Analysing the impact of increasing renewable energy shares on Algerian energy system for prospective transition scenarios

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Received: 04/02/2023; Accepted: 05/07/2023; Published: 25/08/2023

Abstract:

Algerian energy policy goes forward with the diversification of resources and the integration of renewables to ensure energy security with less pollution. The aim of this study is a long-term evaluation of electricity production from renewable energy resources in the south of Algeria. This production is mainly based on solar and wind installations, which are convenient for desert climates and have a relatively long lifetime. The presentation of energy resource maps shows that the Saharan region has important high solar radiation and significant wind energy in the southern regions. Also, this entire region is characterized by wide flat areas, which allow huge expansion to develop profitable photovoltaic and wind farms. In this study, EnergyPLAN and MATLAB software have been used in modelling the hourly distribution and the numerical simulation. The progressive integration of renewable energy started with available data in 2015 and continues following the national renewable energy programme. The results obtained illustrate that by 2050, fuel consumption and CO_2 emissions can be significantly reduced. The cumulative primary energy savings could be more than 183 Toe by 2050. The prospect also shows that CO_2 emissions can reach a 58% reduction in comparison with the Business-As-Usual model. This level of pollutant emission represents a significant effort to close the environmental protection gap and keep fossil fuels available for the development of clean uses.

Keywords: Energy planning; renewable energies; electricity demand and supply; CO_2 emissions; EnergyPLAN

Tob Regul Sci. ™ 2023;9(1): 4595-4614

DOI: doi.org/10.18001/TRS.9.1.321

1. Introduction

The massive use of fossil fuels causes climate change and impacts human beings and the environment. These polluting energy sources increase greenhouse gas emissions, such as carbon dioxide (CO2). If the emissions continue to grow, then it will cause further global warming. For that, the World Bank played an important role in encouraging countries to utilise clean energy sources by providing financial motivation [1]. Many countries invested in renewables and unconventional fossil fuels, which augmented the share of renewable energies to about 10% of total energy in the present [2].

Algeria is characterised by important natural gas resources. Despite the Algerian economy's dependence on hydrocarbon exportation, it is strongly obliged to build sustainable development not based on fossil fuel rent. Therefore, it is necessary to introduce progressively alternative energy, which requires new production technologies based on renewable energy. These new energy sources can satisfy local demand and contribute to future electricity exportation. From this perspective, it is interesting to deploy the rent of fossil fuels to develop tomorrow's energy. In Algeria, the first attempts to integrate wind turbines into the electricity distribution grid were made in 1957 with the installation of a 100 kW wind turbine at the Grand Vent site in Algiers. This prototype is a bi-blades pneumatic type, 30 m high with a diameter of 25 m [3]. Then, after the important discovery of oil in Algeria, the tendency went towards conventional power plants, mainly those equipped with gas turbines. Nevertheless, recently, due to environmental concerns and a shortage of oil reservoirs, the Algerian government has developed an important plan for renewable sources to build strong energy capacity. Also, the policy aims to reduce consumption by improving energy efficiency. In this context, many studies have been largely carried out to concretize this strategy, such as Ghedamsi et al. [4], who studied the thermal comfort and economic energy in buildings during summer days by determining of the optimal insulation concentration for various wall orientations. Saiah et al. [5] addressed current and future scenarios of energy in Algeria for the short, mid, and long terms. A strong trend scenario estimated an augmentation of nearly 4 times the production capacity detected in 2012 (about 223 268 MW in 2062). This increase is accompanied by strong integration of RE, about 40% of total production, such as PV (45%), Wind (18%), and CSP (16%). For medium and low scenarios, they expect to reach 158 308 and 93 347 MW, respectively.

Several studies were carried out to assess the transition from fossil fuels to renewable energy and the rationalisation of energy consumption in many countries. In Denmark, Mathiesen et al. [6] presented the design and the development of a Smart Energy System (SES) as an integrated part of reaching the future of 100% renewable energy with transportation solutions as well. Cosic et al. [7] investigated two renewable energy scenarios in Macedonia. The first scenario was the 50 % renewable energy system for the year 2030 and the second scenario was designed for the

100%. The analysis illustrated that at present time the first scenario seemed much more likely than the second one, but, additional energy efficiency measures lead to reduced consumption and new installation capacities, so the goal could be easily reached. Bekteshi et al. [8] examined an integrated electricity supply–demand in Kosovo. This model is built in STELLA software with Medium Growth Scenarios at 10% of the global electricity production. Greenhouse Gases (CO_2 and NOx) emissions were decreased by 60% and other pollutants (SO_2 and dust) by 40% compared to the BAU scenario. Vidal-Amaro et al. [9] evaluated a 75% renewable-based electricity share goal towards a 100% renewable in Mexico which has 85% electricity generation by fossil fuels. Groppi et al. [10] analyzed the primary and secondary reserves of Favignana Island in order to plan a long-term energy transition using H2RES, a linear single-objective optimization model able to perform a long-term capacity investment and dispatching optimization. The finding showed that the ability of biomass to provide reserves and also decrease the unpredictability of the supply make it favored to both photovoltaic and wind turbines. However, Batteries and Electrolysers may also used for reserve provision. Jia et al. [11] studied by integrating algebraic target approach low-carbon energy planning. This improved approach allows negative emission technologies to better perform their risk-hedging role while facilitating the multi-period planning exploitation of various energy sources, methods of reducing greenhouse gas emissions, and CO_2 removal technologies. They evaluated the approach for two policy scenarios in China, short and long periods.

The impact of increasing renewable capacity could be investigated by EnergyPLAN software. It shows that a strategy for an appropriate share of renewable electricity is intended when every transition step corresponds to the optimal energy mix. Gerse [12] studied the increase of renewable electricity in Hungarian power generation. An analytical country-specific adequacy assessment model enabling the probabilistic modeling of wind generation plants is developed and applied to generating capacity forecasts. Adequacy indicators obtained show increasing reliance on imported electricity in the absence of investments in new power capacity. Morel et al. [13] analyzed the transient stability improvement of a power system containing a great amount of solar and wind generation in Japan. Results showed that sodium-sulfur batteries could maintain the system stability after strong transient disturbances and how the reduction of the inertia within the system could be mitigated by utilizing the kinetic energy of wind turbines. Mentis et al. [14] evaluated the establishment of renewable energy sources (solar and wind) in Greece. By integrating the Green scenario, 28.8% of total electricity production comes from wind and solar power in 2020, compared to only 5.5% in 2010. Taking into consideration a number of aspects, the realisation of the project leads to a 1.15 billion Euro higher profit at the end of 2020. Heaslip et al. [15] investigated sustainable energy society development methodologies in one village in Ireland and two islands in Denmark. They determined the enablers and barriers to their successful development.

The evidence indicates that social barriers are interlinked and reinforce each other, and barriers can be transformed into enablers for supporting successful development. Other studies look at more sectors towards 100% renewable energy systems, including electricity, heat, and transport, which have been developed [16,17]. Auguadra et al. [18] assessed energy storage requirements for a perspective energy plan with high shares of renewable energies to meet electricity demand in Spain. They developed a model by integrating new features such as demand response, correlation between reserve requirements and energy production technologies, and hydrogen. The simulation showed that goals for decarbonising the electricity system would be met at optimistic assumptions including an unexpected important role of energy storage and hydrogen storage when reach 100% renewable energy share.

More tendencies are oriented towards energy savings and renewable energy uses. While electricity savings must be heavily promoted, there is a growing interest in the integration of renewable energy into the electricity system to lower emissions [19, 20]. Ade et al. [21] proposed a combined approach for simultaneously determining strategic energy planning at local and national level. The approach consists of two optimization models; the first model evaluates the energy production configuration at a future date for a single-period. While the second model deals with generation expansion plan to optimize the energy transition over multiple-period from the present until defined future planning date. Hameed et al. [22] integrated a scalable carbon trading modelling approach into DECO2 open-source energy planning software. They proposed direct and indirect optimization approaches consist of superstructure-based mixed-integer nonlinear programming formulations. The models were tested on the power sector in Pakistan. Using direct optimization for minimizing greenhouse gas emissions showed that the carbon trading augmented profits significantly in some planning periods however, using indirect optimization illustrated higher profits in case of no carbon trading for all the periods. Jin et al. [23] proposed a new methodology for the medium-term energy planning of Marche Polytechnic University campus in Italy. The study aimed 50 % reduction of carbon emissions by considering financial investment aspects. To satisfy the end-users' energy demand, the university campus feed with multiple technologies such as photovoltaic, combined heat and power, gas-fired boilers, absorption, and electric chillers. To achieve final target, they investigated a different mix of installed and new technologies such as, energy storage and hydrogen.

The present work analyses the energy situation in Algeria, focusing on electricity demand and supply. It treats the current electricity demand and evaluates its perspective until 2050. Furthermore, it explains the influence of integrating renewable energies into the electricity balance, especially wind power and photovoltaic, to satisfy local demand and realise an excess for exportation. As a result, it can contribute to reducing the primary energy supply and CO_2 emissions.

The structure of this paper is as follows: in the first section, the conventional electricity flow system for actual supply and demand in Algeria is illustrated. We also present three supposed scenarios for electricity consumption. In the second section, electricity flow with integrated renewables, the penetration of renewable energies is shown, focusing on describing the solar energy system model and the wind turbine system model. In the third section, methods and materials, methodology, and used software are discussed. The fourth section deals with the results, interpretations, and main discussions. In the final section, we provide the main conclusions and suggestions for future work.

2. Electricity flow system

Actually, the Algerian electricity supply is predominantly based on fossil fuels, mainly natural gas. So, renewable energy should be introduced more and more into the energy system to reduce energy consumption. Also, it reduces the effect of greenhouse gases emitted from fossil fuel combustion. These reasons lead to across an important transition period, with attention paid to supply security and health risks related to the combustion of fossil fuels. For fossil-based systems in Algeria, fuels are provided for power plants in two forms; liquid and gaseous. The infrastructure and storage facilities are designed to meet the demand. For the transportation of fossil fuels over large distances, both trucks and pipelines are used. Figure 1 shows the diagram of conventional electricity flow. It includes a cooling system equipped with air conditioners and supplied from the electricity grid. But, heating is not included because the majority of houses and other sectors provide heat by burning natural gas and sometimes wood, so it consumes relatively small amounts of electricity.

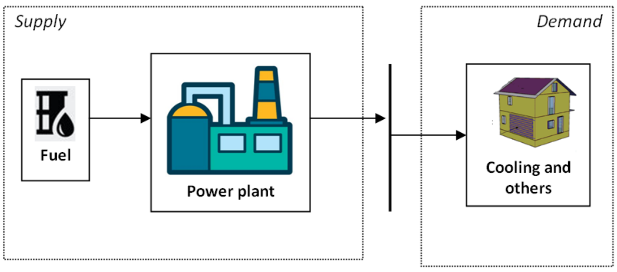


Figure 1: Conventional electricity system

2.1. Forecast of electricity consumption

In Algeria, as the energy demand grows according to population growth, electricity consumption has increased sharply in the last decades, from about 20 TWh in 2000 to nearly 69 TWh in 2015 and more than 84 in 2021 [24]. In this study, forecasting electricity consumption is based on a simple approach, in which increases in demand are fixed at the same levels over several horizons. Therefore, three scenarios of prospect increases in electricity consumption are distinguished:

• **Scenario 1 of no energy efficiency**: we suppose that energy consumption will remain at the same growth rate for the next few years, keeping energy demand values at a high level. So, the adapted average annual growth in demand would be about 3.3% per year.

• **Scenario 2 for less energy efficiency**: we consider the reduction rate of energy consumption proven in the last few years. Compared to scenario 1, the growth in energy demand for this scenario is set at 2.5% on average per year, so it will reach 181 TWh by 2050.

• **Scenario 3 for more energy efficiency**: in addition to the decline in energy demand in scenario 2, a stronger decrease in energy consumption appears due to a more voluntary policy of energy efficiency and the orientation of the country towards a high level of industrial development policy. The growth in energy demand for this scenario is set at an average rate of 1.8% per year.

Firstly, we carry out a comparison of the three different scenarios of energy supposition adopted in this study and the data approved by the Algerian Ministry of energy (see table 1). We observe that the two demand of energy scenarios; scenario 1 (of no energy efficiency) and scenario 2 (for less energy efficiency) can be compared to real scenario (data of real electricity consumption approved by the Ministry of Energy), due to their similarity in terms of energy evolution suppositions over the years 2015 and 2021. Scenario 2 goes very considerably to almost the same energy demand as the real scenario, which respectively achieves 70.55 against 70.75 TWh in 2016 and 78.18 against 79.09 TWh in 2020, while scenario 1 also goes close to the real scenario reaching, 76.16 against 76.57 TWh in 2018 and 84.20 against 84.24 TWh in 2021.

Table 1: Assessment of electricity consumption per scenario [TWh]

Year	Scenario 1	Scenario 2	Scenario 3	Real Consumption
Start 2015	68.77	68.77	68.77	68.77
2016	71.24	70.55	70.00	70.75
2017	73.66	72.39	71.26	76.67
2018	76.17	74.27	72.55	76.57
2019	78.76	76.20	73.85	81.37
2020	81.44	78.18	75.18	79.09
2021	84.20	80.22	76.54	84.24
Scenarios Final year 2050	229.44	181.75	143.71	/

Then, we adjust the perspective scenarios to start in 2021. Figure 2 shows the evolution of the three different scenarios of electricity consumption adopted to predict the growth in consumption until 2050. We observe a surplus rate of energy demand increase, probably provided by conventional fossil fuels and nonrenewable resources. The most worrying thing is that energy demand can reach a double amount (160 TWh) in 2040 and a triple amount (229 TWh) by 2050 if it keeps growing following scenario 1 (of no energy efficiency). However, scenario 2 (for less energy efficiency) and scenario 3 (for more energy efficiency) can be taken as transition scenarios if the country wants to enhance the energy system and reduce electricity consumption by 21% and 38 %, respectively. In this context, the government launched the national efficiency programme (2016–2030), focusing on the rationalisation of consumption, which has an important influence on the energy sector [25]

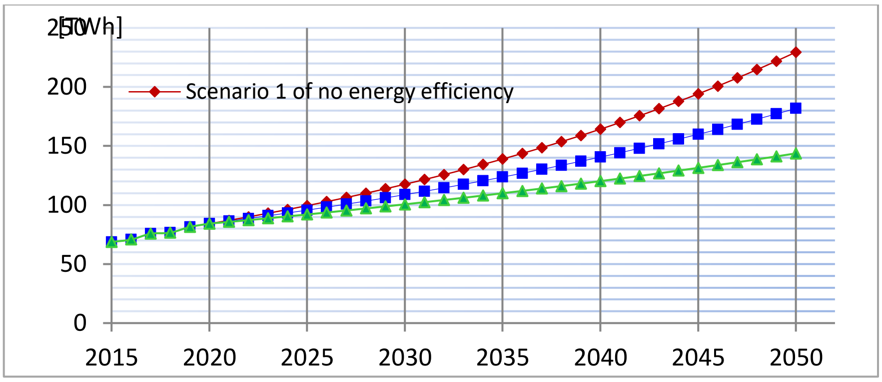


Figure 2: Evolution of electricity consumption

Figure 3 shows the hourly evolution of electricity consumption in 2014, which was collected from the daily consumption published by the Algerian electricity company website [26]. Consumption registered a low level during March due to moderate temperature and more natural lighting. The consumption was maximal in August because of the over use of different cooling means during this high-temperature period.

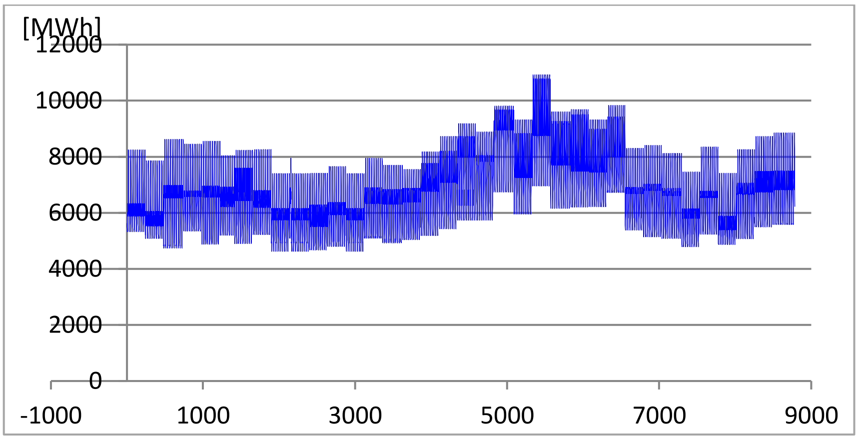


Figure 3: Hourly electricity consumption in 2014

2.2. Installed power capacity

To satisfy the growing demand for electricity, the production capacity has grown continuously at an average rate of about 4.1% [27]. The total installed power capacity reached 15.80 GW in 2014 [27]. Moreover, 99 % of the population has been connected to electricity since 2014 [24]. Currently, the most important national power plants are found in the north of the country, gas turbines are the major technology used to produce electricity. In the south, there is a small capacity that uses diesel generators. Consequently, more than 99% of Algeria's electricity generation comes from fossil-fuel sources [28], and the remaining share of 0.8% comes from renewable energies, in particular hydropower. Over 98% of electricity production is based on natural gas [29].

According to Saiah et al. [5], the production capacity will reach 28.58 GW in 2024, while it was estimated to reach 223.27 GW in 2062. Other scenarios consider more energy efficiency, estimated at 93.35 MW in 2062. However, in this study, minimum installed capacity based on the projected evolution of energy consumption will be considered for the three scenarios.

3. Electricity flow with integrated renewables

Figure 4 shows the alternative electricity flow diagram, which indicates the different energy supply systems, including renewable energy sources (RES). These new resources are illustrated by wind power and PV systems. The energy flow diagram illustrates a specific relationship between demand and supply (i.e., renewable power and electricity demand). The aim here is to define the need to provide integrated electricity systems and identify feasible options for gradually minimising fossil fuel energy consumption. Therefore, the supply and demand systems are met through different pathways for the whole year (i.e., exploiting more fossil fuels when there is a shortage in RES).

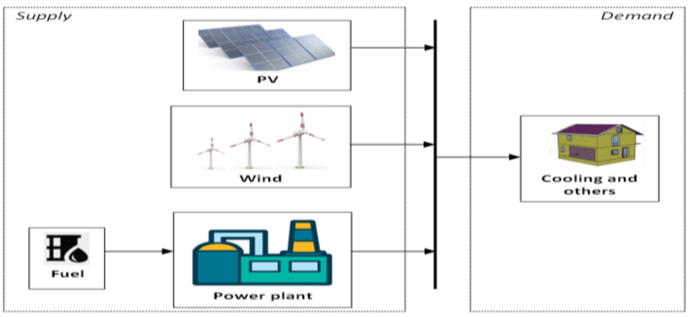


Figure 4: Alternative electricity system

3.1. Solar energy system model

In this study, to develop a solar irradiation map for the region, the solar database given by Meteonorm is used, which allows access to historical time series of irradiation and temperature. The new archive contains hourly data since 2010 and is constantly updated. It can download the time series directly from the Meteonorm software. By using the spatial interpolation technique to predict the solar irradiation in locations where data are not available. Several methods are available to construct an interpolated surface between available point's data measurements [30]. In this study, the method used to convert the point data into raster format is the Inverse Distance Weighted (IDW) method in GIS software to assign the annual average solar radiation map in Algeria (see figure 5).

The average sunshine time over Algerian territory exceeds 2000 hrs annually and reaches 3900 hrs in south of Algeria [31]. The daily energy obtained in a horizontal surface is 5kWh/m^2 over the most part of the national territory, and about 2263 for the south and 1700 kWh/m^2/year for the north of the country. This solar radiation potential explains taking solar energy as an important energy source for different applications of PV solar panels.

The region of northern Sahara has been chosen as suitable locations to install the PV fields. This region is formed by wide plate lands, has high solar radiation and is located near the roads and main electricity networks [30]. PVGIS software (version 5) is used to determine hourly radiation for each day [32], then these data are collected together to form the hourly radiation during one year.

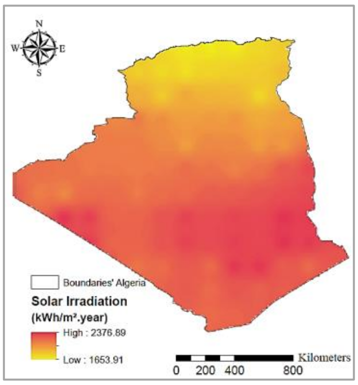


Figure 5: Solar Irradiation (kWh/m²).

3.2. Wind turbine system model

The GIS software is used to assign the map of average wind speed, which shows important wind energy resources (see figure 6). Adrar is considered the windiest region in the whole country; evaluations make this region a very suitable site for the establishment of wind farms, where some wind turbines have been already installed [31]. This region is located in the South-West of Algeria (around, Longitude: **27.88** °N, Latitude: **0.28** °W) is characterised by a high potential for wind energy; the average wind speed reaches 6.62 m/s.

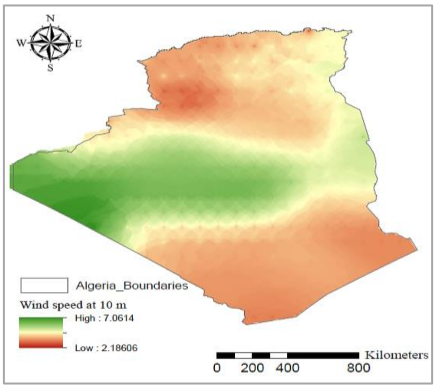


Figure 6: Average Annual Wind Speed (m/s).

The chosen wind turbine is Gamesa G52 which is already used in Kabertan farm in Adrar (Algeria), their factors have to be considered to determine the wind power output. The machine is an MADA type (Asynchronous double feeding machine) of the manufacturer GAMESA. It produces 850 kW sized for an air density of 1.225 Kg/m^3 for a network of 50 Hz, the speed of rotation between 14.6 and 30.8 rpm. The turbine has 4 m/s and 25 m/s as cut-in and cut-out speeds respectively [33]. For this chosen turbine, daily wind speed distribution is determined by Weather underground website [34], then, this data is collected together to form hourly wind speed during 2014.

The distribution of produced wind energy is calculated using the following model and conceived MATLAB program and the specific parameters of Adrar region [35] are taken from input data. Simplified model [36] is chosen to simulate the wind energy; it is described by equation 1 as fallow:

$$Pw(V) = \begin{cases} PR[(V^2 - V_C^2)/(V_R^2 - V_C^2)]; & V_C \leq V \leq V_R \\ PR; & V_R \leq V \leq V_F \\ 0; & \text{otherwise} \end{cases} \quad (1)$$

Where:

PR is the rated electrical power;

P_w is the produced wind power;

V_C is the cut-in wind speed;

V_R is the rated wind speed;

V_F is the cut-off wind speed.

The adjustment of wind profile for height is carried out by using the power law to model the vertical profile of wind speed. The equation 2 is described by [37, 38]:

$$V(H)/V(H_{ref}) = (H/H_{ref})^{\alpha} \quad (2)$$

Where:

V(H) is the wind speed at hub height H, m/s;

$V(H_{ref})$ is the wind speed measured at the reference height H_{ref} [m/s];

α is the power law exponent. The determination of α is very important (equation 3).

$$\alpha = (0.37 - 0.088 ln V_{ref})/[1 - 0.088(H_{ref}/10)] \quad (3)$$

The value of 1/7 is usually taken when there is no specific site data [38, 39].

3.3. Renewable energy plan

The most important advantages of alternative energy sources are the reduction of primary energy and greenhouse gas emissions. For the whole study, the national programme of renewable energy installations in Algeria is taken as support of electricity perspective [29] (see figure 7). This programme has been created to develop the use of renewable energies and encourage energy efficiency. The national programme leans on a plan concentrating on exploiting sustainable energy resources, such as wind and solar energies in order to vary energy sources and begin a new period of renewable energy use. In this programme, the country planned to install up to 22 GW of renewable power capacity from 2011 to 2030, including 12 GW for covering national electricity demand and 10 GW for exporting energy [31].

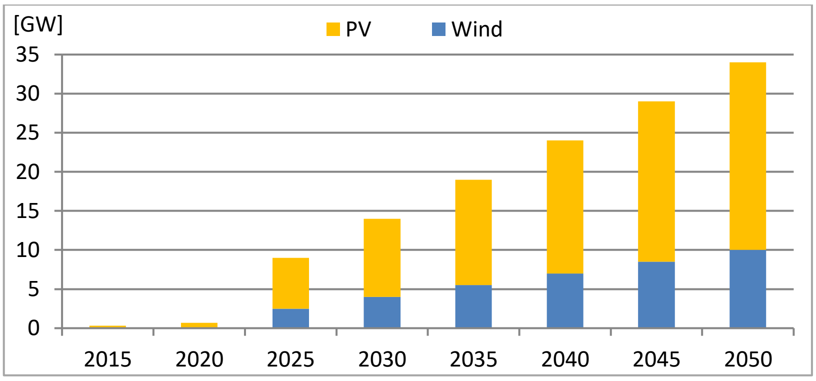


Figure 7: Perspective of renewable energy installed capacity.

Algeria is indeed aiming to be a major actor in the production of electricity from photovoltaic, wind power, and concentrated solar power [26, 31], which will be drivers of sustainable economic development and promote a new model of growth. This last option depends on the availability of a demand that is ensured over the long term by reliable partners as well as on attractive external funding. The latter leads to keep increasing renewable power capacity at the same level, from 22 GW in 2030 to 34 GW by 2050.

4. Methods and materials

In this study, EnergyPLAN software is used to calculate the evolution of the energy situation in Algeria from a long-term perspective. The main task focuses on keeping balance between supply and demand for electricity. While renewable energy is integrating progressively into the national electricity grid. In this work, all interest is given to the integration of energy produced by photovoltaic and wind power.

EnergyPLAN version 12.4 is adopted with the specific characteristics, and the technical simulation option is selected: total electricity demand in [TWh/year] and hourly electricity consumption in [MW]. The hourly consumption is multiplied to be adopted with different energy scenarios (see figure 3). Energy supply in [MW] includes fossil fuel power and RES (see sections 3.1 and 3.2). Fossil fuels will produce electricity in the time-step in which there is under-generation of electricity from RES in order to minimise CO_2 emissions. The first inputs are chosen to achieve the energy required for all scenarios. The second input is obtained by optimising the variables CO_2 in [Mt] under the output section, which correspond to the electricity produced by fossil fuels. The decision variables are installed power capacity, CO_2 emissions and produced energy on which the analysis of power capacity growth is performed. These three variables are chosen as decision criteria together with a number of other factors such as the national plan for renewable energies, energy exchange with neighbouring countries, etcetera. Figure 8 presents a simple explanation of how EnergyPLAN software works.

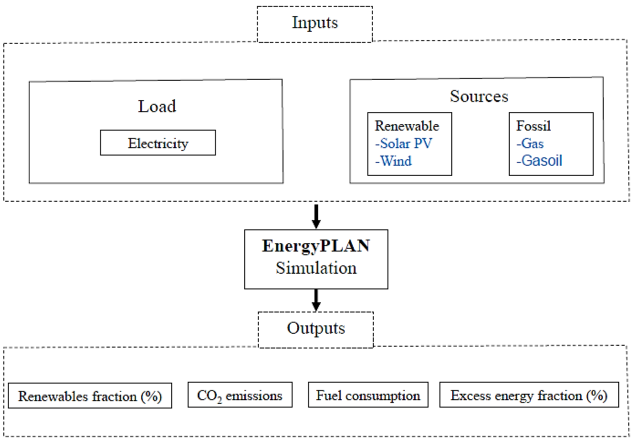


Figure 8: Simplified model architecture of EnergyPLAN software.

5. Results and discussions

5.1. Production capacity outlook

In order to analyse the electricity balance in Algeria, three scenarios (see figure 9) are generated based on the prospect scenarios of electricity consumption that were previously described in Section 2.1. For scenario 1, the minimum production capacity is 76 GW by 2050, of which 44% is expected to be guaranteed by RES. For scenario 2 and scenario 3, the production capacity predicted is less, and the share of RES is respectively 50% and 57% by 2050 compared with the total energy. In term of production technologies, for conventional systems; gas and steam turbines are dominant with 98% of the market. For RES, PV is the principal, with 70% by 2050.

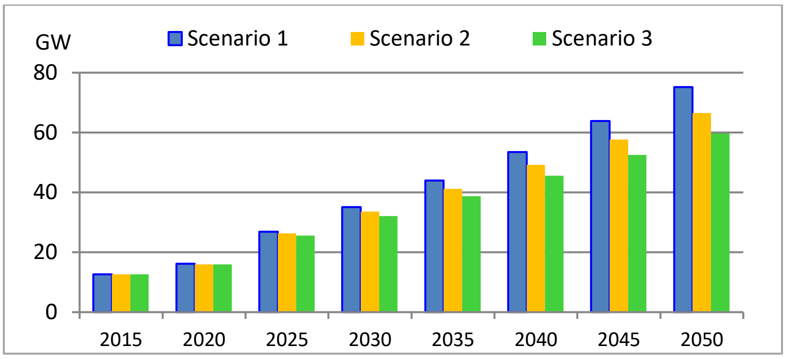


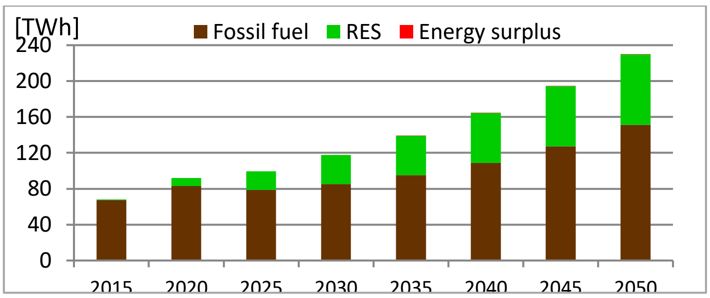
Figure 9: Evolution of electricity production capacity.

5.2. Energy supply

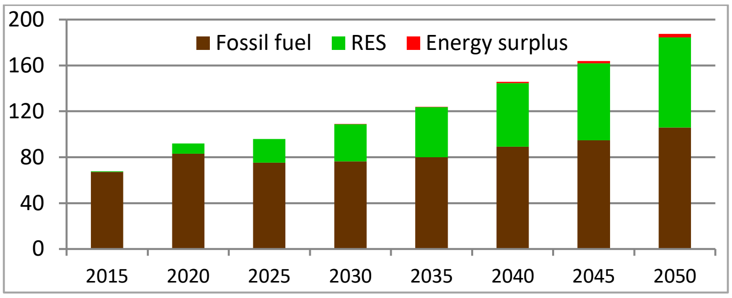
The simulations allow estimating the expected energy planning with different horizons for the three scenarios defined above: scenario 1 (of no energy efficiency), scenario 2 (for less energy efficiency), and scenario 3 (for more energy efficiency).

Figure 10 shows the energy supply for the three scenarios. For both the first and second scenarios, the use of fossil fuel power increases continuously until 2050. From 2030, the energy supply will register small exports, which change according to the RES capacity integration plan. This surplus can be overcome by reducing stock capacity (described in Section 5.3). We notice that the RES share in total energy supply increases when energy demand decreases, so RES contribution for the three scenarios 1, 2 and 3 will be respectively, 34%, 43% and 52% by 2050.

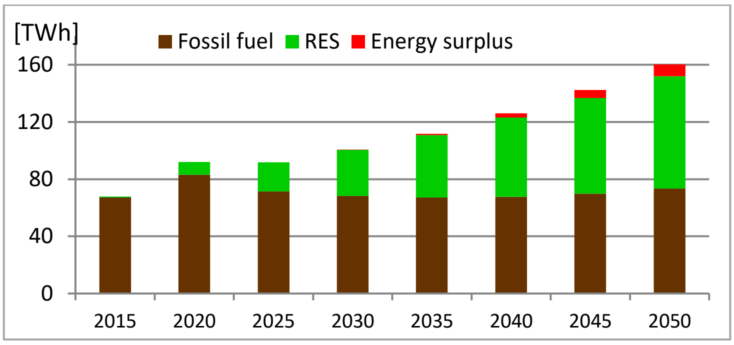
For scenario 3, fossil fuels consumption decreases slightly, which is a positive sign for the national programme for more efficiency. Moreover, an important part of this reduction is compensated by the increase in RES share. In this context, comparing with scenario 1, the cumulative primary energy savings by 2030 will be 19.98 Mtoe (equivalent of 21.84 billion cubic meters of natural gas) and 172.53 Mtoe (about 188.65 billion cubic meters of natural gas) by 2050.



a) Scenario 1



b) Scenario 2



c) Scenario 3

Figure 10: Yearly electricity production by different sources.

5.3. Critical excess of electricity production

CEEP is the critical excess of electricity production of the installed system. In figure 11, we can observe the evolution of CEEP for the period from 2015 to 2050 where CEEP increases progressively for the three scenarios. CEEP is linked to renewable energy production which has the same augmentation per year for the three scenarios. This excess can be remedied by exporting electricity to neighbouring countries in the Maghreb zone like Tunisia and Morocco which are currently exchanging small amounts of electricity across common borders (673 GWh for Tunisia and Morocco in 2019) [24]. But, due to lack of data this parameter cannot be implemented and regulated. In this context, it is highly recommended, for future projects, to push future Algerian plans for exporting electricity to the European market by a linked network across the Mediterranean Sea.

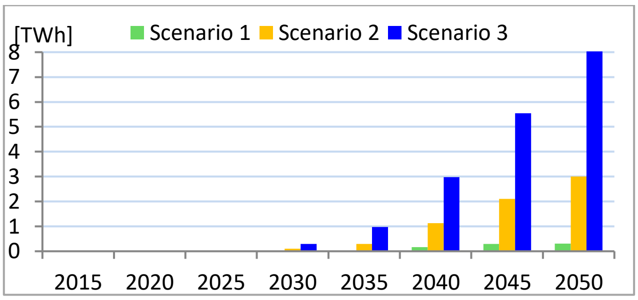


Figure 11: Evolution of CEEP

5.4. Carbon Dioxide emissions

Worldwide, since 1950, CO2 has continued to grow significantly. In Algeria, this emission is growing steadily, from 360 ppm in 1995 to 385 ppm in 2008 [40]. The annual average growth of 2% seems to be in line with the increase in the average annual consumption of energy during this period. For these emissions, the production of electricity accounts for 40% of CO2 emissions [40]. In this context, an important interest is given to CO2 emissions. Figure 12 shows the evolution of these emissions in the three scenarios. It is noticeable that the emissions quantity changes in harmony with the changes in primary energy supply from non-renewable energies. For instance, CO2 emissions vary from 30.68 Mt in 2015 to more than 35 Mt for "scenario 2" and more than 39 Mt for "scenario 1" by 2030. CO2 emissions will also reach critical levels, nearly 69 Mt by 2050, if energy demand keeps growing at the same rate as "scenario 1". On the contrary, if we apply more energy-saving actions as in "scenario 3", CO2 emissions will be reduced to save levels of 33.47 Mt with reduction of 51% compared to scenario 1.

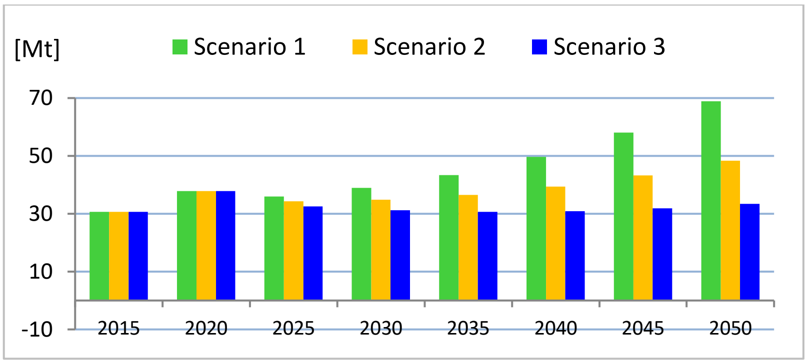


Figure 12: Evolution of CO_2 emissions

5.5. Optimization of energy supply

The last step in this study is the optimisation of energy supply problems relevant to the current analysis. As mentioned before, excess electricity can be exported to neighbouring countries across common borders, and the next project of Algeria's plan is to export electricity to European countries. At the same time, the country can import limited amounts of electricity when needed (i.e., 531 GWh from Tunisia and Morocco in 2019) [24].

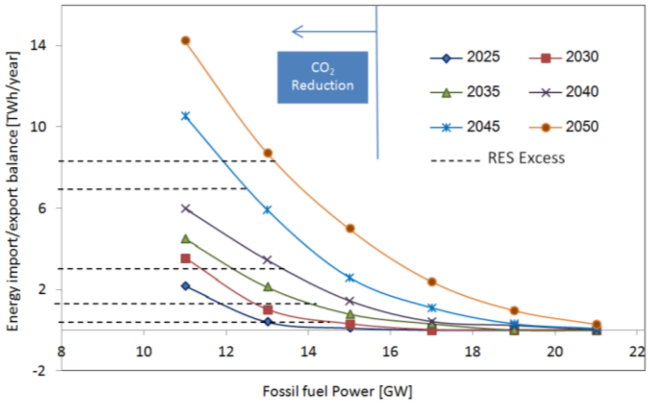


Figure 13: Total energy import/export, fossil fuel and CO_2 emissions

The optimisation problem is formulated to handle the impact of different levels of penetration of RES electricity and their effects on the import/export balance. The RES share is augmented each year as in the national programme of RES; however, the CEEP will also increase (see figure 11). In order to find the optimal solutions, we apply the following considered assumptions: keeping CO2 emissions at the lowest level by reducing the reliance on fossil fuels; covering total electricity demand in hourly consumption variation (see figure 3); activating energy import only when other options are not available; no energy storage is included.

The finding concentrates on the analysis of optimised scenario 3 results and comparing them with those of the other scenarios. In addition, the comparison of the scenarios with similar energy demand scenarios "for more energy efficiency" permits studying the best option to decarbonise the national energy system.

Figure 14 illustrates the characteristics of the chosen scenarios with a comparison of the values of the main cases. This gives an idea of how the optimised scenario, when compared to the best "scenario 3", proves an optimal installed production capacity of the energy system with higher values of RES production penetration. Furthermore, another difference is the higher share of RES in final energy (i.e., electricity in this case): 57% for the optimised scenario (see figure 15), compared to 34% for scenario 1, and 54% for scenario 3. The cumulative primary energy savings by 2030 will be 20.24 Mtoe (the equivalent of 22.13 billion cubic metres of natural gas) and 183.53 Toe (about 200.06 billion cubic metres of natural gas) by 2050.

The reduction of primary energy consumption leads to an important decrease in CO2 emissions. So, the burning of fossil fuels is very sensitive to improving or degrading the pollution situation. In figure 16, a comparison of CO2 emissions between business as usual with no energy efficiency and optimised scenarios is performed. It indicates that, by the horizon of 2050, CO2 emissions will be 29.48 Mt, so the reduction could achieve a savings level of 58%.

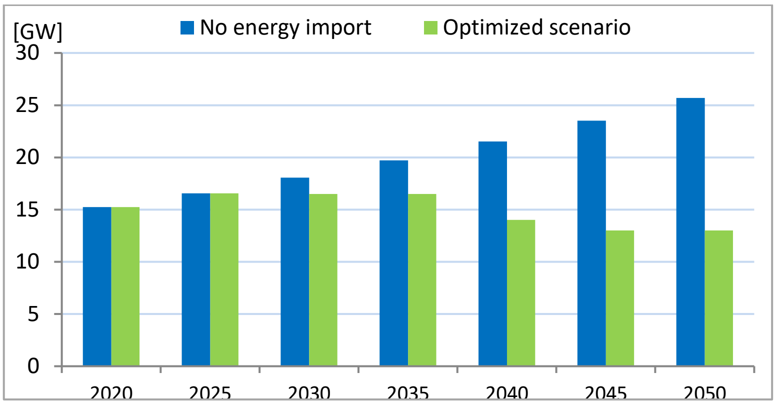


Figure 14: Electricity production capacity "fossil fuels".

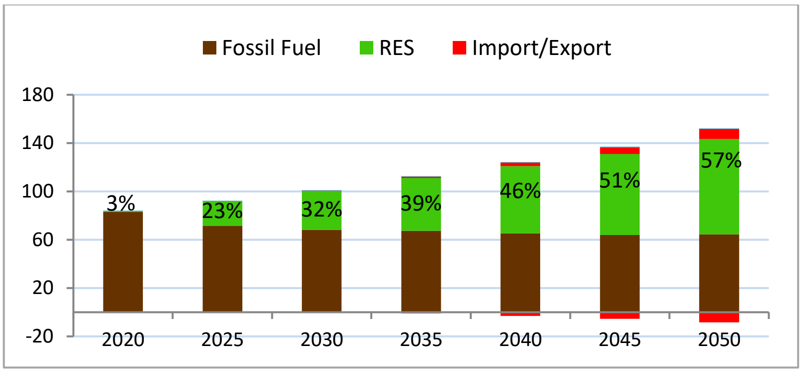


Figure 15: Yearly electricity supply for the optimized scenario.

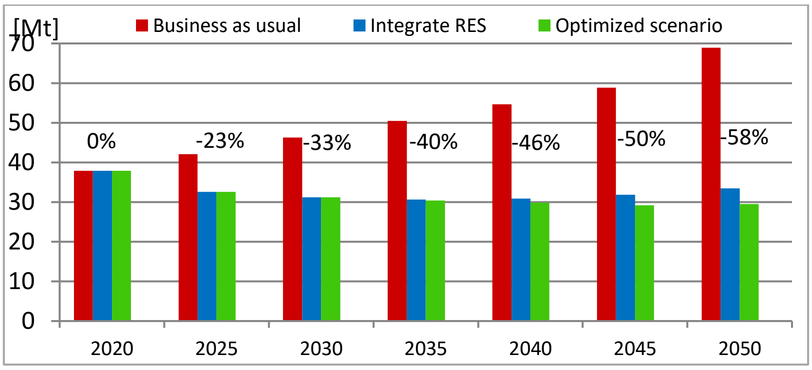


Figure 16: Comparison of CO_2 emissions for studied scenarios.

Conclusions

Electricity production should undergo a serious improvement to increase its current capacity. However, this will be concretized only if Algeria can achieve all the traceable projects in the national program. Fossil fuels provided 98% of the total primary energy in 2020, so they remain the first provider of national energy requirements. The share of renewable energy in the energy supply will increase rapidly if we follow the national programme for renewable energy to reach 22 GW of installed capacity in 2030. This capacity will attain 34 GW by 2050 if we keep increasing renewable power at the same rate.

In the current energy situation, the produced electricity is 84 TWh/year, and the primary energy is 15 Mtoe combined with 37 Mt of CO2 emissions in 2020. This level of pollutant emission presents a considerable challenge in order to minimise the gap in environmental protection, keep non-renewable fuels, and develop clean energy uses. For that, if applying more energy-saving policies and following the national efficiency programme (2016–2030), fuel consumption and CO2 emissions can be significantly reduced, the prospects show that CO2 emissions can reach 58% reduction in comparison with the business-as-usual model by 2050.

Finally, according to the findings of this study, a clear vision of a desirable future is given to policymakers, but it is evident that whatever the proposed scenarios, energy production needs to be developed to stay more secure and meet all future requirements. Moreover, integrating extra renewables such as concentrated solar power, biomass energy, etc. and studying other sectors, for example transportation, will help researchers have a larger energy planning view.

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