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Planning a Long Term Energy System Using the International Atomic Energy Agency Modeling Tool MESSAGE (Model for Energy Supply Strategy Alternatives and Their General Environmental Impacts) Case study: Algeria

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Abstract: *The intense industrialization of recent decades and the proliferation of domestic electrical appliances have led to considerable energy needs, serious impact to the environment and yet the world's oil reserve is shrinking more and more.*
Since energy planning is the systematic analysis of all the factors that influence the evolution of energy systems, it helps to solve problems and allows for the search for links, the evaluation of the advantages and disadvantages of options and the comparison of their consequences thus helping countries to develop an effective energy strategy that contributes to their national sustainable development goals, identify options and assess their strengths and weaknesses.
In this context, this article describes a study on the planning of a long-term energy system with Algeria as a case study in order to provide the most effective and sustainable solutions to the country in the future.
Key words: Energy planning, Energy strategies, Environment, Energy systems.

1. INTRODUCTION:

In Algeria, electrical energy is produced mainly from natural gas. The share of installed power of all plants using this primary energy exceeds **96%,** the rest of the energy used is divided between diesel fuel in diesel plants and renewable energy in remote areas of the country. Algeria has considerable and diversified natural wealth, particularly in hydrocarbons, where it ranks **15th** in terms of oil reserves, **7th** in the world in terms of proven resources, then **5th** in production and the **3rd** in export. Because of its privileged geographical position, it has a very significant renewable energy potential, notably the solar potential.

1.1 Energy Resources of Algeria

1.1.1 Gas Reserves

Algeria is one of the largest producers of natural gas in the world. The gas reserves are estimated at 5,800 Gm³, or 73 years at the current rate of production (80 Gm³ / year). The natural gas consumed by all power plants in 2013 was 11 828 billion m^3 and 12 846 billion of m^3en 2012

1.1.2 Oil Reserve

The Algerian Sahara contains about 11.8 billion barrels of proven oil reserves. With more exploration and discovery of recent oil plans.

Table 1.1: The Algerian proven oil reserves

Year	2002	2003	2004	2005	2006	2008	2010
Proven Reserves	13 100	13 100	11 870	12 460	11 000	14 790	13 420

1.1.3 Solar Potential

Algeria has one of the largest solar deposits in the world with an insolation that exceeds 2000 hours annually and reaches 3900 hours (highlands and Sahara), i.e. nearly 1700 KWh / m^2 / year in the North and 2263 KWh / m^2 / year in the South.

1.1.4 Wind Potential

The wind resource varies from one place to another and it blows at a speed greater than 5 m / s during the whole day and more than 6 m / s for almost 10 hours and this only at 10 m from the ground. Figure I.1 shows the variation of the monthly mean wind speed for the Adrar site.

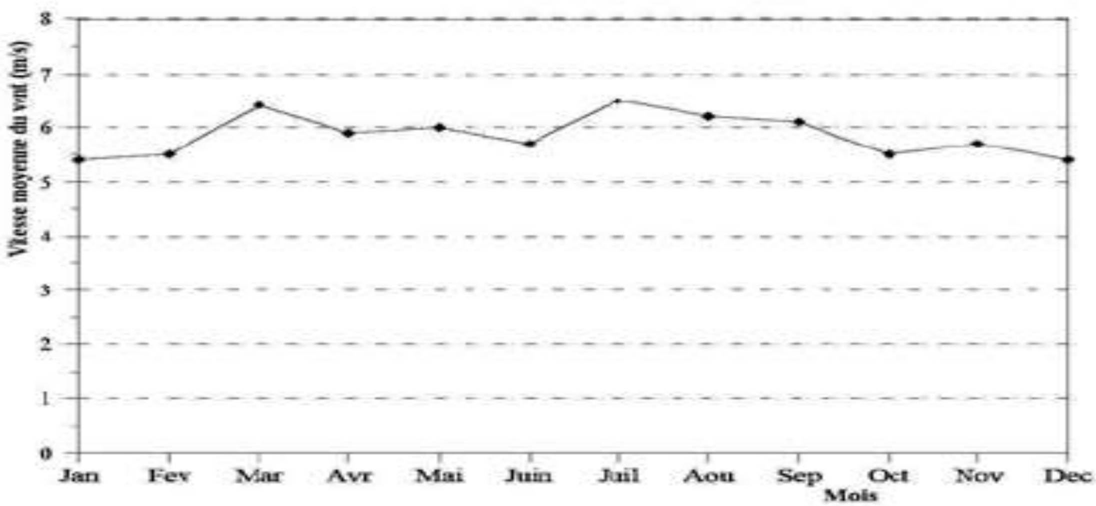

Figure 1.1: Monthly averages of wind speeds at the Adrar site

1.1.5 Geothermal Potential

The Jurassic limestones of northern Algeria, which are important geothermal reservoirs, give birth to more than 200 hot springs located mainly in the northeastern and northwestern regions of the country. These sources are often at temperatures above 40 ° C, the warmest being Hammam Meskhoutine (96 ° C).

1.1.6 Forest Potential

The current potential is estimated at around 37 million TOE (Tone oil equivalent). The recoverable potential is around 3.7 million TOE.

1.1.7 Energy Potential of Urban and Agricultural Waste

Currently, 5 million tonnes of urban and agricultural waste are not recycled. This potential represents a deposit of around 1.33 million toe / year.

I.1.8 Uranium Reserve

According to some sources, Algeria has a reserve of 26,000 tonnes of uranium and plans to build a nuclear plant every five years after its first plant expected to be acquired in 2020.

I.1.9 Coal Reserve

The Béchar region has a large coal deposit with potential reserves of more than 208 million tonnes, the largest of which is Kenadsa with an estimated potential of 142 million tonnes sufficient to run a coal-fired power plant for many years.

I.2 Power Generation Technologies

I.2.1 Combined Cycle Gas Power Plants

A combined cycle power plant, commonly called CCGT (Combined Cycle Gas Turbine) or TGV (Turbine Gas-Steam), is a thermal power plant that combines two types of turbines: gas turbine and steam turbine. Each of these turbines drives a generator that produces electricity ("multi-shaft" configuration) or both types of turbines are coupled to the same generator ("single-shaft" configuration).

In a combined cycle power plant, the gas turbine is driven by gases from high temperature combustion (up to 1500 ° C). At output the gases are still sufficiently hot (between 400 ° C and 650 ° C approximately) to generate steam in a boiler by means of heat exchangers. The steam thus produced drives a steam turbine.

I.2.2 Gas Turbine Power Plant

This is a power plant that consumes a gas with a high calorific value, such as natural gas. A gas turbine looks like an airplane engine and operates in much the same way. The air is heated with a fuel, such as natural gas, to raise the temperature. As the temperature rises, the air expands and creates pressure. This high-pressure, extremely hot air is pushed into the turbine section where it expands and applies pressure to the blades of the rotating turbine. The efficiency of the gas turbine is (25% to 35%).

I.2.3 Steam Turbine Plant

This is a conventional technology of producing steam using a gas-fired boiler, in contact with very hot exhaust gases; the circuit water is transformed into steam that turns a steam turbine that drives a second alternator generating electricity.

I.2.4 Wind Turbines

Wind energy is an indirect form of solar energy. Aero generators - often called wind turbines - use the force of the wind to turn it into electricity. The machine consists of blades (3 in general)

carried by a rotor and installed at the top of a vertical mast. This set is attached to a nacelle that houses a generator. An electric motor is used to orient the nacelle so that the rotor is always facing the wind. The wind turns the blades between 10 and 25 rpm. The generator transforms the mechanical energy thus created into electrical energy injected into the network.

1.2.5 Solar Energy

Solar energy uses the most shared resource: solar radiation. Solar energy can be recovered by two processes: Photovoltaic for the production of electricity with or without storage and Thermal for the production of heat.
The phenomenon of photovoltaic conversion is due to the variation of the conductivity of a material under the effect of light. A PV cell is made from two layers of silicon, one P doped (boron doped) and the other doped N (phosphorus doped) creating a PN junction with a potential barrier. Its principle lies in a collision of incident photons (luminous flux) with free electrons and valence electrons thus creating an energy W_{ph}.

$$W_{ph} = h_p \cdot \frac{c}{\lambda_{ph}} \qquad 1.1$$

Where λ_{ph} represents the wavelength, h_p Planck's constant and c the speed of light. A serial association of several cells gives a module and a series and / or parallel association of several modules makes it possible to produce a photovoltaic panel.

I.2.6 Solar Thermal Power Plant (CSP Concentrated Solar Power)

The solar thermal system as a whole goes through solar collectors, first capturing solar radiation and then transforming it into heat (thermal energy) which heats water, turns turbines and then drive an alternator and thus produce electricity.

I.2.7 Diesel Generator

In a hybrid energy system, the conventional generator is generally the diesel engine directly coupled to the synchronous generator. The alternating current frequency at the output is maintained by a speed governor on the motor. The governor works by adjusting the flow of fuel to diesel, to keep the engine speed and generator speed constant.

I.3 Algerian Electric Generation Park

I.3.1 Interconnected Network

The installed capacity of the Algerian generation fleet at the end of 2013 was 12,977.4 MW for a peak power of 9777 MW. Production in the interconnected grid reached 54.1 TWh at the end of the same year; as shown in the table below;

Table 1.2: Production of the Algerian interconnected grid

Year	Park production (GWh)	Load factor for the System (%)	Peak power (MW)
2008	40 202	66%	6 925
2009	42 500	67%	7280
2010	44 050	67%	7718
2011	48 871	67%	8606
2012	54 100	67%	9777

The generating fleet was composed in 2013 of 100% thermal power plants running on natural gas composed of the following production technology: - Combined cycle CC (39%). - Steam Turbine TV (17%). - Gas turbine TG (44%).

I.3.2 Electricity Generation in Algeria

The production of electrical energy increased from 3,630 GWh in 1975 to 54,086 GWh in late 2013. The exact figures representing the annual production are presented in Table below.

Table I.3: Production of electrical energy of the Algerian system.

Years	2008	2009	2010	2011	2012	2013
Production (Twh)	31,196	40,236	38,501	45,734	48,872	54 ,1

I.3.3 Consumption of Electricity in Algeria

The consumption of electricity in Algeria reached 43,150.1 GWh in 2013 as shown in the table below.

Table I.4: Consumption of electricity in Algeria

Years	2007	2008	2009	2010	2011	2012
Consumption (kwh)	30,555	32,900	30,610	36,576	41,183	46,696

2.0 Introduction to MESSAGE

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) is software designed for setting up optimization models of energy supply systems that can be built at national, sub-regional or regional levels to assess various strategies for energy system development in the medium to long-term considering their general environmental impacts.
Originally conceived by Professor Wolf Häfele and Professor Alan S.Manne for the global energy project conducted at the International Institute for Applied Systems Analysis (IIASA) during the seventies (1970s).
MESSAGE inputs include the description of the energy system, the base year energy flows and prices, the projected energy demands, the possible technology, resource options, various technical and policy constraints.
The model configures the evolution of the energy system from the base year to the end of the study period providing the primary and final energy mix, resource use, schedule for capacity addition in facilities, energy imports and exports, investment requirements of the energy system, emissions and waste etc.

2.1 The Energy System

An energy supply system consists of:

Energy resources such as: - Coal, - Oil, - Gas

Energy forms - energy extracted from resources, - processed, converted, transmitted and distributed energy services (useful energy).

Technologies

- Which extract, process, convert energy from one form to another
- Transmit and distribute - Provide energy services.

Given demands for final energy forms or for energy services a MESSAGE model assures sufficient supplies by utilizing the proper mix of technologies and resources in order to optimize the system expansion and operation, based on a set of specified criteria as in minimizing the total system cost or minimizing the imports of fuels, etc.

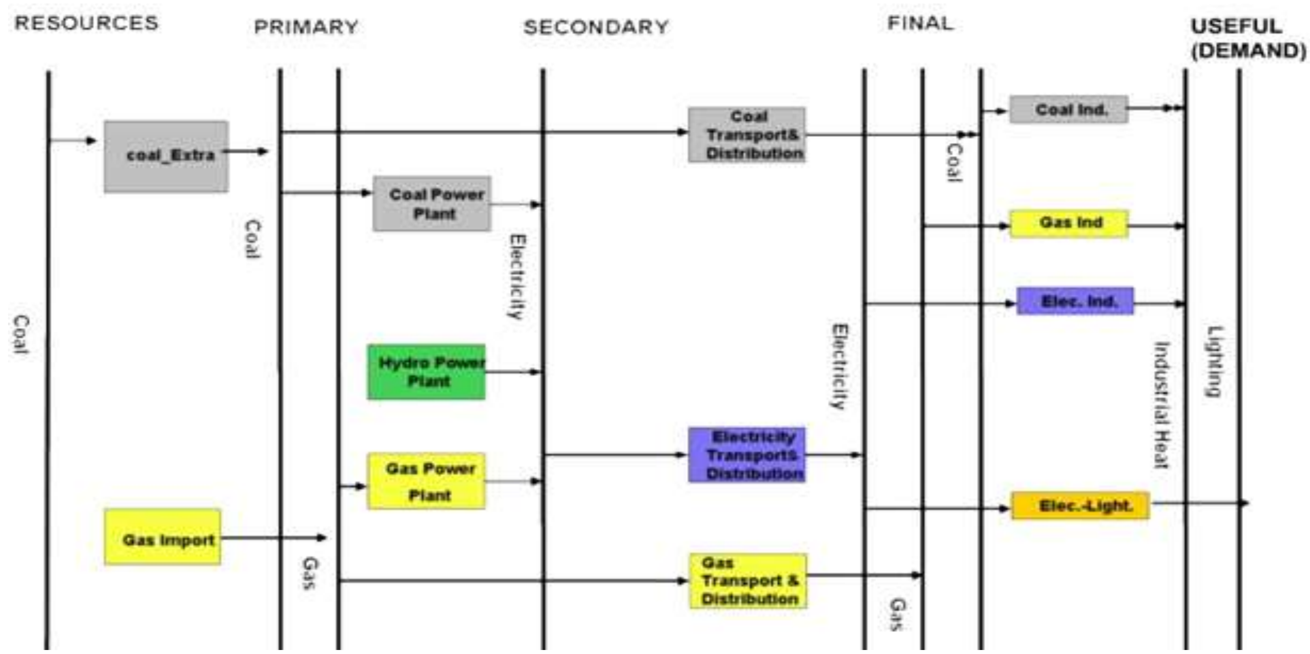

Figure 2.1: A simple energy system: The physical flow network

The levels of energy forms are: Resources, Primary energy, Secondary energy, Final energy, Useful energy (Demand for energy services).

2.2 The MESSAGE Optimization Methodology

Optimization is implemented through the use of a versatile set of methods and techniques: The objective function can be a cost (to be minimized) or a profit (to be maximized);

The constraints will reflect various limits on expansion and use of technologies and resources, including emissions limits due to environmental regulations. The optimization techniques are based on **mathematical programming**, more specifically **linear programming** and **Mixed-integer programming**.

2.2.1 The Objective Function

The objective function is obtained from the system cost. For each period, denoted "t" one records the following:

- Variable Operations & Maintenance costs
- Fixed Operations & Maintenance costs
- Investment costs Penalty costs/taxes induced by regulation

The total system cost is defined as the expression:

$$\sum_{t=1}^{T} \beta^t \sum_{i=1}^{n} c_{it} x_{it} \qquad 2.1$$

Where :

$\sum_{i=1}^{n} c_{it} x_{it}$: Is the sum of the costs incurred in a period t

$\beta = \frac{1}{1+r}$**:** is the discount factor (r is the discount rate)

Now, since we consider the system evolution over a time horizon of **T** periods, one takes the discounted sum of the sequence of periodic costs. The coefficient **"beta"** is the discount factor, typically equal to $\frac{1}{1+r}$. Where **r** is the periodic discount rate.

2.2.2 The Demand Constraint

An important constraint in a model of an energy supply system is the satisfaction of demand expressed at the level of final energy forms (demand for gas, demand for electricity...) or at the useful energy level. The constraint is that supply must be at least equal to demand at each period "t".

$$\sum SUPPLY \geq DEMAND$$

$$\sum_{i=1}^{i=n} Sij\ Xit \geq Djt \qquad 2.2$$

In each period t, the supply of energy form j from all technologies, i = 1,2……n, should atleast be equal to the demand for that energy form.

Djt : Is the demand for the energy form j in a period t
Xit : Is the activity of a technology i in the period t
Sij : Is the rate at which a technology i is producing energy form j

2.3 The MESSAGE Modeling Framework

MESSAGE is a modeling tool that will help you build a model by focusing on the construction of a structured data base through the use of a set of easily filled capture forms. The information entered in MESSAGE concerns: **Time frame** (periods and time horizon), **Load regions** (time slices to describe demand for non-storable energy forms), **Energy levels** (from resources to useful energy), **Energy forms** (at each level which energy form is represented), **Demands** (what are the demands that are driving the energy supply system?), **Technologies** (what are the technologies available, existing or new), **Constraints** (relations), **Storages** (the possibility to store some energy form) **Resources** (availability of resources limits on extraction).
From this set of information MESSAGE will produce a formulation of the linear programming or MIP problem to solve and prepare the input to a "solver”. This is called the "matrix generation" phase, then run the "solver" and obtain an optimal solution which will be exploited to produce a report showing the proposed organization of the energy system over the planning horizon.

2.4 MESSAGE Programme Flow

The user-interface of MESSAGE is an envelope that contains three major programs and databases. The Databases keep all information about the model developed by a user – the structure of energy system, the input data and the results of the model.
The **mxg** program generates the linear program in standard format (a matrix) interacting with the
Databases. The **Optimizer** uses one of the standard **solvers** to solve the linear program

The **Cap** is a utility to extract the results in tabular and graphic forms.

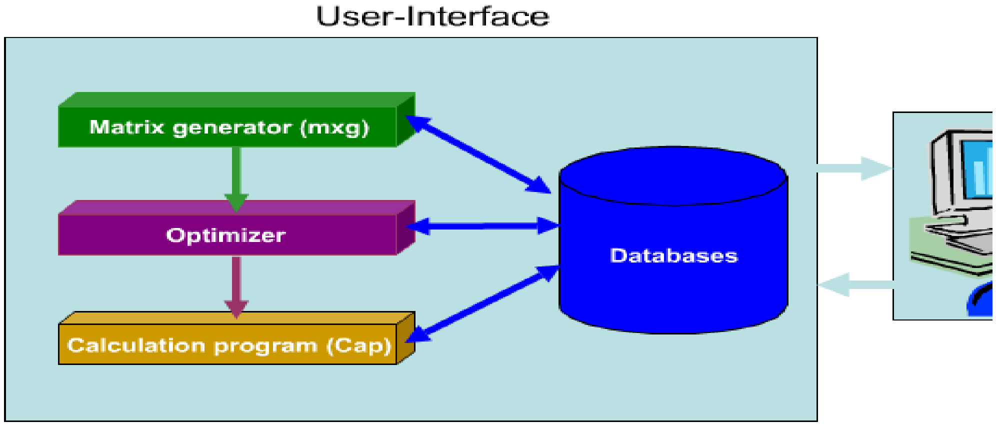

Figure 2.2: MESSAGE programme flow

2.5 MESSAGE Data Structure

The data structure is organized as follows:
The technology data base **(TDB)** contains information on technologies that could be used in several models.
The application data base **(ADB)** of a particular model will import technology information from the technology data base and contain region specific information.
The local data base **(LDB)** contains the information defining the scenarios that we analyze for a particular model.
The update files (**UPD)** allow the user to handle special cases in scenario analyses.

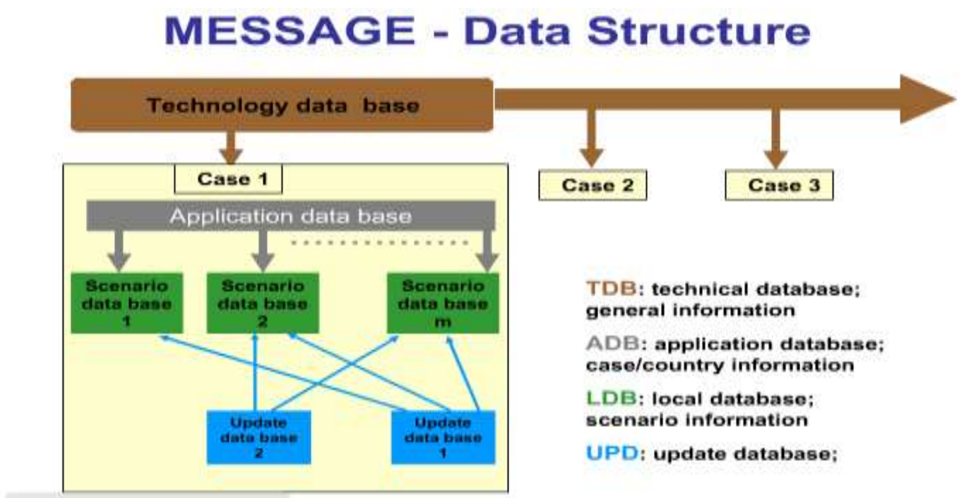

Figure 2.3: MESSAGE data structure

2.6 Storage in MESSAGE

MESSAGE considers two types of energy storage:
Hydro storage to model rivers' system and hydro power generation accounting for water flows and storages. Non-hydro storage to model inflow/outflow from a stock of an energy form.

2.7 Resources

The term Resources is used to model availability and utilization of all types of depleteable energy resources such as coal, oil and gas. Proven and non-proven reserves of different quality or grades can be modeled to represent differences in their quantities available for extraction.

2.8 Constraints / Relations

MESSAGE allows the definition of a variety of constraints in the energy system model; for example, there may be a need to evaluate a minimum contribution from some energy form, like renewable, put limits on the extraction of a resource, assess the impacts of a maximum level of imports allowed and analyze the energy developments under environmental regulations, i.e. limiting emissions from some technologies. Likewise, one may be interested to evaluate GHG mitigation strategies by limiting the CO2 emissions.

2.9 Description of Load Regions and Load Curves

MESSAGE allows modeling of variations in energy demand within a year with seasons, types of days or time of a day. This requires division of the year into parts. These parts of a year are referred to as **"load regions"** while energy demand in these parts is used to construct the, **"load curve".** Load curves in MESSAGE are defined as distribution of annual demand over the Load Regions.

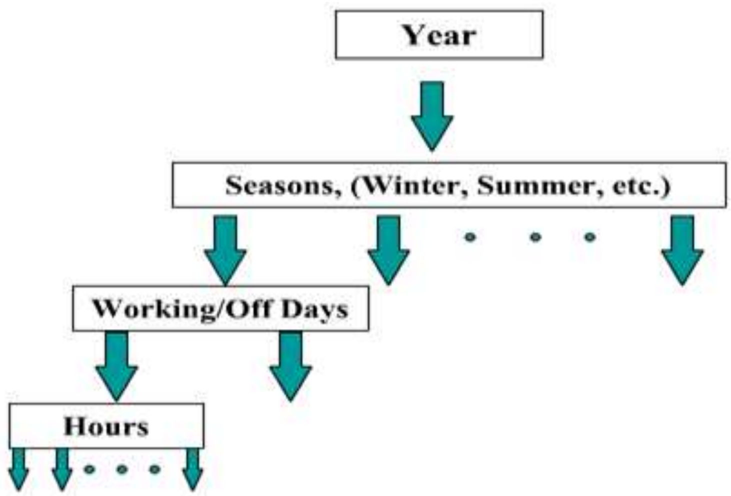

Figure 2.4: Load regions sub division of a year

2.10 Modeling of Renewable Energies

Modeling of these technologies in MESSAGE is different from other technologies in two respects. First, no input is defined for these technologies, and second it is vital that time of day and seasonal variations in their production capacity or output are defined.

2.11 Modeling of Environmental Aspects in MESSAGE

2.11.1 Energy Technologies and the Environment

Environmental impacts from the energy sector can be grouped into three categories on the geographical scale. The emissions polluting **local environment** such as particulates in cities, SO_2 emissions causing **regional acid rain problem**, and CO_2 emissions causing **global climate** change as shown in the figure below.
The emission rates can be defined for each facility either per unit of energy input or per unit of energy output allowing the introduction of limits on emissions from an energy facility, a group of facilities or the whole energy system.

3.0 Modeling of the Algeria Case Study (Implementation)

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3.1 General Information

For the model, the study period covers the horizon of 2012 - 2035 with the three-year time step for the first period of the 2012-2015 and then a five-year step for all other periods of 2015 - 2035. The year 2012 represents the base year, while the year 2015 represents the year of departure in the optimization process "first model year".

The planning periods are 2015, 2020, 2025, 2030 and 2035 thus four optimization periods. The discount rate is assumed to be 7% in Algeria, The energy unit and other units being MWyr and MW for energy and power respectively and monetary values being dollars of "000.

Figure 3.1 shows the modeling of general information on MESSAGE .

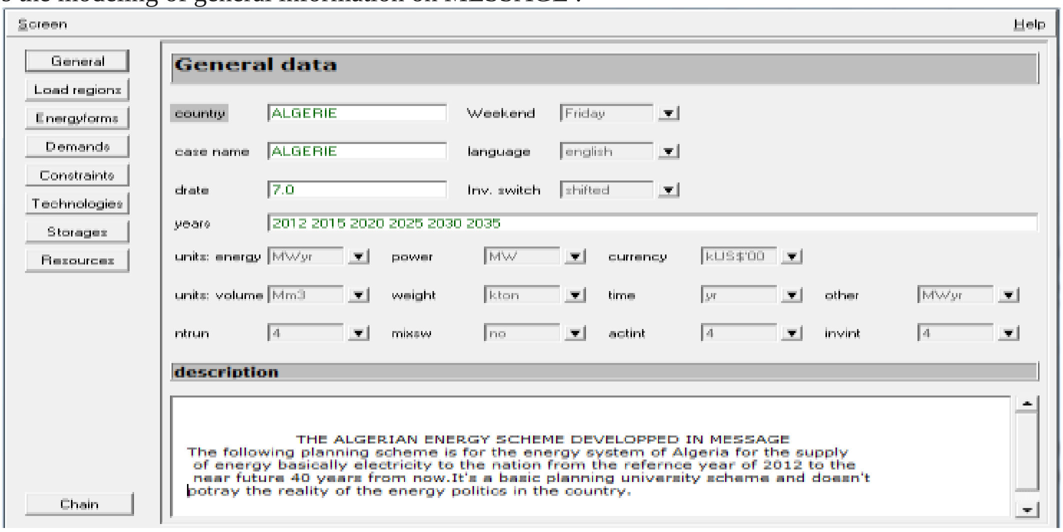

Figure 3.1: Modeling of general data

3.2 Load Curve

Based on the annual load curve for 2012 obtained from SONELGAZ (Société National de l'Electricité et du Gaz). Five seasons were deduced for this model.

• Season 1: from January 1st to February 28th,
• Season 2: from March 1st to April 30th,
• Season 3: from May 1st to July 14th,
• Season 4 (peak): from July 15th to August 31st,
• Season 5: from September 1st to December 31st.

From this report, the variation in demand for each season was evaluated as shown below.

Table 3.1: Portions of seasons in the year

Season	Season 1	Season 2	Season 3	Season 4	Season 5
Portion in the year	0.157	0.154	0.244	0.200	0.245

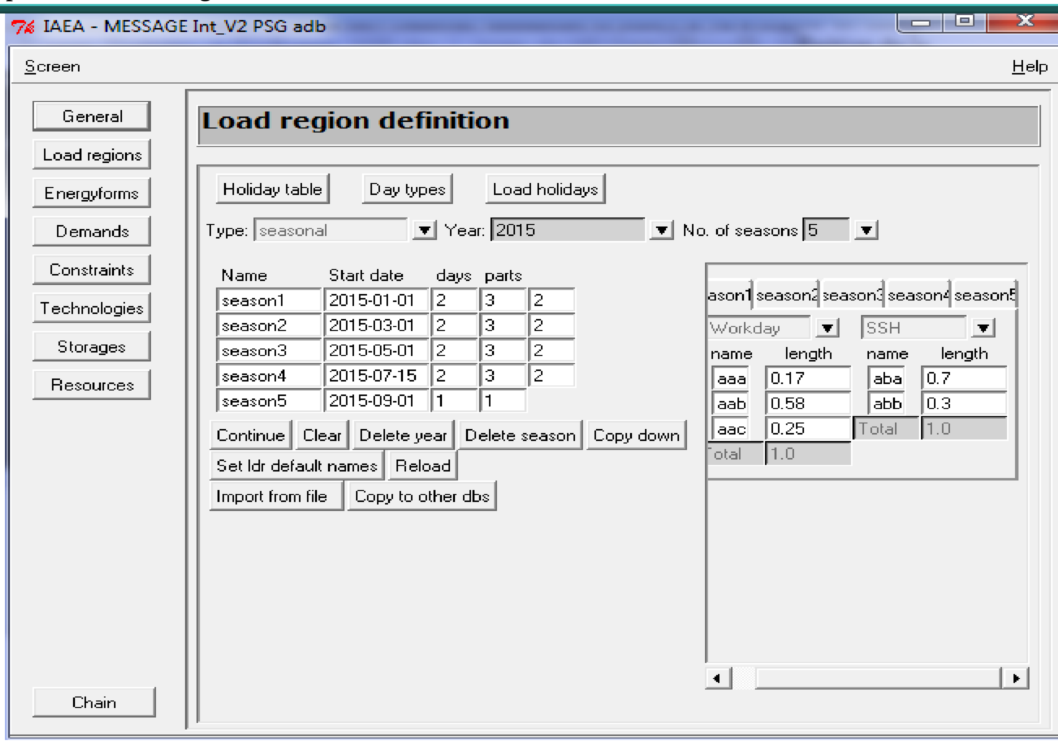

Figure 3.2 Illustrates the modeling of Algeria's energy reference system on MESSAGE

3.3 Modeling of Forms and Energy Levels

Four levels of the energy system are considered: The National Resource (Natural Gas), Primary Level, Secondary Level and Final Level. Energy levels are interconnected by energy conversion technologies such as extraction, processing, production (power plants), transportation and distribution.

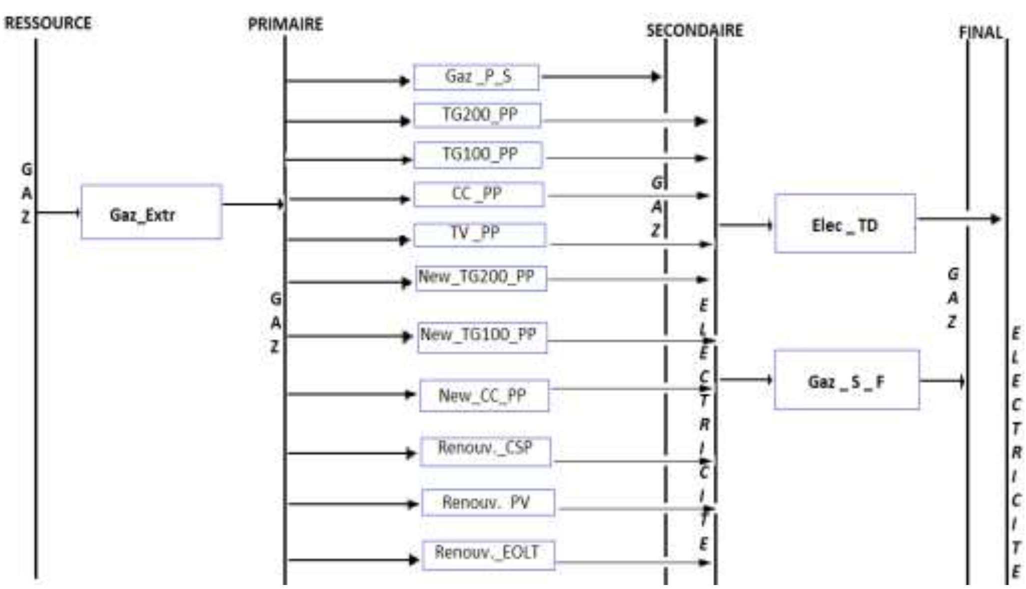

Figure 3.3: The Algerian energy system, including energy levels and technologies

• CC: Combined cycle.

• TV: Steam turbine.

• TG: Gas turbine.

• CSP: Concentrated Solar Power Solar.

• PV: Photovoltaic.

• S_F: Secondary to Final.

• Elec_TD: Transmission and distribution of electricity.

• PP: Power Plant

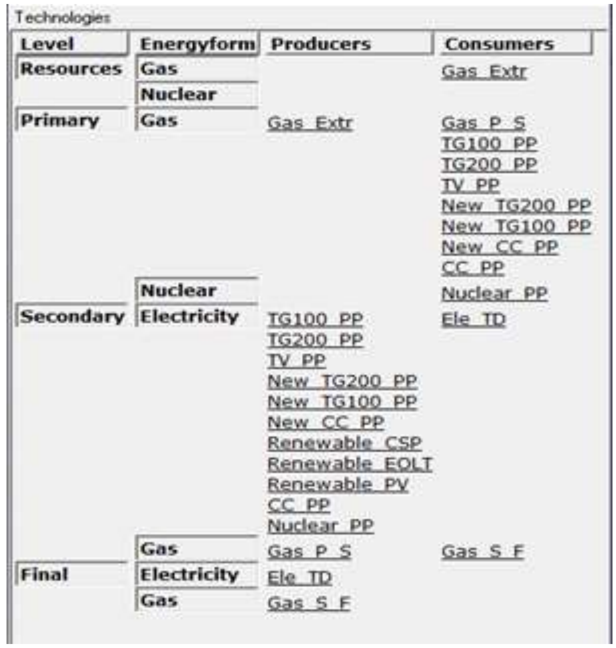

Figure 3.4: Algerian energy system on MESSAGE

3.4 Demand

The Electricity demand as forecast by the Electricity Generation Company (SPE) in Algeria is given below.

Table 3.2: Projected demand for electricity

Planning period	2015	2020	2025	2030	2035
Electricity Demand (MW)	11432	14520	19590	35868	48570

3.5 Resources

The focus has been centered majorly on natural gas resources given that the majority of plants use gas as fuel.

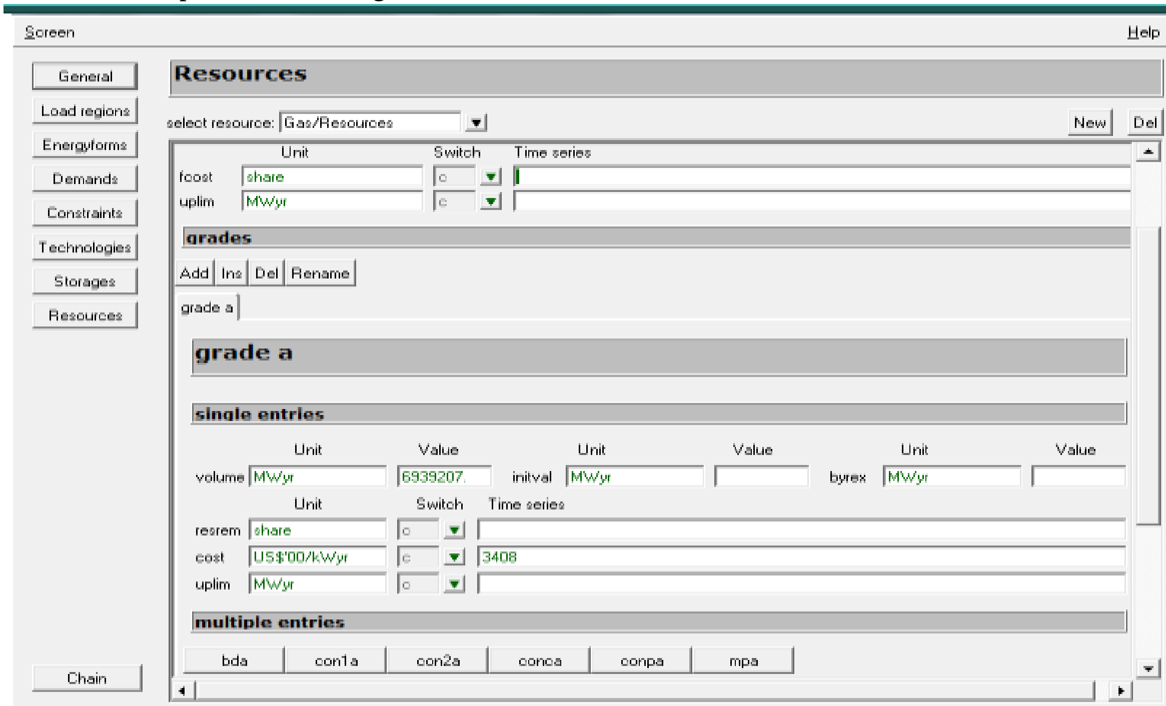

Figure 3.5: Modeling resources on MESSAGE

3.6 The Technologies

The technical, economic parameters and installed capacities of the production technologies in the reference year are presented in Table 3.3 and Table 3.4.

Table 3.3: Technical and economic parameters of the Algerian system

Parameter	Unit	TV	TG 200	TG 100	CC	CSP	PV	Wind
Usage factor	years	60	60	20	83.2	77.5	23	22.8
Construction time	years	5	5	5	4	6	5	5
Life time	years	25	25	25	25	35	20	20
Investment cost	US$(2008) kW	800	621	814	957	5835	3919	1844
Fixed investment cost	US$(2008) kW- years	15.6	16.4	17.5	11.6	61.4	25.5	33.1
Variable investment cost	US$(2008) MWh	4	3.7	4.2	2.8	0	0	0
Efficiency	%	38	33	33	55	37	17	22

Table 3.4: Installed capacity in the reference year.

Technologies	TG100	TG200	TV	CC	CSP	PV	Wind
Installed Capacity (MW)	2012	1488	848	4545	100	5	80

3.7 Environmental Impact

In the modeling of the environmental impact of the system, relations of electric production of the power stations and emissions in the air have been defined according to the values of table 3.5.

Table 3.5: Emission factor

Pollutant	Emission Factor (Kg / kWh)
CO2	0.664292
SO2	0.349805

4.0 Results and Discussion
4.1 Scenario Assumptions

The following assumptions were considered;
The modeling of the system only considered the electricity demand of Algeria and thus did not include the interconnections between the national network with the networks of Morocco and Tunisia hence adoption of the official reserves of natural gas described.
The final demand for electrical energy is covered by the current technology configuration.
• TG100: power plants 100 MW gas. • TG200: power plants 200 MW gas. • TV: steam turbine plants. • CC: combined cycle plants.
• PV: photovoltaic plants. • Eol: wind farms.
• CSP: concentrated solar power plants (Concentration Solar Power). And new production technologies: • New TG100: new plants 100 MW gas turbines. • New TG200: new plants
200 MW gas turbines. • Coal_PP: Coal plants.
The different scenarios of the project consist of the following cases:
1. Reference Scenario based on the configuration of the Algerian energy system as per the year of reference with the current price of the fuel as mentioned including the national renewable energy program of 22000 MW by 2030, as well as new technology conversions to cover the future electricity demand.

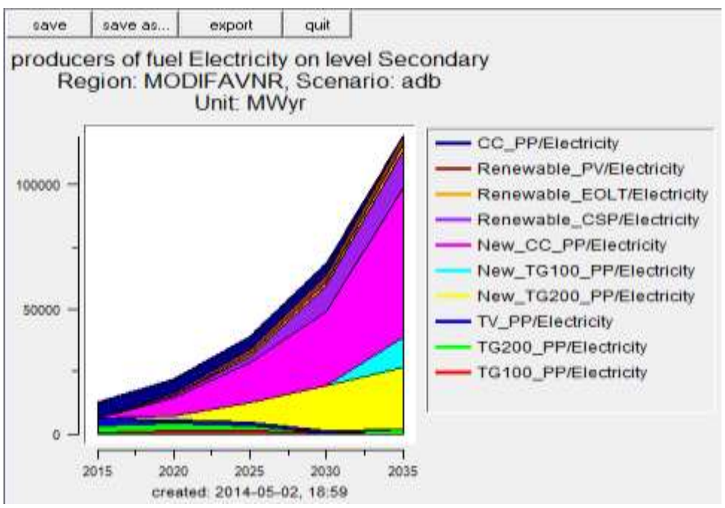

Figure 4.1: Electricity generation by different technologies reference scenario

During the first planning period, much of the electricity is generated by CC_PP combined cycle and TG200 gas turbine power plants. From 2020 onwards, we notice the intervention of the new combined cycle plants "New_CC" and of course a considerable contribution from the new "New_TG200" gas turbines, contributing to the satisfaction of demand.
The contribution of renewable energies for this scenario is negligible but still of paramount importance in the coverage of electricity demand during the last planning periods.

2. Optimal case. A case proposed according to MESSAGE without involving renewable energies.

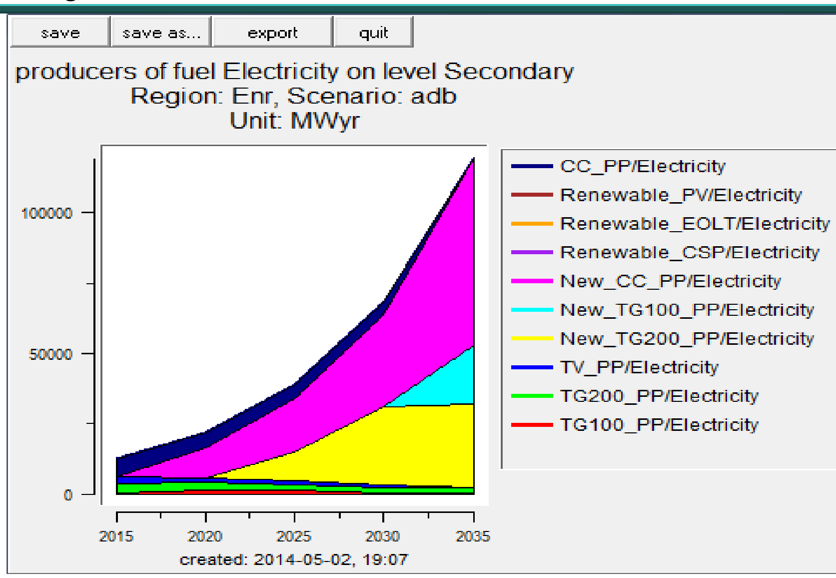

Figure 4.2: Electricity generation by different technologies optimal case

It can be noted that there's no contribution from renewable energies, a large generation comes from the new combined cycle plants "New_CC_PP", new gas plants "New_TG200" and the old production technologies. The "New_TG100" gas plants intervene during the last planning period.

3. Limit on CO2 emissions. The objective of this scenario is to evaluate greenhouse gas emissions and to assess how limiting the level of emissions to a given level "11 Mton" affects the energy supply strategy and production capacities for some technologies.

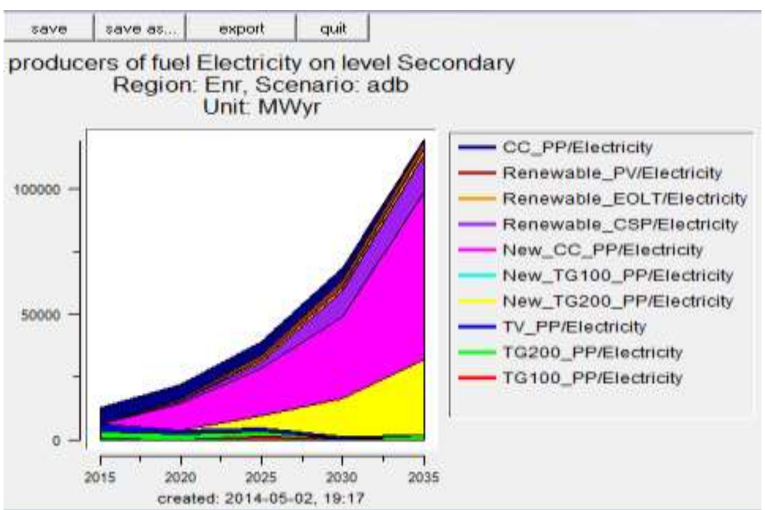

Figure 4.3: Generation of electricity by different technologies "limit on CO2" MESSAGE

A large part of the production comes from new combined cycle plants "New_CC_PP", new TG200 "New_TG200" and solar concentrating plants. No new TG100 and a weak generation of new TG200s during the planning period. Thus a considerable generation of photovoltaic and wind.

4. Nuclear energy. This scenario serves to demonstrate the impact of nuclear energy on the national production park of the country.

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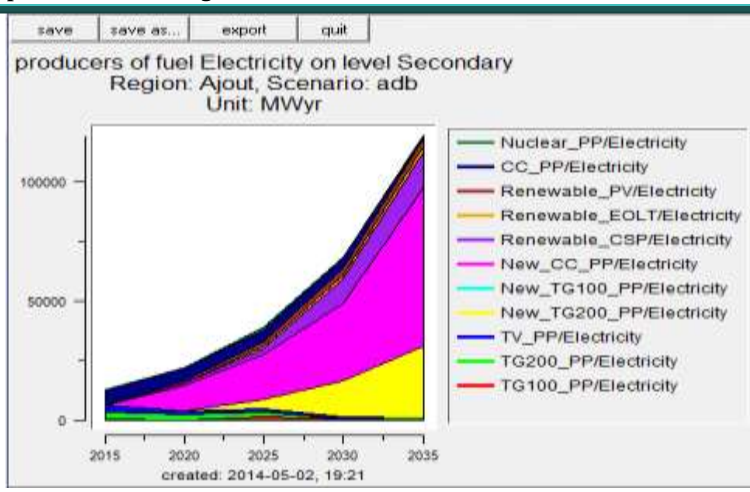

Figure 4.4: Generation of electricity by different technologies nuclear energy scenario

The results obtained differ little from those obtained in the reference scenario in that we realize the disappearance of the New_TG100 technology, New_TG200 contribution is replaced by the intervention of the nuclear technology in the third planning period [2025 2030]. The new combined cycle technology New_CC happens to have huge contributions over other technologies during the planning period.

4.2 The Green House Gas Emmisions

The cumulative GHG emissions for the study period from 2012 to 2035 in each of the scenarios are presented in Table 3. These emissions are significantly lower in the nuclear scenario. Putting limits on GHG emissions reduced them compared to the optimal and reference scenario.

Table 4.1: Cumulative GHG emissions for different scenarios (2012-2035)

Scenario	CO2 emissions (Million tonnes)	SO2 emissions (Million tonnes)
Reference Scenario	12401	6735
Optimal case.	16409	8206
Limit on GHG emissions	7630	3535
Nuclear energy.	5352	2534

4.0 Challenges

A couple of challenges were encountered during the project design and implementation stages.

1. Difficulty in acquisition of Field Data on some of the generating plants as most of this information is considered “Matter of national security”. I overcome this through establishing confidence with the authorities.

2. Lack of user-experience of MESSAGE simulation software given the fact that even my entourage didn’t have an exposure of it. But through reviewing user tutorials on related subjects coupled with Mr. Rogner’s help at IAEA headquarters in Vienna, I was able to maneuver.

5.0 Conclusion and Recommendations

5.1 Conclusion

Gas remains the dominant fuel for production of electricity during the study period. Introduction of significant nuclear capacity replaces gas to some extent and also contributes to reduction in carbon dioxide emissions.

Introduction of renewables also replaces gas to some extent and thus contributes to reduction in carbon dioxide emissions. Further scenarios can be designed in the form of hybrid scenario where both nuclear and renewables capacity can be increased along with utilization of hydropower to reduce the dependency on gas.

5.2 Recommendations

This study allowed me to learn and understand the modeling philosophy of energy systems on MESSAGE and analysis in order to deal with the problem of energy planning. In perspective, I propose continuity in this line of research, while involving other planning tools such as:
MAED: Energy Demand Analysis
WASP: Power Generation Expansion
FINPLAN: Financial Analysis of Energy Plans
In order to improve and concretize the aspect of energy planning work making the results fairer and more exploitable.

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