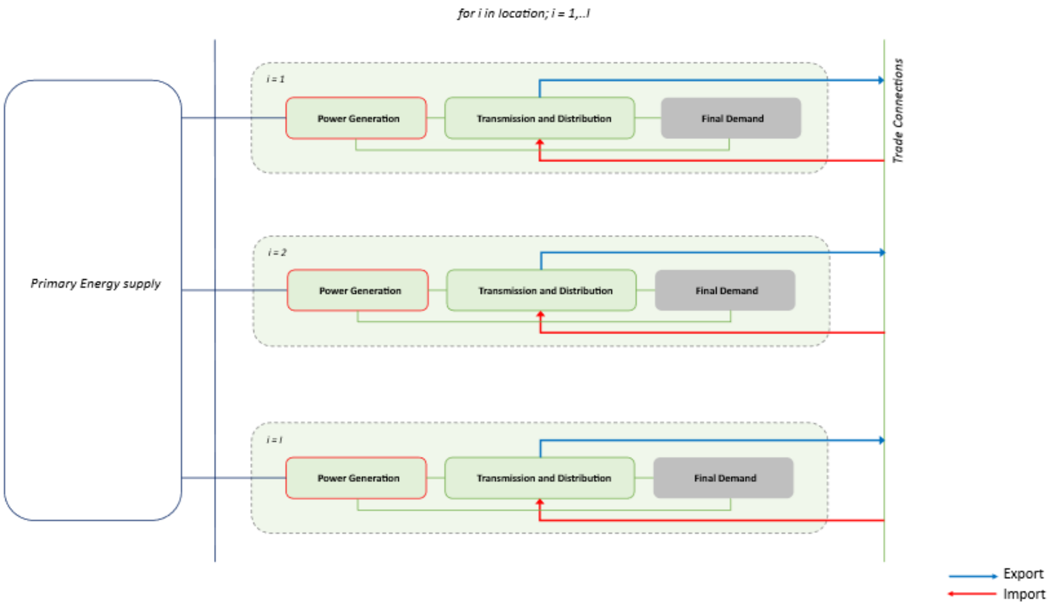


Figure 8 – The structure of the electricity trade between the three countries

3.2.3 Techno-economic parameters

For the definition of an energy system within OSeMOSYS framework, the techno-economic parameters need to be identified. The values for every specific parameter are listed in Annex I.

Discount Rate: The discount rate is the degree at which the future values are discounted to the present. The discount rate is used to compute the present value of all costs and reimbursements, so that they can be compared. OSeMOSYS is an energy system optimization framework, which minimizes the net present cost, which is the total discounted cost of the system. While there are scientific approaches to estimate the discount rate, many assumptions must be set. Moreover, only one discount rate is used at a point in time to find the net present cost, while this parameter is changing overtime, with wide variations in the case of African countries. Due to uncertain and risky nature of the energy investments in the context of African countries, high values of discount rate are usually used for energy models in Africa [6,12–14]. As the primary input, discount rate is considered 10% which is close to the stable discount rate in Egypt from 2002, as shown in **Figure 9**.

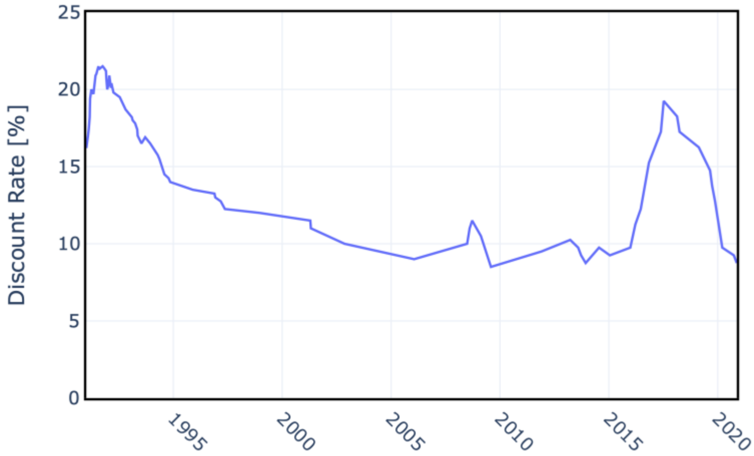


Figure 9 – Historical discount rate in Egypt [13]

Operational lifetime: The operational lifetime of a technology defines the number of years, from the installation year, in which the technology will be dismantled.

Efficiency: The efficiency of a technology defines the conversion ratio of an energy carrier to another one. The conversion technologies produce electricity consuming some natural or primary resources. As for the renewable technologies, the fuel cost is null, the efficiency is not defined for them.

Costs: For each technology, the components of the overall cost must be detailed as capital, fixed and variable costs. The capital cost represents the technology investment cost, per unit of technology installed capacity. The fixed cost is the O&M cost of a technology in each year per unit of capacity stock. The variable cost of a technology can be defined based on the fuel cost.

Availability Factor: Availability factor defines the capacity available on average over one year, expressed as a fraction of the total installed capacity. It should not be confused with the capacity factor. The capacity factor for a given period can never exceed the availability factor for the same period. The differences arises when the capacity of the plant is not fully exploited, in which case the capacity factor is less than the availability factor. Typically, the term availability factor is used for power plants dependent on an active, controlled supply of fuel, typically fossil or nuclear. The emergence of variable renewable energy, such as hydro, wind and solar power stations, which operate without an active, controlled supply of fuel and comes to a standstill when their natural supply of energy ceases, requires a more careful distinction between the availability factor and the capacity factor. By convention, such zero production periods are counted against the capacity factor instead of availability factor. In our case, due to the lack of data for the availability of water resources on different countries, for the calibration phase, an average availability factor for the hydro resources is considered. This assumption can be modified in the future based on the possible integrations with the Meso-Level model.

Capacity Factor: Capacity factor should be defined over the different time-slices characterizing the model, to consider the variability of the resources. Due to the level of aggregation of the model (where the whole country is considered as a single node) the capacity factor of the technologies should be an estimation of the average availability of the resources over the country. To calibrate this parameter, average hourly capacity factor for every country is collected based on historical data. As the mode has not an hourly time resolution, the average capacity factor for the defined time slices should be calculated based on the definition of the time slices.

3.2.4 Historical calibration

To have more accurate results in terms of future power system configuration, the energy model needs to be well calibrated for a historical period in terms of stock of capacity and power production by source. The lack of solid historical data for the model spatial scope makes the possibility of high detailed calibration a very difficult task and multiple sources with different categorizations of technologies are used to derive an estimation of the capacity stocks. Starting with Egypt, which has the highest availability of data, the capacity stocks of different power plants in the calibration time horizon are collected in **Table 4** from three different sources of data. As it can be seen in Table 4, the data for every year are divided into three different columns by different sources and the last column named Final, shows the values used for the model calibration. NA (Not Available) shows the case where the data was not available in one of the sources. As it can be seen, different sources of data, have different level of technological aggregations. For example, UN database[15], considers oil fuel, coal fuel, natural gas fuel and biofuel power plants as a single category called combustible power plants. Referring to the IEA data[5] on the electricity production for the country, it can be seen that there is considerable amount of electricity produced from oil, while regarding the data provided by the government, there is no installed capacity of oil fuel power plants. This is due to the fact, that in some years, the shortage of natural gas for the power plants, some of the natural gas fuel power plants have been fed by oil. As a result, no capacity existed for the oil fuel power plants. While for Egypt, the data are provided by the government, for Sudan and Ethiopia, the only reliable sources of data are the UN database[15], IRENA database[16], and IEA database[5]. Moreover, using the level of production of different technologies based on the three databases, the disaggregated values for the technologies are estimated. The following tables show the data collected from different sources and the final data used for the calibration for Ethiopia and Sudan.

Table 4 – Stock of capacity [GW] in Egypt[15–17]

	2015				2016				2017				2018			
	UN	Government	IRENA	Final	UN	Government	IRENA	Final	UN	Government	IRENA	Final	UN	Government	IRENA	Final
nuclear_pp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
oil_pp	32420	0	NA	0	32420	0	NA	0	42008	0	NA	6000	51424	0	NA	0
coal_pp		0	NA	0		0	NA	0		0	NA	0		0	NA	0
ng_pp		31734	NA	31734		35170	NA	35170		41321	NA	41321		51224	NA	51224
bio_pp		0	67	67		0	67	67		0	67	67		0	67	67
cs_pp	140	140	20	140	140	140	20	140	140	140	20	140	190	140	20	140
pv_on		147	25	147		147	48	147		147	169	147		647	750	647
pv_off		0		0		0		0		0		0		0		0
wind_pp	547	540	750	540	747	740	750	540	747	940	750	540	967	1360	1125	540
geo_pp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hydro_pp	2800	2800	2850.8	2800	2800	2800	2850.8	2800	2800	2800	2850.8	2800	2832	2800	2850.8	2800

Table 5 – Stock of capacity [GW] in Sudan[15,16]

	2015			2016			2017			2018		
	UN	IRENA	Final	UN	IRENA	Final	UN	IRENA	Final	UN	IRENA	Final
nuclear_pp	0	NA	0	0	NA	0	0	NA	0	0	NA	0
oil_pp	1717	NA	1527	1935	NA	1745	2004	NA	1814	2013	NA	1823
coal_pp		NA	0		NA	0		NA	0		NA	0
ng_pp		NA	0		NA	0		NA	0		NA	0
bio_pp		190	190		190	190		190	190		190	190
cs_pp	11	0	0	12	0	0	13	0	0	18.6	0	0
pv_on			0			0			0			0
pv_off		11.1	11.1		12.3	12.3		12.6	12.6		17.6	17.6
wind_pp	0	0	0	0	0	0	0	0	0	0	0	0
geo_pp	0	0	0	0	0	0	0	0	0	0	0	0
hydro_pp	1593	1593.2	1593.2	1593	1593.2	1593.2	1753	1928.2	1928.2	1907	1928.2	1928.2

Table 6 – Stock of capacity [GW] in Ethiopia[15,16]

	2015			2016			2017			2018		
	UN	IRENA	Final	UN	IRENA	Final	UN	IRENA	Final	UN	IRENA	Final
nuclear_pp	0	0	0	0	0	0	0	0	0	0	0	0
oil_pp	143	NA	1.4	99.2	NA	1.4	104	NA	1.4	104	NA	1.4
coal_pp		NA	0		NA	0		NA	0		NA	0
ng_pp		NA	0		NA	0		NA	0		NA	0
bio_pp		141.6	141.6		141.6	141.6		141.6	141.6		166.6	166.6
cs_pp	9.84	0	0	13.94	0	0	12.19	0	0	11.2	0	0
pv_on			9.8			13.9			12.2			11
pv_off		9.8	0		13.9	0		12.2	0		11	0
wind_pp	324	324	324	324	324	324	324	324	324	324	324	324
geo_pp	7	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
hydro_pp	1940	2158.7	2158.7	3807.6	2158.7	2158.7	3814	3817.3	3817.3	3814	3817.3	3817.3

Besides the calibration of the stock of capacities, the technologies production must be also calibrated due to two main reasons. First, checking the feasibility of the problem (if the stock of capacity can cover the reported production levels and total demand of electricity) and second, better definition of the availability and capacity factors. Using IEA, UN, IRENA, and government data (if available), an estimation of historical production level is used for the calibration. More detailed data on the historical production of technologies are available in the Annex I. **Figure 10** shows the calibrated production and demand for every country. The differences between the values for total production and total demand can be related to:

- Losses of the transmission and distribution
- Energy industry own uses
- Statistical differences and errors due to using different sources of data.

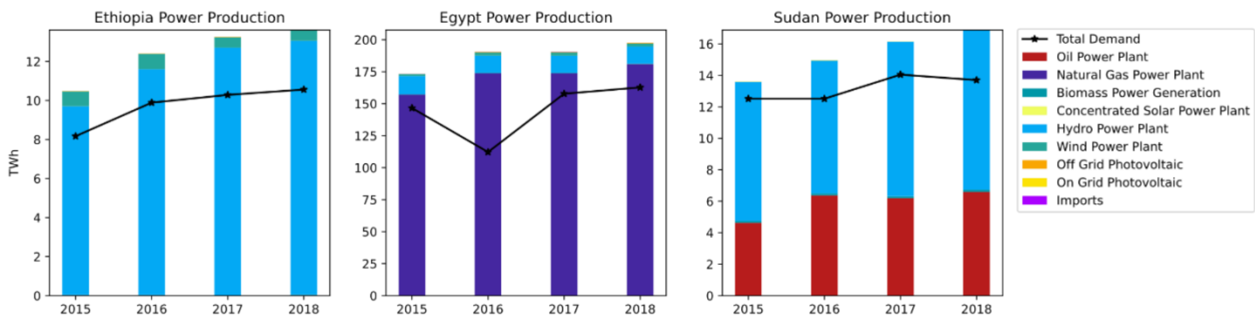


Figure 10 – Calibrated production and demand for historical period

4. DEMAND PROJECTION

4.1 DEFINITION OF ENERGY DEMAND

The term "Energy Demand" normally refers to any sort of energy used to fulfil individual energy needs such as cooking, heating, and traveling, in which, energy commodities are used, as fuel. Energy commodities can also be utilized as raw materials in some industries, such as petrochemical industries, which is out of the scope of the AWESOME energy model.

There is a clear distinction between energy consumption and energy demand. Energy demand represents a relationship between an economic variable, like income or price, and quantity of energy. In the other words, energy demand exists before the consumers make purchasing decisions and it shows which quantities will be purchased at a given economic variable and how the change of the variable would impact the demand. Energy consumption, on the other hand, is defined as the energy purchased and consumed. Even though there are basic differences between these two terms, they are interchangeably used in this report assuming a perfect elastic energy demand and e relation. For the sake of the AWESOME project, future GDP projections are used as the economic variable to estimate the demand of energy, using the Input-Output based economic approach.

This section intends to provide the methods that are used for this task, to estimate the future energy demands of the countries.

4.2 ECONOMIC PROJECTIONS

4.2.1 Model

The level of economic activities, besides their energy consumption intensities, are the main identifiers of energy demand by industries. For the households, on the other side, the income and some behavioural factors will define how the energy will be required. Contrary to econometric approaches, which estimate the future demand of energy for the aggregate level of economic activities, in this project, energy demand needs to be analysed at a disaggregated level. For this purpose, we choose a Leontief Input-Output framework[18].

An IO model is grounded on IOTs, which provides comprehensive overview of a national economy or a set of national economies, in a defined time frame, which is usually one year. IOTs are grounded on empirical data, expressing the value of goods and services exchange among industries, provided as sectoral investments, and invoked by households for final consumption. Linear and non-linear planning optimization models based on the IO framework are widely adopted for different environmental and economic assessments[19].

In this case, a multi-sectoral optimal resource allocation model is adopted, also known as linear programming model, which is extensively described in the literature[20–22], and its underlying assumptions can be deeply customized based on data availability and the complexity of the market mechanism to be modelled. Specifically, the model selected, is based on a constant input-output technology structure, which is referred as the Leontief technology assumption, and on a fixed final demand structure, known as *Kantorovich* assumption. This model implies no technological change, no substitutability between inputs and a perfect elasticity of the demand with respect to the price changes. Consistently, it will be referred to as the *Leontief-Kantorovich* model [23].

Considering one generic national economy with n sectors, l final demand categories (such as households' and government expenditure, investments, and exports), k factors use categories (such as labour, capital, rents and loyalties, and taxes), and j environmental transactions (for example: primary energy use, water use, and CO_2 emissions), the IO database will be constituted by the following matrices:

Table 7- Description of the data in Input-Output database

Matrix	Name	Dimension	Description
Z	Intermediate transaction flow matrix	$(n \times n)$	Represents the supply and consumption of goods and services among industries
Y	Final demand matrix	$(n \times l)$	Represents the consumption of goods and services by final users
V	Factors use matrix	$(k \times n)$	Represents the use of factors by industries
E	Environmental transaction matrix	$(j \times n)$	Represents the production and consumption of environmental factors by industries

Based on the fundamental national production balance, the total economic production by sector, represented by X $(n \times 1)$, can be expressed by Equation (1).

$$Zi_{n\times 1} + Yi_{l\times 1} = X \qquad (1)$$

Where i vectors are known as summation vectors.
Based on the data represented in **Table 7**, coefficient matrices, which represents the structure of the economy, can be identified as shown in **Table 8**. It should be noted that small letters of any previously defined nomenclature represent coefficients, while the capital ones indicate the flows.

Table 8 – Description of coefficient matrices

Matrix	Name	Dimension	Description
$z = Z\hat{X}^{-1}$	Technical coefficient matrix	$(n \times n)$	Represents the supply and consumption of goods and services among industries for a unit production of industries
$y = Y(\widehat{Yi_{l\times 1}})^{-1}$	Final demand basket coefficients	$(n \times l)$	Represents the share of goods and services by final users with respect to whole final demand

Matrix	Name	Dimension	Description
$v = V\hat{X}^{-1}$	Factors use coefficient matrix	$(k \times n)$	Represents the use of factors by industries for a unit production of industries
$e = E\hat{X}^{-1}$	Environmental transaction coefficient matrix	$(j \times n)$	Represents the production and consumption of environmental factors for a unit production of industries

Having all the data, a *Leontief-Kantorovich* model can be specified for every specific year (t), as a linear optimization problem, as follows:

$$
\begin{aligned}
&MAX(s) \\
&s.t.: \\
&\quad (I - z)X_t \geq y.s \\
&\quad v\widehat{X_t} \leq V_t \\
&\quad e\widehat{X_t} \leq E_t \\
&\quad X_t \geq 0, s \geq 0
\end{aligned}
\qquad (2)
$$

Where s is a scalar variable representing the total demand of final users in the economy (final user expenditure), I is the identity matrix, X is the production variable, E_t and V_t are the available resources in terms of environmental resources and economic factors, assuming that the structure of economy (represented by y, v, e, and z) is not changing. Constraint a represents the constraint on the production to cover the intermediate demand and final demand, while b and c represent the constraints on the availability of resources and factors, and constraint d avoids negative non-sensical results. These assumptions can be modified, and new constraints can be added to the model for different purposes.

The model intends to find the optimum solution by maximizing the final user's expenditure, respecting the production balance in the economy and the availability of the resources. Due to the nature of the Input-Output model, sectoral activity projections can be derived and used for energy demand estimation. Next sections will provide a detailed description of such approach.

4.2.2 Input-Output data

The Input-Output tables has long been used for economic and energy analysis[24–27], as they provide a consistent framework of analysis and can capture the contribution of economic activities through inter-industry linkages in the economy. As discussed in section 4.2.1 Model, this study relies on input-output framework for the projection of future sectoral demand. While for many countries, input-output tables are available and published regularly by governments, for specific spatial context of this model, the data usually are not provided by governments. In the lack of such accessibility, we rely on data provided by EORA database [28,29]. Single region databases of the three target countries for the reference year of 2015 are utilized and aggregated to the same level of the energy model scope, with the aim to estimate the sectoral energy demand.

4.2.3 GDP and sectoral production projections

The *Leontief-Kantorovich* is a linear optimization problem aiming to maximize the nation expenditure exploiting the resources and factors available in the economy. From different constraints that can be subjected to the model, GDP is used for this project. GDP can be calculated as the sum of all the factors used in the economy namely $Vi_{k\times 1}$. Moreover, no specific constraints on the environmental resource are considered. Consequently, Equation (2) can be rewritten as follow:

$$
\begin{aligned}
& MAX(s) \qquad (3)\\
& s.t.:\\
& \quad (I-z)X_t \geq y \cdot s\\
& \quad vX_t \leq GDP_t\\
& \quad X_t \geq 0, s \geq 0
\end{aligned}
$$

Data for GDP evolution for Egypt and Ethiopia are taken from D2.1 report, while for Sudan, data are taken directly from SSP database[30] as it was not covered in the report. SSPs are scenarios of global socioeconomic projections up to 2100. These scenarios are:

- SSP1: The green road scenario (Sustainability)
- SSP2: Middle of the road scenario
- SSP3: The rocky road scenario (Regional Rivalry)
- SSP4: A road divided scenario (Inequality)
- SSP5: Fossil-fueled development road

The GDP data are represented in **Figure 11**.

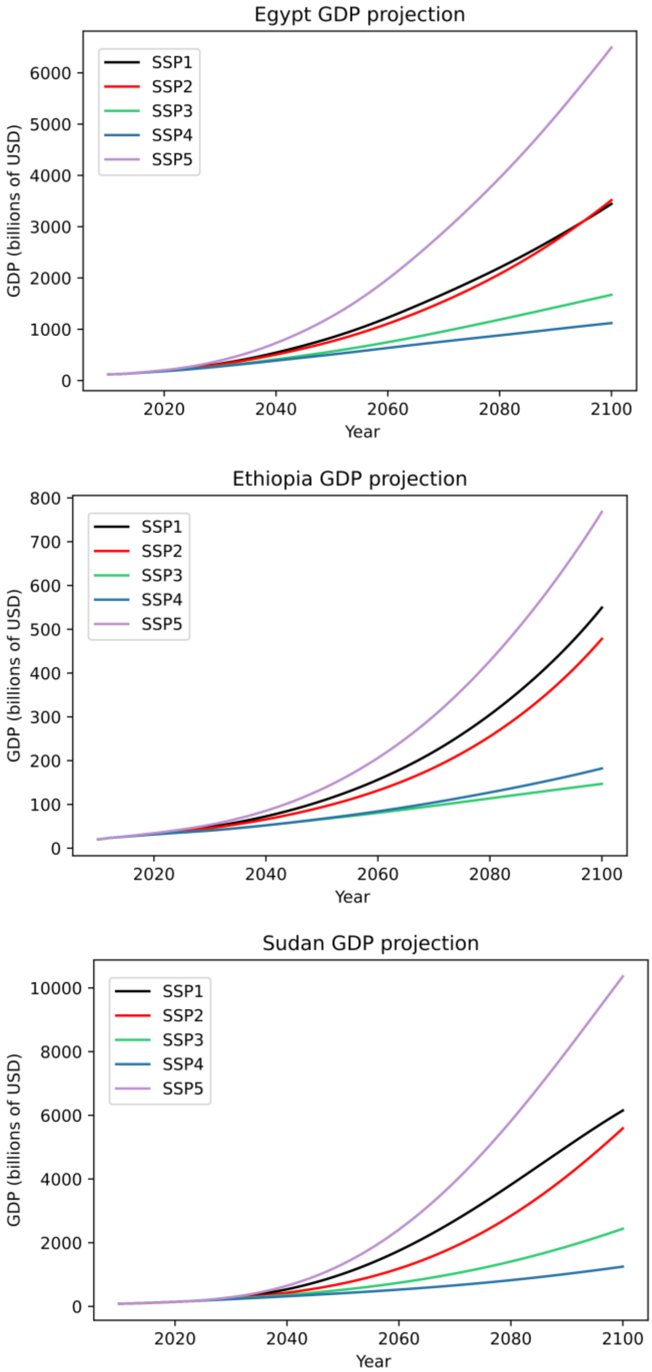


Figure 11- GDP projections for Egypt, Ethiopia, and Sudan

As an example, the sectoral production projections for scenario SSP5 are represented in **Figure 12**.

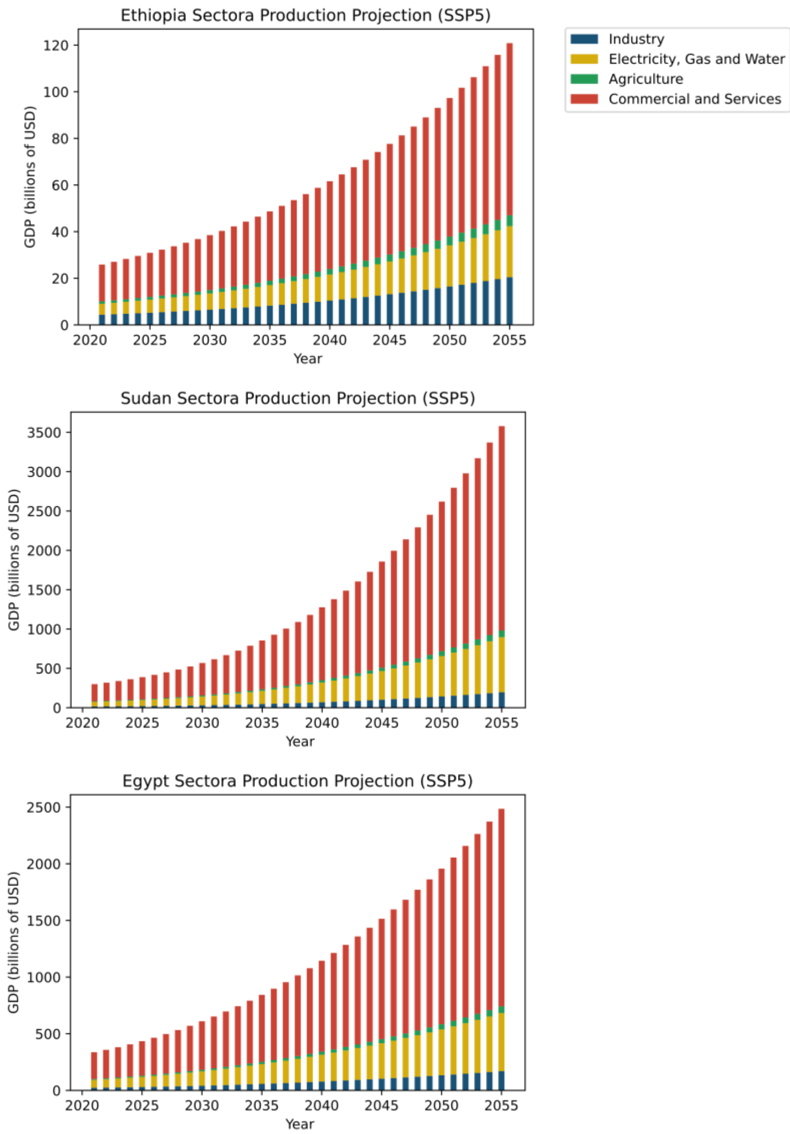


Figure 12- Sectoral Production projection for SSP for Egypt, Ethiopia, and Sudan

Sectoral productions can be used to estimate the sectoral demand of power using the Factor (or Decomposition) Analysis, which will be described in the following section.

4.2.4 Factor (or Decomposition) Analysis

This method aims estimating the future energy requirements by analysing the factors affecting the energy demand. This particular method, known as decomposition method, has been widely used [31]. Generally, the method relies on assessing the changes of the energy demand arising from:

- Changes in economic activities (the activity effect)
- Changes in technological efficiency of energy use at the sectoral level (the intensity effect)
- Changes in the economic structure (the structural effect)

The activity effect captures the influence of the changes in the economic activity of the country, assuming that other factors do not change. Economic activities, captured by the output generated in an economy, do not remain constant between two periods.

Structural change within the economy refers to shifts in the shares of economic activities at sectoral level. For example, many developed countries have moved from energy intensive industries to service-related activities.

The intensity effect captures the role of changing intensities within the sectors. Technical energy efficiencies are the major determinants of energy intensities and changes in the processes and product mixes affect the energy intensities of industries. For the sake of this project, the last two effects are not considered, assuming the energy intensity of industries and the structure of economy remains constant. This assumption can be modified in case of integration of the energy model with a specific economic model like the CGE model applied by WP3.

The framework for analyzing the changes in the energy consumption between the two time periods is based on the simple relation (Equation *(4)*):

$$E = \sum_{i} (EI_i Q_i) \tag{4}$$

Where, EI_i is the energy intensity in sector i and Q_i is the economic activity in sector i. As previously mentioned, the contribution of every factor to the overall change is analysed by looking at how the factor under consideration has varied over time, while keeping the other factors constant. As in this study, only the effect of economic activities matters, the change of energy between periods t and period 0 will be:

$$\Delta E = \sum_{i} (Q_i^t - Q_i^0) EI_i^0 \tag{5}$$

While sectoral economic activities are projected by the Leontief-Kantorovich model, the intensities need to be identified based on a reference year for different sectors and final users in every country.

Based on the last comprehensive data available for the country, the intensities are calculated for 2015. As discussed in MS6, the lack of appropriate data can lead to considerable errors in the definition of the model. Based on the data reported by IEA[5] and the outputs of the model, the energy intensities (just for power) are reported in **Table 9** for 2015.

Table 9 – Energy intensities (GWh/billion USD)

Demand category	Ethiopia	Egypt	Sudan
Industry	643.3	2474.7	128.2
Agriculture	0.0	1154.9	221.7
Commercial and Services	183.2	213.5	13.7
Residential	200.8	362.2	61.9

4.2.5 Sectoral demand projection

Based on the results derived in previous sections for sectoral production projections and the energy intensities, sectoral demands can be projected for different SSP scenarios using Equation (5). The results for SSP1 are depicted **Figure 13** in for different regions.

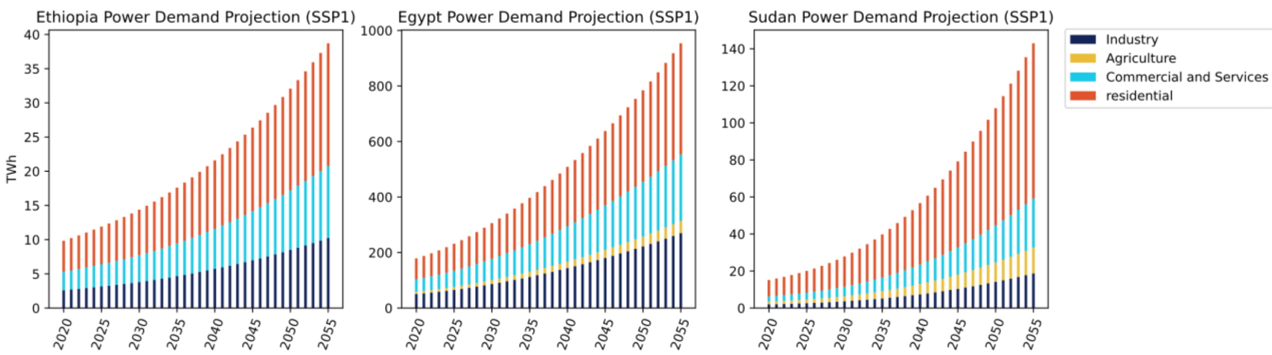


Figure 13 – Demand projections for SSP1 scenario

5. ENERGY SCENARIOS

5.1 SCENARIO DEFINITION

The energy demand is the main driver of the energy model; thus, the scenarios should be projected with the energy demand projections. While five different pathways may be considered from the SSPs, three scenarios namely SSP 5 (highest demand projection), SSP 4 (lowest demand projection) and SSP 2 (middle road demand projection) are chosen. Beside the three SSPs, a business-as-usual scenario defined by current policies is considered. In this scenario, the demand is estimated by 3.8% annual increase based on IEA world energy outlook[32]. Beside the demand scenarios, three different policy and cost scenarios are considered. Within these scenarios, we will analyse the impact of multiple parameters such as the cost of renewables in future, the discount rate, the role of carbon tax policies and the fossil fuel phase out on energy situation of the three regions. While **Table 10** lists the energy projection scenarios, policy and cost scenario are described in **Table 11**.

Table 10 – Future demand projection scenarios

Demand Scenario	Acronym
Current Policy	CP
Shared Socioeconomic Pathways 2	SSP2
Shared Socioeconomic Pathways 4	SSP4
Shared Socioeconomic Pathways 5	SSP 5

Table 11 – Policy and cost scenarios definition

Scenario	Renewable cost	Discount rate	Emission penalty	Fossil fuel new investment phase out
A	25% yearly reduction until 2030	15%	30$/ton and 2.5% yearly increase till 2050	After 2040
B	50% yearly reduction until 2030	5%	40$/ton and 2.5% yearly increase till 2050	After 2035
C	70% yearly reduction until 2030	2.5%	50$/ton and 2.5% yearly increase till 2050	After 2025

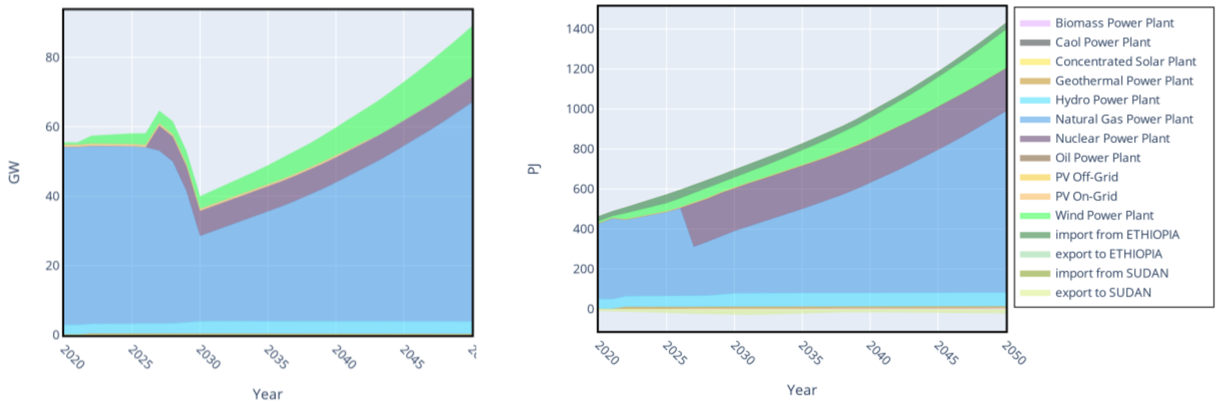
In all the scenarios considered, the total production, or capacity of specific technologies in different countries, are limited based on the availability of natural resources as shown in **Table 12**.

Table 12 – Maximum capacity / production of VRES in the area[33]

Country	Hydro Power (TW)	Solar PV (TWh/y)	Wind (TWh/y)	Geothermal (TW)
Egypt	3.664	32218	685	n/a
Ethiopia	46.500	27154	3002	5
Sudan	4.947	87817	9837	0.4

5.2 CURRENT POLICY SCENARIO (BAU)

The evolution of the power generation mix of each country is highly dependent on the availability of the primary resources within it. Firstly, considering Egypt, the installed capacity will reach approx. 86 GW in 2050, as illustrated in **Figure 14**. This capacity will be dominated by the electricity generated from natural gas power plants with a limited share of renewables (7%); specifically, hydro and wind resources. While wind is an economically profitable option in the production mix, solar power production technologies are not emerging considerably mostly due to the lower capacity factor of the technology during nights, which coincides with the peak in the electricity demand. As shown in the same figure, there is a decrease in the installed capacity between the period that starts in 2026 until 2030. That could be justified by the fact that, Egypt has installed a 14.4 GW high-efficiency natural gas fired power plants in 2018; such capacity exceeds the assumed peak demand under this scenario until 2030. By 2027, nuclear power will appear in the Egypt's power generation mix, due to an imposed capacity constraint, i.e., Egypt currently executes a project to install 7.2 GW nuclear power plant. However, the economic viability of that option might be questionable, as nuclear power plants do not exist in any of the assumed scenarios. Furthermore, the least cost power generation mix will include imports and exports from other regions, as shown in the same figure. The availability of cheap electricity from hydro resources in Ethiopia, makes this country a candidate for Egypt to import electricity and cover a part of its demand.

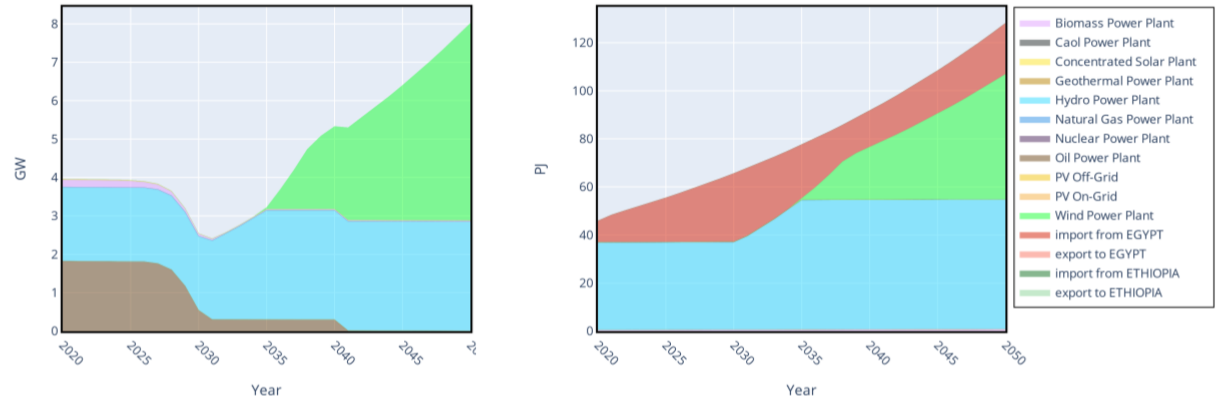


(a) (b)

Figure 14 – Egypt total installed capacities (a) and electricity generation mix by technology (b)

It is worth to note that reaching a renewable target set by the government of Egypt 22% and 40% in 2022 and 2040, respectively, is not attainable, if wind and hydro resources are the only renewable sources to be considered. However, Egypt has a vast solar resource that could be exploited to increase the renewables share in the power generation mix, the pattern of its electricity demand hinders the exploitation of those solar resources, i.e., the peak power occurs in night hours. Therefore, it might be essential to impose new demand-side policies to change the pattern of the electricity demand curve.

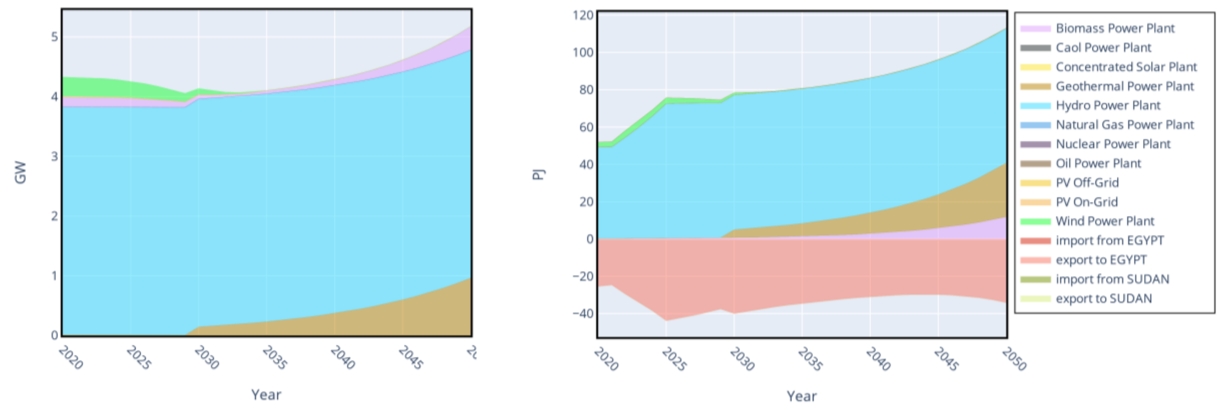
Secondly, considering Sudan, under the assumption of the CP scenario, the total installed capacity of in the country will reach 8 GW, dominated by hydro and wind resources. However, Sudanese power generation mix currently includes oil-fired power plant and their exploitation does not contribute to the least cost power generation mix. As illustrated in **Figure 15**, this could be justified by the fact that the hydro, wind, and imports from Egypt are cheaper than running oil power plant. Since Egypt has an installed capacity that exceeds its demand, it is cost effective for the optimization model to partially exploit that additional installed capacity in Egypt to satisfy part of the Sudanese demand.



(a) (b)

Figure 15 - Sudan total installed capacities (a) and electricity generation mix by technology (b)

Thirdly, given to vast renewable resources available in Ethiopia, the total installed capacity in Ethiopia under the assumption of this scenario will reach 5.3 GW, composed of hydro, geothermal, biomass, and wind, as shown in **Figure 16** (a), the phasing out of the Wind power plants technology is solely due to economic consideration, i.e. electricity produced from Geothermal and Biomass technologies are cheaper. As before, the solar technologies are absent from both Sudanese and Ethiopian electricity mix due to the assumed pattern of the electricity demand.



(a) (b)

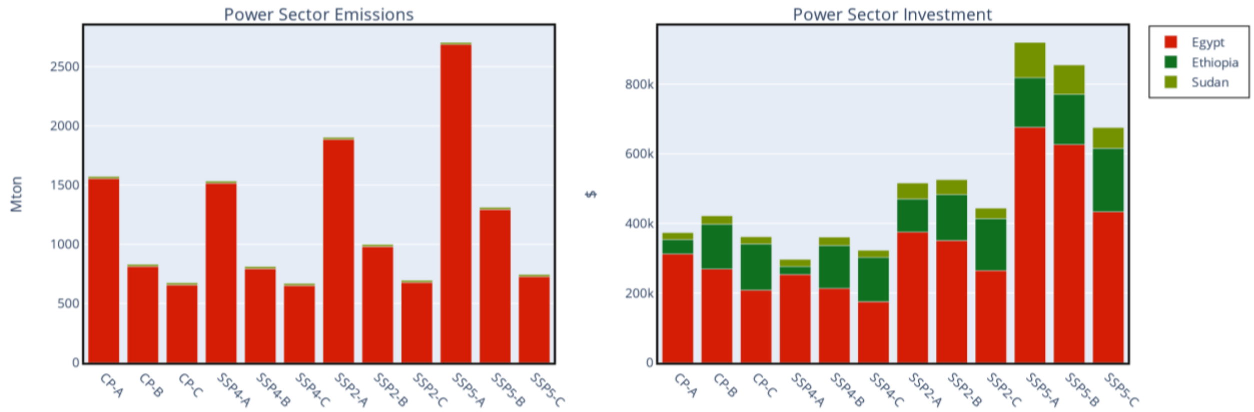
Figure 16 - Ethiopia total installed capacities (a) and electricity generation mix by technology (b)

5.3 SCENARIO ANALYSIS

As shown in **Table 11**, we analysed three different cases for every single demand evolution scenario in which the policy and cost parameters change from scenario A which reflects the condition in which the renewables are not favourable to invest towards scenario C in which the most favourable condition for investing in renewables happens. Indeed, significant reduction in the investment costs of renewable coupled with lower discount rate on capital, expensive emission penalties, and earlier limits to prevent building new fossil fuel plants, are perfect conditions to stimulate substantial investments in renewables.

5.3.1 Emissions and costs

Based on the availability of natural resources in the area, Egypt is the highest emission producer. The availability of hydro resources in the Ethiopia and Sudan leads to a cleaner power production mix, as demonstrated in **Figure 17** a). Similarly, Egypt dominates the total investments required in the power sector, as it has the highest demand among the three countries, shown in **Figure 17** (b). It could be seen in **Figure 17** (b) that, as the renewables penetration increases under the assumption of sensitivity Case C, the total investments required decreased. In such cases, the power generation mix will be dominated by renewables to avoid emission penalties.



(a) (b)

Figure 17 – Power sector total period emission (a) and investment (b) in different scenarios

While, due to higher availability of hydro resources, Ethiopia and Sudan have a very clean local power production, Egypt production mix will need strong policy and VRES cost reduction to increase the penetration of VRES. As it can be seen in **Figure 18**, which shows the average share of renewables in three cost scenarios (solid line), the shaded area represents the change in the range for different demand scenarios, reaching a high renewable share in Egypt. This is not the economically preferable, if there is no strong VRES policy supports. Specifically in higher demand scenarios, like SSP5, the share of VRES will be lower.

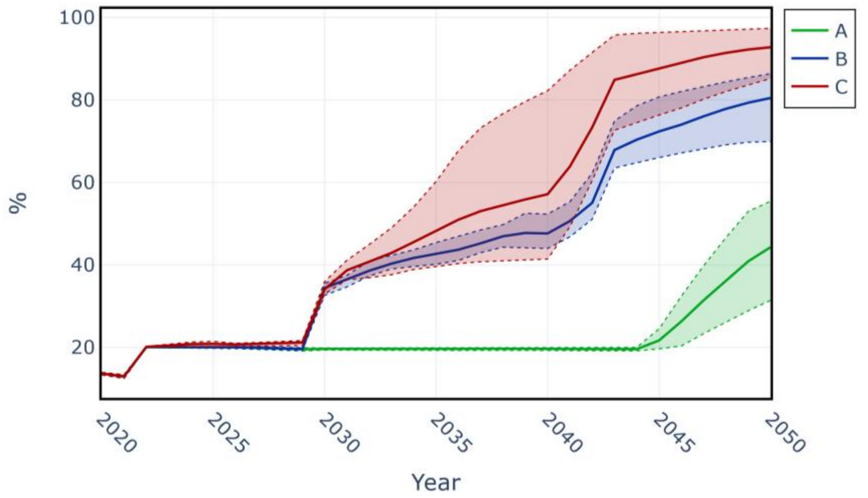


Figure 18 – Share or renewables in Egypt in different scenarios

In case of very high increase of energy demand, the environmental impact of the penetration of VRES in the area will be considerable. Indeed, the emission intensity of Egypt as the biggest energy consumer will drop to almost one third in scenario C with respect to scenario A, as shown in **Figure 19**. Again, the emission intensity in Ethiopia is zero, as its power generation mix includes only renewable resources.

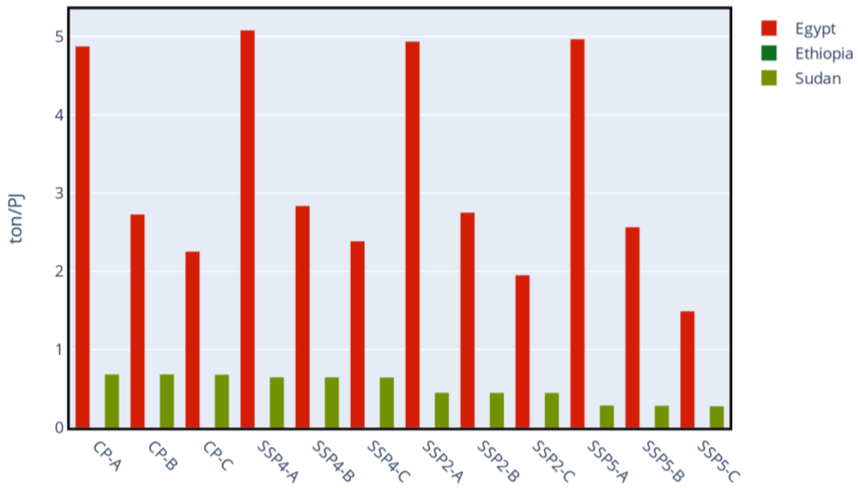


Figure 19 – Emission intensity of the electricity production system in different scenarios

5.3.2 Electricity trades

A holistic insight that can be driven from the above results is that the level of the energy trade between the three countries will be highly impacted by the penetration of VRES within them. Pushing towards more VRES, will make the countries higher renewable sources net exporters, while countries like Egypt, with limited access to the hydro resources, may rely highly on the import of electricity as it will be the least-cost solution to meet its prospective electricity demand. As it can be seen in **Figure 20**, the increase in the VRES penetration, makes Egypt a net importer from Ethiopia, which has the lowest cost electricity production due to its hydro power resources.

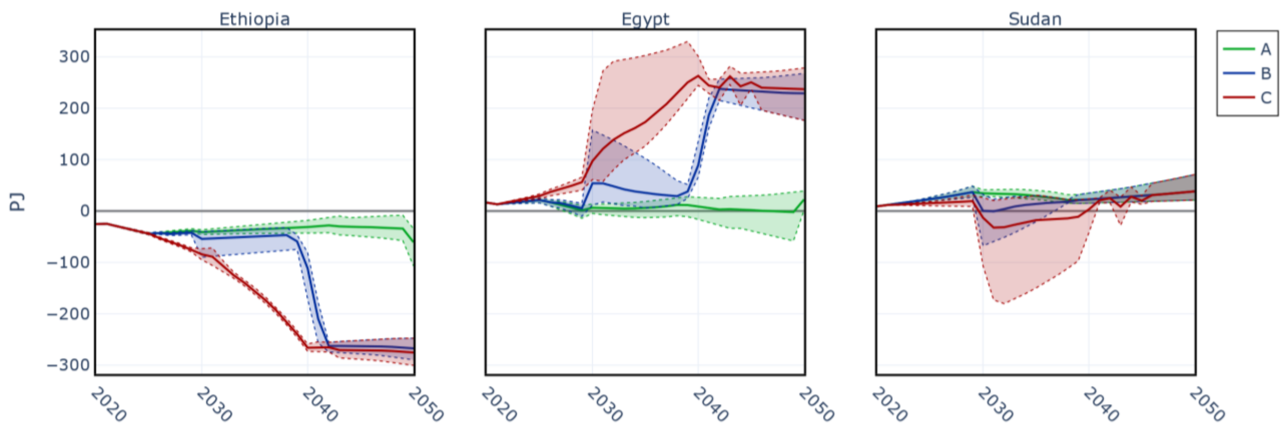


Figure 20 – Electricity imports (+) and exports (-) by each country in different scenarios

The increase of imports from Ethiopia will impact relevantly on the energy security in Egypt (more than 25% dependency on imports as shown in **Figure 21**, specifically considering the political conflicts around the hydro resources between the two countries[ii].

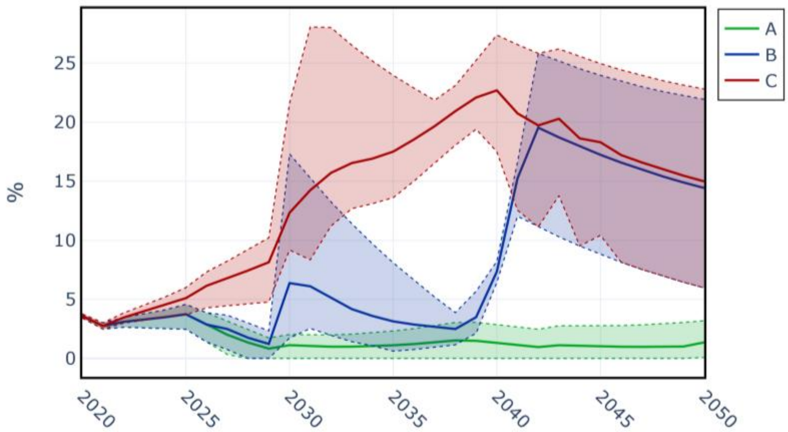


Figure 21 – electricity import dependence in Egypt

5.3.3 Hydro power role

As the power production in the area (specifically in Sudan and Ethiopia) is highly dependent on hydro power, it is worth to analyse the impact of the outcomes of the scenarios on the exploitation of hydro resources. As it can be understood from **Figure 22**, the total production of hydro resources in the area is increasing and, in the most favourable scenarios for VRES penetration, it gets to its maximum estimated hydro power production before 2040. While the total production of hydro power is always substantial in the production mix, during time, its share will decrease in the mix mostly due to two reasons:

- The decrease in the cost of other renewable technologies will make them more competitive to let them enter the production mix
- As the hydro resources are limited, there is the need to increase the production of other electricity resources specially in cases that demand is very high

[ii] Egypt and Ethiopia have a political dispute over the Grand Renaissance Ethiopian Dam. Egypt claims that the dam will disrupt its water supplies, especially during years of drought.

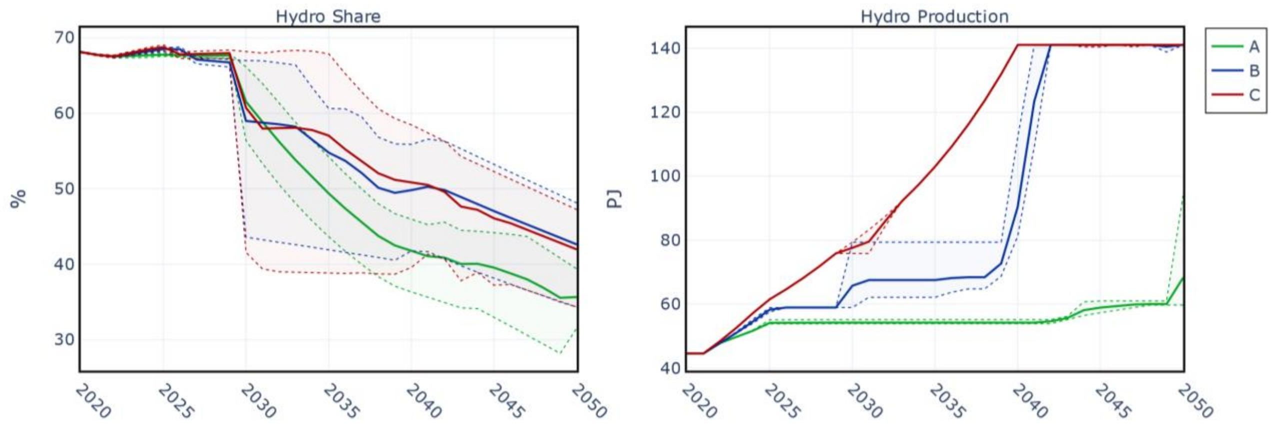


Figure 22 – The share and total electricity production from hydro resources in the whole area in different scenarios

5.3.4 Energy security

Beside the import dependency as an important indicator of the energy security, the local production mix is the most important indicator that assess if the production mix is qualitatively secure or not. Between different indicators, the Shannon-Wiener Index (SWI) is chosen. The SWI is expressed by accounting for the share of each primary energy source as follows[34]:

$$SWI = -\sum_{i=1}^{N} p_i \ln p_i \qquad (6)$$

Which, p_i is the share of primary energy supply by the ith energy source ES_i in the total primary energy supply ES_T and is calculated as:

$$p_i = \frac{ES_i}{ES_T} \qquad (7)$$

The smallest value of the SWI is zero, in the case where there is only one primary energy supply option in the region. It means the sole option takes 100% of the total primary energy supply. In contrast, the theoretical maximum value of the SWI may be obtained when the shares of primary energy sources are even, meaning that p_i equals $1/_N$ and the number of types of energy sources becomes larger. As a result, higher SWI values, represents more diverse energy production mix and consequently higher energy security. Looking at the results, represented in **Figure 23**, Egypt has the most diversified electricity production, due to its access to fossil fuel technologies. In the scenarios

SSP2-B, SSP2-C, SSP5-B and, SSP5-C with very high energy demands and high penetration of VRES, the diversity will drop since the share of imports will increase a lot. The high dependency of hydro resources in Ethiopia and Sudan keeps the energy security of the two countries very low, specifically over the time interval in which more hydro power still is available. To diversify the mix in the scenarios of which VRES penetration is very high (SSP2-B, SSP2-C, SSP5-B and, SSP5-C), more diffusion of PV technologies is required. Since PV technology availability is low during the night hours, which is the peak of the demand, demand management policies are needed to allow the deployment of that specific technology in the area, considering the availability of huge solar resources.

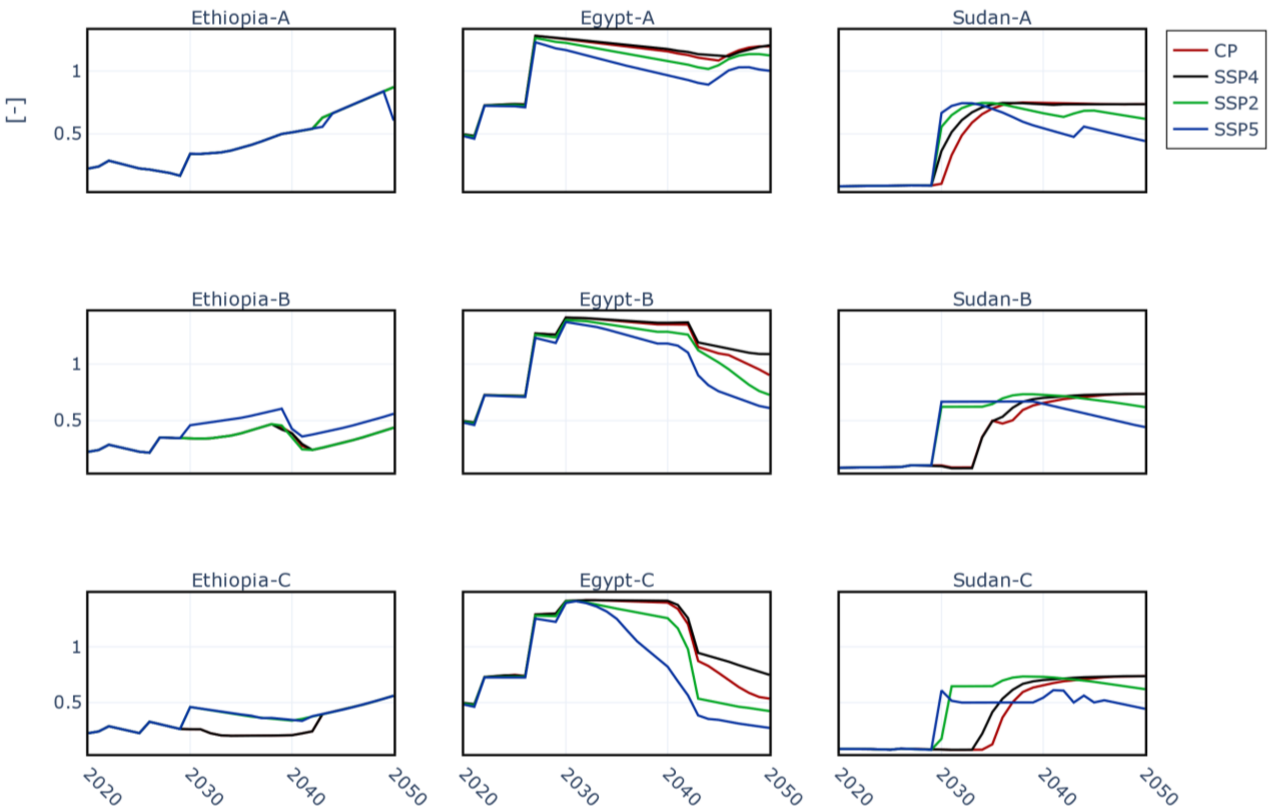


Figure 23 – SWI for different scenarios in the three regions

6. FINAL REMARKS

Deliverable D2.4 of WP2 is a comprehensive report that presents the models developed for energy future scenarios generation for the AWESOME project.

The historical data of the energy demand and supply, demographic projections and input-output tables are collected for the specific spatial resolution of the model (Egypt, Ethiopia, and Sudan) for the calibration of demand projection and power system evolution for different scenarios over time. Rapid projected economic growth, the improvement in the energy access, the environmental concerns raised by exploiting fossil fuel sources, beside the conflicts about the hydro sources in the area, makes the future energy planning a task with multiple undertenancies and complexities. The use of energy system optimizations models eases the path towards such complex analysis. The model presented in this study aimed to analyse the impact of multiple parameters to assess the optimal cost path towards the evolution of power system. The availability of hydro resources in the area provides the chance to produce considerable amount of clean and cheap power. Furthermore, from the construction of cross border transmission lines, the opportunity to share cleaner and cheaper power in the area can arise. At the same time, high availability of hydro resources increases the risk of the stability of the power supply system, if the production mix won't be diversified, especially in the case of Ethiopia. The role of wind power in the future production mix of the area can be considerable, while for the solar power generation, more policy-oriented actions may be needed as the consumption patterns and the availability of resources does not match properly in the area. While the shares of renewables in Ethiopia and Sudan are considerably high, Egypt deeply relies on fossil fuel technologies. As seen in the results, rapid economic growth with possible decrease in the renewable costs, accompanied by renewable energy policies such as emission penalties, will make renewables more competitive, while having better power production infrastructure in Egypt provides higher energy security. Moreover, pushing towards more renewable energy generation can provide Ethiopia with the opportunity to export electricity, thanks to its hydro resources, while making electricity import for Egypt from Ethiopia profitable.

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ANNEX I

I. MODEL SETUP AND CONFIGURATION

Table I. 1 - Share of each time-slice in a full year

Time-slice	Number of hours	Ratio
S1D1	1080	0.123
S1D2	360	0.041
S1D3	720	0.082
S2D1	1092	0.125
S2D2	364	0.042
S2D3	728	0.083
S3D1	1104	0.126
S3D2	368	0.042
S3D3	736	0.084
S4D1	1104	0.126
S4D2	368	0.042
S4D3	736	0.084

Table I. 2 - Operational Lifetime of power technologies

Technology	Lifetime [Years]
nuclear_pp	40
oil_pp	25
coal_pp	25
ng_pp	25
cs_pp	30
wind_pp	25
geo_pp	25
hydro_pp	80

Technology	Lifetime [Years]
pv_on	25
pv_off	25
bio_pp	25

Table I. 3 - Efficiency of the technologies

Technology	Efficiency
nuclear_pp	33%
oil_pp	38%
coal_pp	39%
ng_pp	65%
transmission	83%

Table I. 4 – Technologies costs

Technology	Capital Cost [$/kW]	Fixed Cost [$/kW]	Fuel Cost [$/GJ]	Variable O&M [$/GJ]
hydro_pp	4416.32	55		
ng_pp	1422.84	20	7.85	
pv_on	2200	24		
cs_pp	3646.52	200		
wind_pp	2607.41	48		
coal_pp	3519	65	7.35	
nuclear_pp	10778	170	0.21	
pv_off	2200	28		
oil_pp	900	44	9.655	
geo_pp	3000	60		0.93
bio_pp	1810	55		2.89

Table I. 5 – Technologies availability factor

Technology	Availability Factor [-]
nuclear_pp	0.95
oil_pp	0.92
coal_pp	0.95
ng_pp	0.92
geo_pp	0.95
hydro_pp[iii]	0.6
bio_pp[iv]	0.95

Table I. 6 – Capacity factor of technologies in different time-slices

		Solar Based			Wind Based		
Season	**Day split**	**Egypt**	**Ethiopia**	**Sudan**	**Egypt**	**Ethiopia**	**Sudan**
S1	**D1**	0.418	0.444	0.449	0.410	0.254	0.258
	D2	0.002	0.022	0.017	0.449	0.635	0.334
	D3	0	0	0	0.410	0.462	0.406
S2	**D1**	0.406	0.307	0.384	0.401	0.246	0.308
	D2	0.016	0.013	0.026	0.552	0.384	0.315
	D3	0	0	0	0.497	0.359	0.482
S3	**D1**	0.425	0.312	0.388	0.332	0.392	0.215
	D2	0.015	0.013	0.026	0.488	0.173	0.242
	D3	0	0	0	0.468	0.501	0.397
S4	**D1**	0.391	0.420	0.447	0.355	0.247	0.287
	D2	0.001	0.021	0.013	0.452	0.425	0.292
	D3	0	0	0	0.434	0.333	0.379

[iii] In the case of hydro_pp, more instead of using general technical data, the real production and installed capacities are used to calculate the availability factor.
[iv] Assuming that the biogas is 100% available

Table I. 7 - Historical production in Egypt [GWh]

	2015					2016					2017					2018				
	UN	Government	IRENA	IEA	Final	UN	Government	IRENA	IEA	Final	UN	Government	IRENA	IEA	Final	UN	Government	IRENA	IEA	Final
nuclear_pp	0	0	NA	0	0	0	0	NA	0	0	0	0	NA	0	0	0	0	NA	0	0
oil_pp	43500.56	0	NA	38237	0	42738.89	0	NA	29424	0	31952.78	0	NA	22046	0	28439	0	NA	22046	0
coal_pp	0	0	NA	0	0	0	0	NA	0	0	0	0	NA	0	0	0	0	NA	0	0
ng_pp	121608	170363	NA	118819	157056	133259	173762	NA	132193	173762	147331	173762	NA	147334	173762	158664	181006	NA	147334	181006
bio_pp	238.3333	0	318.1	0	318.1	236.1111	0	311.2	0	311.2	236.1111	0	305.2	0	305.2	238	0	NA	0	238
cs_pp			23.4		23.4			23.9		23.9			23.9		23.9			NA		23.9
pv_on	253	167.5			168	168	580			556.1	580	580			556.1	537	537			513.1
pv_off			42	168	0			80.6	580	0			578	537	0			NA	537	0
wind_pp	1345	2058	1444	2058	1444	2058	2200	2058	2200	2200	2200	2200	2200	2334	2200	2234	2334	NA	2334	2334
geo_pp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	0	0
hydro_pp	13432	13545	13822	13545	13545	13460	12850	13545	12850	12850	12850	12850	12850	12726	12850	12726	12726	NA	12726	12726

Table I. 8 - Historical production in Ethiopia [GWh]

	2015				2016				2017				2018			
	UN	IRENA	IEA	Final	UN	IRENA	IEA	Final	UN	IRENA	IEA	Final	UN	IRENA	IEA	Final
nuclear_pp	0	NA	0	0	0	NA	0	0	0	NA	0	0	0	NA	0	0
oil_pp	4	NA	4	4	4	NA	4	4	4	NA	4	4	5	NA	5	5
coal_pp	0	NA	0	0	0	NA	0	0	0	NA	0	0	0	NA	0	0
ng_pp	0	NA	0	0	0	NA	0	0	0	NA	0	0	0	NA	0	0
bio_pp	38	30.4	0	30.4	36	28.2	0	28.2	36	22.4	0	22.4	36	NA	0	36
cs_pp		0		0		0		0		0		0		NA		0
pv_on	18			18	21			21	22			22	20			20
pv_off		18	18	0		20.8	21	0		22.4	22	0		NA	20	0
wind_pp	759	499	759	759	782	786	782	782	533	782	533	533	533	NA	533	533
geo_pp	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	0	0
hydro_pp	9674	9018.9	9674	9674	11753	9674	11573	11573	12681	11753	12681	12681	13018	NA	13018	13018

Table I. 9 - Historical production in Sudan [GWh]

	2015				2016				2017				2018			
	UN	IRENA	IEA	Final	UN	IRENA	IEA	Final	UN	IRENA	IEA	Final	UN	IRENA	IEA	Final
nuclear_pp	0	NA	0	0	0	NA	0	0	0	NA	0	0	0	NA	0	0
oil_pp	4627	NA	4627	4627	6378	NA	6378	6378	6195	NA	6195	6195	6599	NA	6599	6599
coal_pp	0	NA	0	0	0	NA	0	0	0	NA	0	0	0	NA	0	0
ng_pp	0	NA	0	0	0	NA	0	0	0	NA	0	0	0	NA	0	0
bio_pp	111	111	0	111	110.5	110.5	0	110.5	116.6	116.6	0	116.6	118.1	NA	0	118.1
cs_pp		0		0		0		0		0		0		NA		0
pv_on	0			0	0			0	0			0	0			0
pv_off		13.3	0	13.3		18.5	0	18.5		20.5	0	20.5		NA	0	20.5
wind_pp	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	0	0
geo_pp	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	0	0
hydro_pp	8420	8420	8420	8420	8051	8051	8051	8051	9347	9346.9	9347	9347	9657	NA	9657	9657