Renewable Energies in Algeria

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***Abstract*—The Algerian economy is dominated by its oil and gas resources, which account for 98 percent of the country's exports. The hydrocarbon sector represents about almost half of total GDP and about two-thirds of budget revenues. If the economy remains too dependent on hydrocarbons and does not diversify, it will remain vulnerable to negative shocks on oil prices and will not be able to generate enough jobs. Every time Algeria faced a large drop in oil prices, it then had to cut back on public spending. The country can theoretically avoid future crises smoothly as it has broad reserves of other power resources. There is respectable capacity to use renewable power sources, particularly regarding solar, wind and biomass energy. This thesis is a presentation of the current energy-production situation in Algeria and the possible integration of renewable energies and its benefits for the country.**

I. Introduction

When it comes to security and stability of a country, economic stability is considered a big factor. Throughout the history of civilizations, poverty has been the lead cause of riots and protests which are more likely to drive the country into more interior conflicts and eventually civil wars, putting more emphasis on the importance of having stable resources that generate systematically a stable income. Furthermore, the unemployment rate is expected to decay if the country was introduced to new energy resources other than fossil fuels.

Unlike conventional energy sources, renewable energy sources are those found in nature in unlimited quantity, which can be regenerated naturally or artificially and whose impact on the environment is practically nil or reversible. Among renewable energies we can find hydroelectric, wind, solar, geothermal, tidal, and biomass energy.

Energy consumption in the world is growing constantly throughout the years, as the sectors: industry, domestic, transport, and trades/commerce, are getting larger. A big portion of the energy used is generated from fossil fuels, lignite, and coal. Many countries adapted nuclear power, which is cleaner while generating electricity. Nuclear fission provides energy without releasing greenhouse gases such as carbon dioxide. However, nuclear power plants generate radioactive waste, a critical factor when doing a fossil fuel to nuclear power pollution comparison.

The greenhouse effect is a natural process that warms the Earth's surface. When the Sun's energy reaches the Earth's atmosphere, some of it is reflected back to space and the rest is absorbed and re-radiated by greenhouse gases. The absorbed energy warms the atmosphere and the surface of the Earth. This process maintains the Earth's temperature at around 33 degrees Celsius warmer than it would otherwise be, allowing life on Earth to exist.

Producing electricity from coal and natural gas releases huge amounts of CO_2, contributing to global warming. Global warming, the gradual heating of Earth's surface, oceans and atmosphere, is caused by human activity, primarily the burning of fossil fuels that pump carbon dioxide (CO2), methane and other greenhouse gases into the atmosphere. Higher temperatures are worsening many types of disasters, including storms, heat waves, floods, and droughts. A warmer climate creates an atmosphere that can collect, retain, and drop more water, changing weather patterns in such a way that wet areas become wetter and dry areas drier. Extreme weather will damage property and critical infrastructure, impact human health and productivity, and negatively affect sectors such as agriculture, forestry, fisheries and tourism. In addition to lower rainfalls, that might lead to water shortage.

Speaking of climate, Algeria is the biggest country in North Africa, containing various geographical territories with different climate attributes, which makes it suitable for the application of different renewable energies that require certain environmental attributes. The Algerian government in recent years has put efforts and focus on 3 main renewable energies: Solar, wind, and biomass energies.

Although only half of the solar radiation makes it to the Earth's surface and the rest is either absorbed or reflected by clouds and the atmosphere, still, we receive enough power from the sun to meet the power demands of all mankind — millions of times over. Solar energy can be used directly for heating and lighting homes and businesses, and for generating electricity. Most critical, given the growing concern over climate change, is the fact that solar electricity generation represents a clean alternative to electricity from fossil fuels, with no air and water pollution, no global warming pollution, no risks of electricity price spikes, and no threats to the public health. Once a system is in place to harness the solar resource and convert it into useful energy, the profit margin becomes more attractive to further investments. One of the most common ways to use solar power is to use photovoltaic systems, which produce electricity directly from sunlight. The semiconductor materials used in these solar energy systems absorb sunlight which creates a reaction that generates electricity – to be exact, the solar energy knocks the electrons loose from their atoms which makes them flow through the semiconductor material and produce energy. Because of their adjustable size photovoltaic arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. Another way of electricity generation by solar energy, is similar to nuclear energy generation, except that the solar radiations boil the water to turn a turbine instead of the heat of nuclear reactions. The power tower system uses a large field of mirrors to concentrate sunlight onto the top of a tower, where a receiver containing molten salt sits. The salt's heat is used to generate electricity through a conventional steam generator. Molten salt retains heat efficiently, so it can be stored for days before being converted into electricity. That means electricity can be produced on cloudy days or even several hours after sunset.

Using wind as a renewable energy source has fewer effects on the environment than many other energy sources. Wind turbines do not release emissions that can pollute the air or water (with rare exceptions). Wind turbines may also reduce the amount of electricity generation from fossil fuels, which results in lower total air pollution and carbon dioxide emissions. An individual wind turbine has a relatively small physical footprint. Groups of wind turbines can be located on open land, on mountain ridges, or offshore in lakes or the ocean. Although the good framing wind energy has, it also causes some problems. Modern wind turbines can be very large machines, and they may visually affect the landscape. Furthermore, producing the metals and other materials used to make wind-turbine components has impacts on the environment, and fossil fuels may have been used to produce the materials.

Thirdly, biomass is a renewable energy resource derived from the waste of various human and natural activities. Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel. Installing a biomass boiler reduces household CO2 contributions, making it an incredibly green way to run houses heating.

Theoretically, a combination of the three previously mentioned renewable energy sources exists in such a way that not only convers the energy demand but creates a market for exporting energy that leads to economic growth.

There are also other types of renewable energies that this thesis is not focusing on. Geothermal energy is a renewable energy source that comes from reservoirs of hot water beneath the Earth’s surface. Geothermal power plants use hot water to generate steam to turn a turbine for electricity generation. Since the heat of the water is the essential component of a geothermal power plant, these active systems are typically located where hydrothermal reservoirs exist. Hydropower is the process of utilizing the mechanical potential energy of flowing water, transforming it into electrical energy to generate electricity. Hydroelectricity is generated at a hydroelectric facility (hydroelectric dam holding back a large quantity of water, creating a reservoir). The reservoir holds water at a higher elevation than the rest of the original body of water (generally a river). Compared to the water in the river, the water in the reservoir has more potential energy. When a gate is opened at the top of the dam, the water flows through channels called penstocks down to the turbines. When the water reaches the turbines, the potential energy it held from being stored up in a reservoir is transferred to the rotational motion of the turbines. As the turbines spin, they move a generator and generate electricity.

Energy storage plays an important role in this balancing act and helps to create a more flexible and reliable grid system. There are many types of storing energy. Energy can be stored in chemical storage such as hydrogen storage. Which can be stored as a gas typically requiring high-pressure tanks or as a liquid requiring cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is -252.8°C. Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption). Thermal energy storage stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time. Sensible heat storage technologies includes water tank, underground, and packed-bed storage methods, latent-heat storage systems associated with phase-change materials for use in solar heating/cooling of buildings, solar water heating, heat-pump systems, and concentrating solar power plants as well as thermo-chemical storage. Pumped storage stores energy by pumping water from a lower reservoir up into a holding reservoir. Excess energy is stored as gravitational potential energy of water. Since these reservoirs hold such large volumes, pumped water storage is considered to be a large scale energy storage system which is moderately efficient. It is a dispatchable source of energy since it can be deployed whenever demand is needed. A flywheel system operates like a dynamic battery that stores energy kinetically by spinning a mass around an axis. Electrical input spins the flywheel rotor up to speed, and a standby charge keeps it constantly spinning until it is called upon to release the stored energy. The amount of energy available and its duration are proportional to its mass and the square of its revolution speed. For flywheels, doubling mass doubles energy capacity, but doubling rotational speed quadruples energy capacity. Electrochemical energy storage is a method used to store electricity under a chemical form, benefiting from the fact that both electrical and chemical energy share the same carrier, the electron. This common point allows to limit the losses due to the conversion from one form to another. Rechargeable batteries and supercaps are essential as they are essential parts of any portable media devices (smartphones, tablets) as well as key to a more sustainable future (energy storage from renewable sources, electric cars).

Transmission plays a key role in covering demands and exporting energy. For a country as vast as Algeria, transmission lines may introduce an unnecessary load on the budget if not implemented in the most efficient way. The strategic allocation of generation stations is also an important factor in reducing the cost of transmitting energy both nationally and internationally. On the other hand, storage is systematically integrated in the process of implementing renewable energy generators, as both of the demand and generation experience fluctuations.

To meet the air-conditioning requirements of building, absorption chillers and heat pumps can be used, which transfer water or a refrigerant through a cycle of evaporation and condensation. Biomass can be also used for heating as it can be cheaper than fossil fuels, however it isn’t climate neutral. Heat also can be generated from ammonia and hydrogen when used like LPG as they can be renewably produced. Lastly Solar-thermal vacuum collectors can a significant amount of heat energy due to the higher efficiency.

Converting transport on land to be renewable energies based, can be done through the electrification of vehicles using hydrogen fuel cells and battery electric drive or hybrid systems as they can overcome non-electrified track sections (trains). Concerning transport by sea, renewable energy use is profitable for only short range ships. The type of storage used depends not only on the efficiency needed but also on the volume. When it comes to transport by air, the biggest issue is the power-to-weight ratio of the electric motors, whereas hydrogen or electric drive supplies can be used as a form of propulsion.

Reducing the amount of CO_2 in the atmosphere is an important part of reversing the global warming trend. It can be reconverted to carbon or captured directly from air (DAC), however permanent storage is crucial as releases can be lethal. On the other hand, geoengineering aims to reverse global warming by managing the solar radiations, which can be done in multiple suggested ways such as increasing the earth surface reflection rate, yet reasonable methods are further to be discussed.

The current situation in the country is presented along the energy demands to display the importance of shifting to renewable energies for not only critical reasons, but also attractive financial profits.

II. Current Energy-Production and Its Consequences in Algeria

A. *Primary Energy Production* [1]

Commercial production of primary energy recorded a virtual stability (-0.2%) by compared to the achievements of 2016, reaching 165.9 M Toe.

Thus, the increase in natural gas production partially offset the decrease in production of liquids (petroleum and LPG) due in particular to the application of the agreement reduction in OPEC production.

TABLE I. Primary Energy Production (K Toe) in Algeria

Product	2016	2017	Evolution (%)
Natural gas	89,731	9,128	1.7
Crude oil	56,193	54,564	-2.9
Condensate	10,449	10,436	-0.1
LPG	9,726	9,416	-3.2
Primary Electricity	80	150	86.3
Solid fuels	6	10	72.2
total	166,184	165,861	-0.2

Note that the doubling of primary electricity production (including the hydropower), which rose from 336 to 635 GWh in 2017, following the construction of new renewable electricity production capacities. Thus, the year 2017 saw the entry into production of 5 photovoltaic power plants, one combined capacity of nearly 125 MW; which increased the share of original production solar and wind in the total primary electricity production to more than 90%.

In contrast, hydroelectricity production fell (-22%) to 56 GWh, given the low rainfall, reducing its share to less than 10% of primary electricity.

B. *Derivative Energy Production* [1]

Derivative energy production reached 64.2 M Toe, up 1.8% from the achievements of 2016, following the increase (+6.0%) in the production of liquefied natural gas (LNG), thermal electricity (5.2%) and LPG (5.3%). This increase has more than offset the drop in production of petroleum products (-2.7%).

TABLE II. Derivative Energy Production (K Toe) in Algeria

Product	2016	2017	Evolution (%)
Oil Products	29,953	29,139	-2.7
Thermal Electricity	16,860	17,743	5.2
LNG	14,963	15,862	6
LPG	1,316	1,386	-3.2
Blast Furnace Gas	-	85	-
Total	63,091	64,215	1.8

C. *Energy Exchange* [1]

The balance of energy exchanges shows a net export balance of 104.1 M Toe, -2.3% compared to 2016, following the drop in primary energy exports (-3.8%).

TABLE III. Energy Exchange (K Toe) in Algeria

	2016	2017	Evolution (%)
Exportations	110,643	108,257	-2.2
Primary	78,673	75,679	-3.8
Derivative	31,970	32,578	1.9
Importations	4,124	4,189	1.6
Primary	257	244	-4.9
Derivative	3,868	3,945	2
Exportation net	106,519	104,068	-2.3

D. *Electricity Generation by Source*

The electricity generation in Algeria is dominated by oil and natural gas. The total electricity production during the year 2017 reached 71,470 GWh [2].

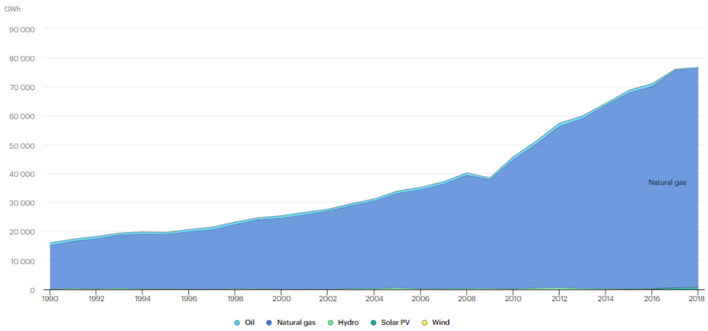

Fig. 1. Electricity production by source

E. *Current Energy Production in Relation to Unemployment Rate*

The Algerian population experiences a growth of approximately 2% annually [3], while consisting of 42.97% in the age category of 25-54 years (male 9,067,597 female 8,833,238) [4].

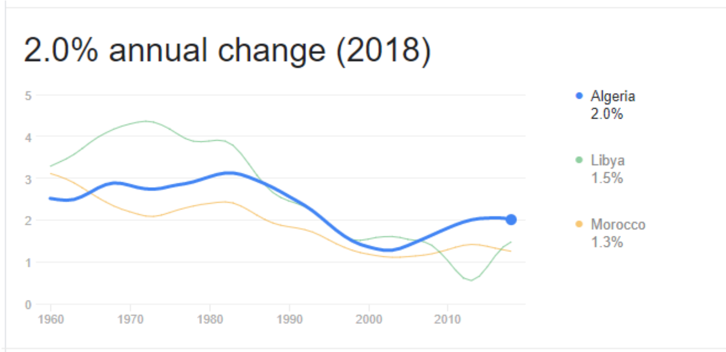

Fig. 2. Population growth in Algeria

Although this seems a high potential for workers capacity at first glance, this opportunity, with the current stagnant production system, only puts pressure on the economy due to the increasing unemployment rate causing more decay in the sociological state of the population.

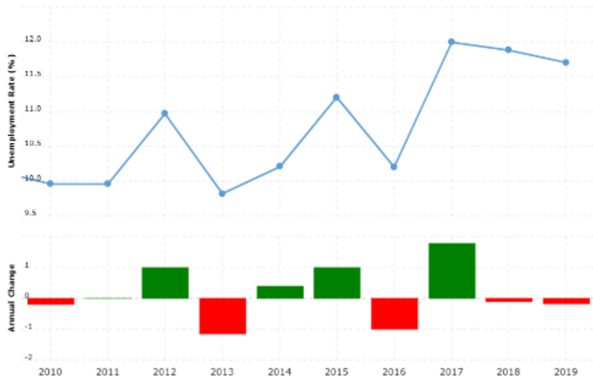

Fig. 3. Unemployment Rate in Algeria (2010-2019) [5]

F. *Emissions in Algeria*

With most of the electricity being generated from fossil fuels, emissions in Algeria, although having only 0.5% share of world emissions, surpassed 150 M tons [6].

In addition, refineries in Algeria do not refine the fossil fuels into a high quality product such as gasoline, although the five exiting refineries [7] (accumulated capacity of 562,000 barrels per day) can cover the country needs in oil products theoretically.

Therefore, any systematic development in the industry such as upgrading the refineries, or constructing new factories is going to load the energy production, elevating the emissions not only due to consumption but also in production process.

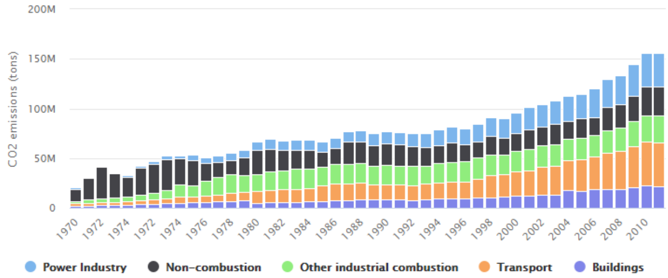

Fig. 4. Algeria Emissions by Years (tons) [9]

G. Fraud in Energy Distribution

Algerian Electricity and Gas Regulatory Commission (CREG) has revealed that fraud on energy installations, unlawful connections to the power grid in particular, caused the loss of 11 billion Algerian dinars ($92,500,731) to the Electricity and Gas Distribution Company (SDC) in 2018. According to the commission's figures, 2,430.5 MWh of electricity were trafficked over the past year. This damage is mostly the result of illegal connections to the network, and illegal handling of electricity meters to reduce the amount of energy consumed [8] which makes rebounding off of crises even more difficult for the economy.

H. Economic Crises in Algeria

Algeria faced many economic crises since the independence in 1962. Many of them were followed by protests and riots, making them one of the main factors in the instability of the country [9]:

- October 1985: revenues from gas and oil exports fell by more than 40 per cent. The authorities held back the investments, and many factories closed. Unemployment rose, and the government borrowed externally to close the deficits. In 1988, the debt-to-service ratio more than doubled, from 35 to 80 per cent leading to riots that were the most serious since independence in 1962. A civil war then took place through the 90s.
- June 2014: oil prices collapsed. Algeria had $178 billion in foreign reserves and $37 billion in its sovereign wealth fund. Yet, at the beginning of 2018 only $97.3 billion of reserves remained. Authorities, optimistic that oil prices would rebound, calculated the state budget for 2017 on the basis of an oil price recovery to $70 barrel by 2020. Unfortunately, the price was not maintained since the first quarter of 2018. Riots started again in 2019, having one demand: Prosecuting the people responsible for making financial decisions.

It is only obvious to deduce the causality of oil prices collapse on an economy dependent of its revenues, and what this leads to, from rising unemployment rate to riots and social instability. One can start thinking that fossil fuels as an economic axis is not sustainable in the long term.

III. Fossil Fuels in The Long Term

A. Oil Security

Fossil fuels, not being a renewable energy, are limited in quantity and set to an end inevitably. It is estimated that fossil fuels and coal reserves will empty out by the end of the 21st century. Therefore, the reliance on any of these materials as energy sources is not a sustainable choice, and will not last for future generations.

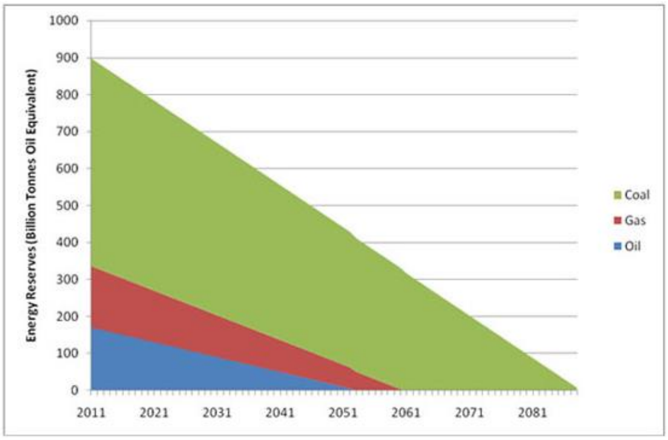

Fig. 5. Energy reserves expectancy [10]

B. Limiting The Global Warming

A study published in the journal Nature says that a third of all oil reserves, half of gas reserves and over 80% of current coal reserves would need to remain in the ground for the international community to reach its goal of staying below a maximum two degrees Celsius global average temperature rise [11]. The greenhouse gas emissions contained in present estimates of global fossil fuel reserves are around three times higher than can be burned for the world to stand a chance of avoiding the worst impacts of climate change. The report details the type and geographical distribution of fossil fuels that must remain in the ground to keep the average temperature rise within the agreed limit. The results are shown in this infographic by the Guardian newspaper:

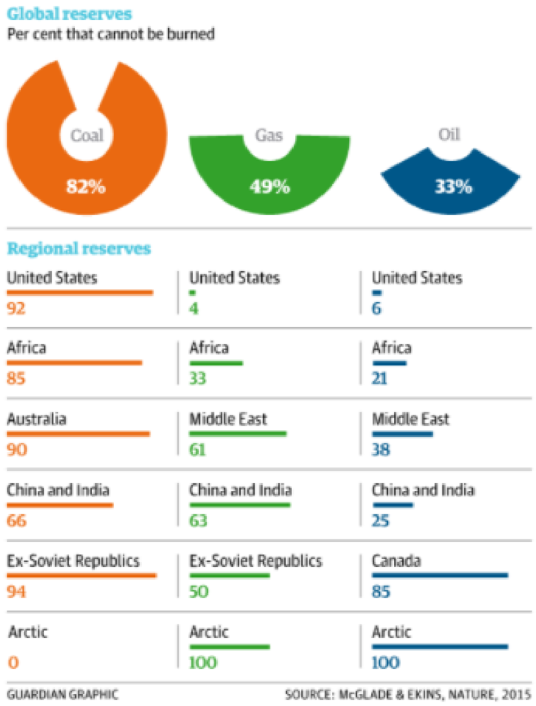

Fig. 6. The compiled percentage of unburnable fossil fuels regionally [12]

This emphasizes the importance of considering fossil fuels as backup reserves instead of main sources, as not only their market is instable, but also further laws, regulating their extraction relating to the study, are expected to be introduced to join the laws of production limitations that concern pricing. In addition, Algeria is a developing country which means energy demands are constantly growing.

IV. Power and Energy Demand in Algeria

The energy demand in the country has 3 main sectors: residential, industry, and transport. The demand has been increasing at a high rate throughout the recent years. In 2010 the energy consumption was measured to be 31,500 ktoe, 8 years later it reached 42,379 ktoe, increasing by 34% in 2018. This is only natural as the country is still providing new buildings for the habitants, paving new roads, and adapting relatively new industries in the area.

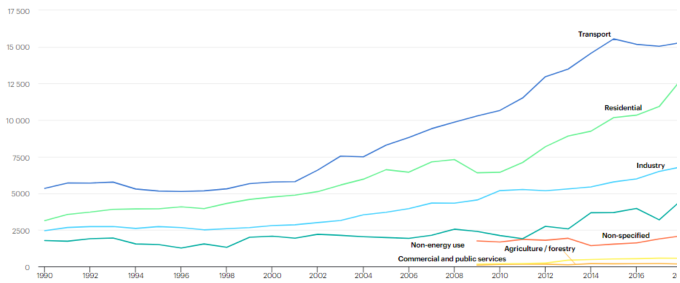

Fig. 7. Energy Consumption (ktoe) by sector in Algeria 1990-2018 [2]

A. *Evolution of Maximum Power Demand*

There are 3 grid sections in Algeria [13]:

- National Interconnected Network **RIN**: RIN covers the north (including the regions between Bechar and Ghardaia) it is supplied by around 10 power generation plants, linked together through a network of 220 kV and 400 kV transmission lines, allowing the transfer of energy from production sites to consumption centers.

The maximum power demand of the national interconnected grid reached 14,182 MW in 2017.

TABLE IV. MAXIMUM POWER DEMAND ON RIN

Years	**2006**	**2010**	**2016**	**2017**
Registered Max Power Demanded (MW)	6,057	7,718	12,839	14,182

- Pole In-Salah Adrar Timimoune **PIAT**

This pole is supplied by the gas turbine plants of the area, the Kabertene wind farm, and the 7 PV plants, interconnected through a 220 kV network. Renewable sources contribute with an overall installed capacity of 53 MW.

TABLE V. MAXIMUM POWER DEMAND ON PIAT

Years	**2008**	**2010**	**2016**	**2017**
Registered Max Power Demanded (MW)	106	149	302	313

- The Isolated Networks of the South **RIS**

These are 32 sites (29 conventional and 3 PV) in the south, supplied by local networks through diesel groups. The installed capacity of the RIS reached 1,133 MW in 2017.

TABLE VI. MAXIMUM POWER DEMAND ON RIS

Years	**2011**	**2012**	**2016**	**2017**
Registered Max Power Demanded (MW)	139.7	167	285	271

B. *Evolution of Different Aggregate* [1]

National energy consumption (including losses) reached 59.6 M toe in 2017, reflecting an increase of 2.1% compared to 2016, driven mainly by that of final consumption (+4.1%). Conversely, non-energy consumption and that of the energy industries experienced respective declines of -19.5% and 5.1%.

TABLE VII. CONSUMPTION BY AGGREGATE (K TOE) IN ALGERIA

	2016	**2017**	**Evolution (%)**
Final	42,883	44,646	4.1
Non-energy	4,330	3,486	-19.5
Energy Industries	7,439	7,057	-5.1
losses	3,690	4,394	19.1
National Consumption	58,341	59,582	2.1

This shows a strengthening of the share of final consumption at the expense of energy and non-energy industries

C. *Non-energy Consumption*

Non-energy consumption refers to the quantities consumed as raw material in the petrochemical industry and other industries. It reached 3.5 M Toe in 2017, a sharp drop (-19.5%) compared to 2016, following the reduction (-20.5%) in natural gas withdrawals from Sonatrach customers in the sector petrochemicals of nearly one billion m^3. Also, the use of petroleum products for non-energy use (especially for bitumen) fell by 13% in 2017 to 0.5 M Toe.

TABLE VIII. NON-ENERGETY CONSUMPTION (K TOE) IN ALGERIA

Products	2016	2017	Evolution (%)
Natural Gas	3,782	3,007	-20.5
Oil Products	548	470	-12.7
Total	4,330	3,486	-19.5

The share of non-energy industries in national consumption has fallen sharply to 5.9% against 7.4% in 2016.

D. *Energy-Industries Consumption* [1]

The consumption of energy industries includes those of energy industries processing and transport (refineries, power plants, LNG & LPG units, Oil and Gas Pipelines). Its share is nearly 12% of national consumption. It reached a volume of 7.1 M Toe, -5.1% compared to 2016, due to in particular the reduction of nearly 0.5 billion m^3 in gas self-consumption natural in liquefaction units.

TABLE IX. NON-ENERGETY CONSUMPTION (K TOE) IN ALGERIA

Products	2016	2017	Evolution (%)
Crude Oil	558	498	-10.8
Natural Gas	5,007	4,559	-8.9
Electricity	1,856	1,984	6.9
LPG	18	16	-12.3
Total	7,439	7,057	-5.1

E. *Evolution by Form of Energy* [1]

Domestic consumption increased 2.1% from 2016 level, drawn notably by that of electricity (5.5%), natural gas (1.4%) and LPG (5.0%). Conversely, the consumption of petroleum products fell by 1.6% for come in at 15.9 M Toe.

TABLE X. CONSUMPTION BY FORM OF ENERGY (KTOE) IN ALGERIA

Products	2016	2017	Evolution (%)
Natural Gas	21,732	22,029	1.4
Oil Products	16,141	15,883	-1.6
Electricity	16,880	17,812	5.5
LPG	2,247	2,361	5.0
Crude Oil	1,036	1,085	4.8
Condensate	19	23	22.6
Solid Waste	6	48	691.8
Others*	279	341	22.1
Total	58,341	59,582	2.1

*Liquefied natural gas / blast furnace gas

The structure of national consumption remains dominated by natural gas (37%) followed by electricity (30%) and petroleum products (27%).

It should be noted the continuing rise in electricity consumption, which saw its share rise to nearly 30% to settle at 17.8 M Toe, reflecting the needs induced by the socio-economic development of the country. It should also be noted a sharp increase (+19.1%) in losses, driven by a doubling of losses of gaseous products and a 20% increase in those of liquid products.

Regarding electricity losses, which represent almost 60% of overall losses, they increased slightly to 10.9 TWh. The distribution of these losses is given below:

- Distribution losses (78%), including non-technical losses due to the phenomenon network hacking, which increased by 1.5% in 2017
- Transport losses (22%), up 2.5% compared to 2016

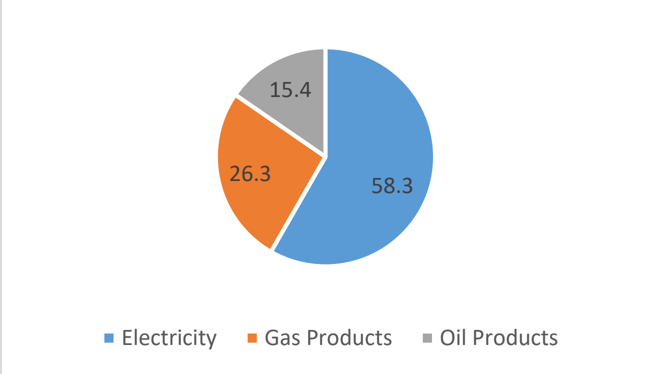

Fig. 8. Structure of energy losses in Algeria (2017)

F. *Final Consumption by Product* [1]

Final consumption increased from 42.9 M Toe in 2016 to 44.6 M Toe in 2017, reflecting an increase of 1.8 M Toe (+4.1%), driven by that of natural gas, electricity and LPGs which more than offset the drop in petroleum products.

TABLE XI. FINAL CONSUMPTION BY PRODUCT (KTOE) IN ALGERIA

Product	2016	2017	Evolution (%)
Oil Products	15,527	15,338	-1.2
Natural Gas	12,654	13,655	7.9
Electricity	12,476	13,270	6.4
LPG	2,220	2,337	5.2
Metallurgical Coke	-	38	-
Wood	6	10	70.2
Total	42,883	44,646	4.1

- Significant increase (7.9%) in natural gas consumption to 13.7 M Toe induced by the growing needs of Sonelgaz customers, particularly those in the households, and where the total number of subscribers reached 5.3 million in 2017, i.e. more than 345 thousand new customers.
- Growth in electricity consumption (6.4%) to reach 13.3 M Toe, continued in particular the increase in demand from high and low voltage customers (mainly households), whose total number of subscribers exceeded 9.2 million at the end of 2017, compared to 8.8 million at the end of 2016 (+4.3%).
- Decrease (-1.2%) for the second year in a row in consumption of oil products at 15.3 M Toe, due to the rise in fuel prices, in particular for diesel (+9%) and gasolines (+ 14%).
- Increase in demand for LPG (+5.2%) to 2.3 M Toe, driven by that of LPG/C which increased sharply (30%), following measures to promote this product, including the prices becoming very attractive (9 AD/ L).
- Conversely, demand for LPG-fuel decreased (-1%) to 1.5 million tons, following the substitution by natural gas, a consequence of continued efforts to the state as part of the public gas distribution program.

G. *Final Consumption by Sector* [1]

By sector of activity, the evolution of final consumption in 2017 shows the following:

- Decrease in consumption of the transport sector of 1.1% to 14.9 M toe compared to the prior year, driven by that of road fuels, following the rise in prices in the domestic market.

- Increase in consumption in the industry sector of 7.6%, from 9.2 M Toe to 9.9 M Toe, following the increase in consumption of the sub-sector of building materials (+7.5%) and ISMME (45.9%).
- Growth in consumption in "Households and others" of 6.6% to reach 19.8M Toe, driven by that of the residential sub-sector (5.7%) and in particular by needs in gas and electricity induced by the increase in the number of Sonelgaz customers.

TABLE XII. FINAL CONSUMPTION BY SECTOR (KTOE) IN ALGERIA

Sector	2016	2017	Evolution (%)
Industry	9,242	9,943	7.6
Construction Material	4,065	4,370	7.5
ISMME	524	765	45.9
BTP	470	441	-6.2
Manufacturing Industries	1,070	1,134	6.0
Agri-food	953	1,011	6.0
Others	2,786	2,895	3.9
Transport	15,057	14,895	-1.1
Road	14,293	14,138	-1.1
Air	482	496	2.9
Households and others	18,584	19,808	6.6
Residential	14,196	15,003	5.7
Agriculture	416	440	5.7
Total	42,883	44,646	4.1

The structure of final consumption remains dominated by the "Households & others" (44%), followed by transport (33%) and finally the industry sector (22%). However, it should be noted the drop in the transport sector in 2017, following the drop in fuel consumption.

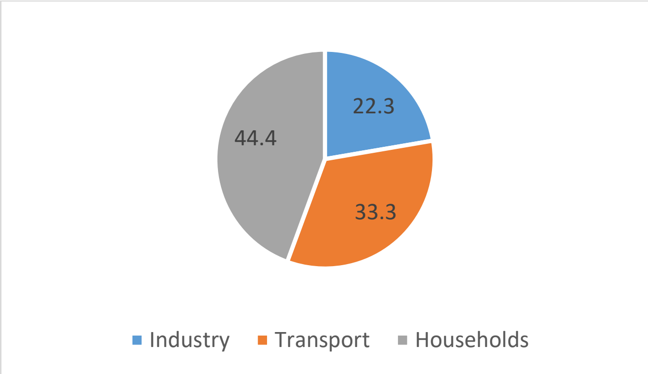

Fig. 9. Structure of final consumption by sector in Algeria (2017)

H. *Industry Demand*

The industry sector in Algeria represents 22% of total final consumption. The building materials industry is the first energy consumer with a share of 60%; steel, metallurgy, mechanics, electrical and electronics (ISMME) industries share 15% of the final consumption, basic chemicals 3%, food industry 9%, manufacturing 11%, and finally mines and quarries with 2%. Natural gas consumption in the sector exceeds 76% of the energy in the industrial sector, 6% is consumed as petroleum products and 17% in the form of electricity [14].

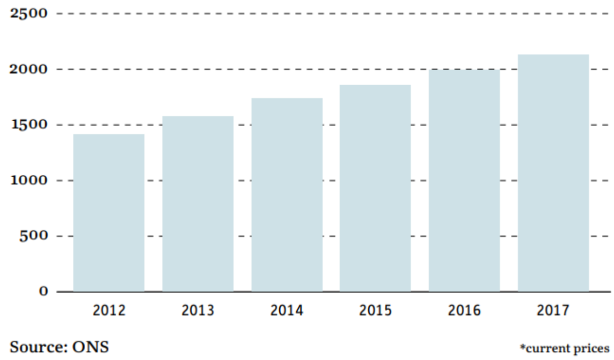

Fig. 8. Building sector GDP in bn Algerian Dinars (2012-2017)

The fastest-growing industrial segment in the second quarter of the year, in annualized terms, was wood, paper and cork (10.1%), followed by water and energy (8.2%), and agro-industry (3.7%).

With low oil prices imposing limits on capital expenditure, the government is seeking to attract more private sector investment, both domestic and foreign, as part of more general economic diversification efforts, and to reduce the import bill by stepping up local production.

To achieve growth targets for this sector, authorities have taken several steps to facilitate investment in manufacturing. Finance Law (2016) [15] introduced five-year exemptions from taxes on corporate profits, corporate revenues and professional activities, as well as a 3% interest rate subsidy for bank loans for companies operating in a wide range of industrial segments, including steel, metallurgy, and electrical and electronic goods.

Heavy industrial activity is growing rapidly in Algeria, with plans for large-scale expansion in several segments, such as steel and construction materials. Manufacturing industries also appear set for growth as foreign and domestic firms, bound by import restrictions, build production facilities in the country. However, the success of these industries will depend on how quickly they can build effective and profitable local ecosystems, increase integration rates and generate considerable economies.

Furthermore, as mentioned previously, refineries in the country are up for development to generate more revenues from petrol and gas, instead of exporting them crude for much cheaper than what they would make if they were refined.

I. *Transport Demand*

The energy consumption in the transport sector is around 15,000 K Toe [2]. For a total number of 6,418,212 vehicles, 500,000 were converted to LPG [16], the length of road network: 112,696 km. The railway length is equal to 10,515 km, and the main fuel used is diesel. The maritime fleet has 201 vessels, 30 helicopters, 2 MPA aircraft. The air fleet has 582 aircraft, with a total number of 36 airports [17].

Although transport energy consumption did not experience a high rate of increase in recent years, it is still the highest in terms of total consumption with 15,308 ktoe in 2018 (over 90% from oil products). According to the National Statistical Office (ONS), Algeria's motor fleet reached 6,418,212 vehicles in 2018, an increase of 4.15% compared to 2017 which is the equivalent of 255,538 new vehicles.

Due to the lack of inconvenience in public transportation, passenger vehicles represents 64% of total vehicles [18].

Moreover, 3 cases can be considered for comparison and analysis concerning the future of vehicles, as the government is encouraging the conversion to LPG:

- Converting petrol-vehicles into gas-vehicles and supplying the total by refined gas from fossil fuels.
- Converting all of vehicles into electric, and supplying them with electricity generated from natural gas generators.
- Converting all of vehicles into electric, and supplying them with electricity generated from renewable energies.

The Algerian motor fleet is dominated by passenger cars, and therefore they are mainly targeted in this comparison. Another factor is the mileage. Taking it as an average of 15,000 km, the following results are obtained:

- **Gas cars**: the average consumption of a gas car is 9.8 L per 100km (24.9 mpg_{USA}), which makes the annual consumption:

$$E_{gas-total} = \frac{9.8\ L}{100\ km} \times 15{,}000\ km = 1{,}470\ L$$

The price of gas in Algeria is 0.357 USD/L making the annual cost 524.79 USD. As the mileage is kept constant through the comparison, the margin of error in its estimation does not affect the study as the differences between cases are percentages of one another.

One gallon of gasoline is equal to 33.705 kWh, thus:

$$E_{gas-total} = 33.705 \frac{kWh}{gal_{us}} \times 1{,}470\ L\ \times 0{,}264\ \frac{gal_{us}}{L} = 13{,}08\ MWh$$

- **Electric cars**: Energy consumption of an electric car is up to 15 kWh per 100 km, which makes it annually:

$$E_{E-total} = \frac{15\ kWh}{100\ km} \times 15{,}000\ km = 2.25\ MWh$$

When electric cars are used, the energy consumption annually reduces by 82.79%.

The annual cost when electricity is generated from natural gas is 135 USD (0.06 USD/kWh).

On the other hand, if electricity is generated renewably, the cost is 156 USD (0.07 USD/kWh)

The difference in pricing does not stand long because generation by natural gas has side effects that require further payment as discussed in (VI. *C.*), in addition to its unstable market that is predicted to lead to price risings.

An important condition is: electricity, consumed by electric cars, must be generated from renewable energies, if electric cars are to be introduced in the country. Otherwise the emissions would rise as shown in the following figure:

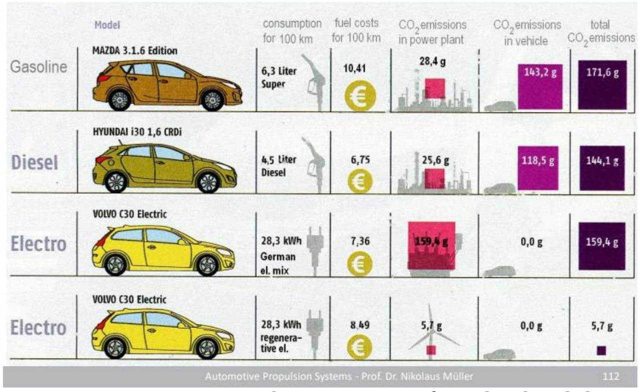

Fig. 10. Consumption, cost, and CO2 emissions of gas, diesel, and electric cars relative to electricity generation sources

J. Residential Energy Demand

The growth rate of Algerian residential electricity consumption has been higher than that of industry, especially over recent years. While, in 1990, electricity use by the industry sector was 48.5% of total electricity consumption and by the residential sector was 49.15%; in 2014, the industry sector electricity consumption was only 35% and the residential consumption was more than 63%. This greater residential electricity consumption may be explained by several factors, such as changes in lifestyles and population growth [2].

K. Cooling and Heating Demands Across The Country

Although the Algerian desert (the Sahara) is very hot and can be very cold which at first gives the impression of high cooling/heating demand, it has one of the lowest population densities on earth, thus it is more appropriate to neglect it (1.5% of maximum power demand of the network RIN). Therefore 3 cities were chosen for estimation to include the 3 different climate zones in Algeria: Algiers, Tlemcen, and Ghardaia.

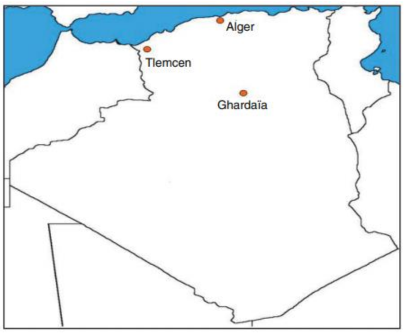

Fig. 9. Geographic location of climate sites

When it comes to comfort, it depends not only on the temperature but even more on the humidity of the ambient air. In 1991 Givoni suggests a bioclimatic diagram located the comfort zone between 18 and 25 ° C in winter and between 20 and 27 ° C in summer for temperate climates in calm air conditions, with an increase of 2°C for the upper limit for hot regions [19]. The monthly neutral temperature is obtained from the monthly mean temperature through Auleciems equation:

$$T_{neutral} = (0.31 \times\ T_{mean}) + 17.6\ °C$$

The following data is based on the analysis of energy consumption for Algerian building in extreme North-African climates [20]

TABLE XIII. AMBIENT & ADAPTIVE COMFORT TEMPERATURES IN DIFFERENT SEASONS IN EACH CITY

Cities	Ambient Comfort Temperature (°C)		Adaptive Comfort Temperature (°C)	
	Summer	Winter	Summer	Winter
Algiers	21.1	25.9	19.1	27.9
Tlemcen	20.9	25.1	18.9	27.1
Ghardaia	21.1	28.6	19.1	30.6

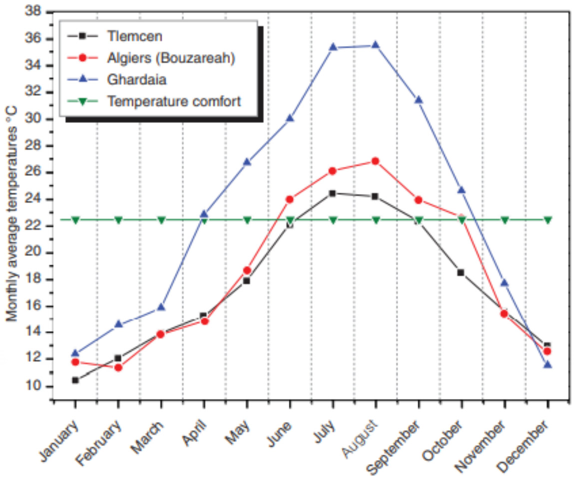

Fig. 10. Monthly average temperatures for selected climatic regions

Consumption is calculated by the following formula:

$$C = 24 \times Q_{needs} \times D_j = \frac{24 \times DP_{envelop} \times D_d}{1000}$$

D_d (degree days): a special data type of weather data, calculated off readings of outside air temperature, used in calculating building energy consumption.

$DP_{envelop}$: heat loss of envelop

The loss of envelop is the combination of the losses of walls, doors, ventilation… It is included in the calculation for more realistic values, as most Algerian buildings are not designed in an efficient way of preserving thermal energy while refreshing the air, which is the case for most developing countries.

The national company for producing and transmitting electricity and gas (SONELGAZ) charges bill by quarters, therefore it is more appropriate to present data accordingly.

The size of a typical building that's used in the study is 10 m by 11 m for ground floor + 2 floors.

TABLE XIV. REQUIRED BUILDING ENERGY CONSUMPTION FOR EACH SITE

Cities	Quarter	T_{avg} (°C)	D_d	C (MWh)
Algiers	**Dec-Feb**	11.83	318.50	1.88
	Mar-Mai	15.73	205.33	1.22
	Jun-Aug	25.66	-98.166	0.58
	Sep-Nov	20.56	54.76	0.51
Tlemcen	**Dec-Feb**	11.76	321.26	1.92
	Mar-Mai	15.63	209.50	0.84
	Jun-Aug	23.53	-33.76	0.24
	Sep-Nov	19.10	111.93	0.66
Ghardaia	**Dec-Feb**	12.73	292.80	2.24
	Mar-Mai	21.80	20.60	0.86
	Jun-Aug	33.60	-343.63	0.26
	Sep-Nov	24.60	63.30	1.24

Heating needs are slightly more than half of total needs in Algiers and Tlemcen (51.76%, 53.65% respectively), whereas in Ghardaia they represent 69.06%. This can be explained by the fact that cooling is only needed during the summer time (Jun-Aug) while heating needs extend from September till April. Calculating the annual energy consumption leaves us with the values of: 12.21, 12.64 and 16.6 MWh/year for the sites Tlemcen, Algiers, and Ghardaia respectively [20]. At first, it seems cheaper to live in the capital (Algiers), however the unit price is half in south of Algeria which is a state policy to encourage a more equal population distribution between the south and the north of Algeria. It is for this reason that the unit price of the electric energy consumption is cheaper compared to the electricity bill cost in the majority countries of the world.

Electricity is the main consumed source for cooling as the air-conditioners are the one used. However gas is mainly used in heating as most heaters and boilers are gas-based. For instance, a house needs a 24-27 kW boiler (7 to 10 radiators) while the price of natural gas in Algeria is 0.003 U.S. Dollar per kWh [21]. On the other hand, an electric heater uses 1.5 kW, therefore using 10 electric heaters in one hour consumes 15 kWh while the price of electricity in Algeria is 0.042 U.S. Dollar per kWh [22]. Not only that electric heaters may be a cheaper option, but are easier and cheaper to install compared to gas central heating that requires pipes, vents and ducts. They don't require flue or pipework so there are no restrictions on building layout or design. Nor are there any planning issues. A simple connection to the electric circuit is all that is required, so for new build properties, this means it can go in at the second fix wiring stage. Going further, heat pumps may be considered even a better alternative as installing a heat pump system in a well-insulated house will transform the comfort levels in the house and reduce heating bills by improving your energy efficiency.

Shifting from gas-based to electric-based appliances seems the right option for more economic expenditure. Furthermore, the country is known for its renewable energy potentials that are capable of covering the total current demands in addition to the future electricity load that will be generated from this shift.

V. RENEWABLE ENERGIES POTENTIAL IN ALGERIA

Having a high sunshine duration with high radiation annually, minor population rate in the south, and excess in solid waste, Algeria provides what seems at the first glance the perfect territory for solar, wind, and biomass energy applications.

A. *Geography of Algeria*

Algeria's geographic location has several advantages for extensive use of solar and wind energies. Algeria situated in the center of North Africa between 38° to 35° of latitude north and 8° to 12° longitude east, has an area of 2,381,741 km² and a population of 42.23 million inhabitants (2018). The Sahara covers a total area of 2,048,297 km², approximately 86% of the total area of the whole country. The geographic location of Algeria signifies that it is in a key position to play an important strategic role in the implementation of renewable energy technology in the north of Africa, as well as providing sufficient energy for its own needs and even exporting the excess of energy of such projects internationally [23].

The German Aerospace Center (DLR) concluded that Algeria has the largest solar potential in the Mediterranean basin [24], where this solar capacity represents [25]:

- 169,440 terawatt-hours / year
- 5000 times Algeria's electricity consumption
- 60 times Europe's electricity consumption
- 04 times global electricity consumption.

B. *Solar Energy*

Algeria not only is exposed to a dead time of 2000 hours in the highlands and 3900 hours in the south annually but also provides a solar energy capacity of 1900 kWh/m² and 2650 kWh/m² respectively [26].

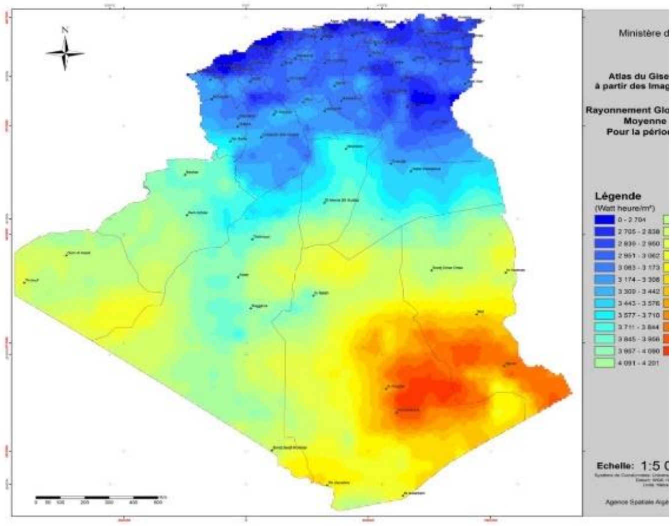

Fig. 11. Global Direct Annual Average Irradiation Map (Period 2002-2011)

TABLE XV. SOLAR ENERGY CAPACITY BY REGION IN ALGERIA [26]

Regions	Coast	High lands	Desert
Area %	4	10	86
Average annual hours of sunshine	1800	2000	3900
Rated power (kWh/m²/ year)	1700	1900	2650

The amount of solar radiation in Algeria means that it would be feasible to consider solar energy as a potential energy source for different applications in the form of individual photovoltaic solar panels or systems. Solar photovoltaic energy is being developed in Algeria mainly for six applications: domestic uses, water pumping, refrigeration, village electrification, lighting, and telecommunication. The development of solar energy plants is supported by the Ministry of Energy and Mines, and realized mainly by SONELGAZ and other private installers companies. The solar energy is regarded as an important line of research within the structure of the Department of renewable energies of SONELGAZ. Manufacturing PV modules at ENIE (National Electronics Industry Company) are limited in mono and polycrystalline silicon solar cell elaboration, assembly PV modules, and fabricating the support structure. UDES/CDER (Solar Equipment Development Unit in collaboration with the Renewable Energies Development Centre) ensures the development of solar thermal and photovoltaic equipment (domestic, industrial and agricultural), electronic, thermal and mechanical devices and systems involved in the application of solar energy. This means that the establishment of a silicon production industry is possible in Algeria to supply the local, MENA, and European markets, as it is mentioned in the Algerian-Japanese project description.

C. *Wind Energy Potential*

Wind in Algeria varies from one place to another. This is mainly due to a very diverse topography and climate. The country is subdivided into two large distinct geographic areas. The Mediterranean north which is characterized by a coastline of 1200 km and a mountainous relief, represented by the two chains of the Tell Atlas and the Saharan Atlas. Between them, there are plains and highlands with a continental climate.

The South, for its part, is characterized by a Saharan climate. The map shown below shows that the South is characterized by higher speeds than the North, more particularly in the Southeast, with wind speed greater than 7 m/s and which exceeds the value of 8 m/s in the Tamanrasset region.

Regarding the North, we note overall that the average speed is low. However, we note the existence of microclimates on the few coastal sites and on the highlands (6 to 7 m/s), and the Great South (>8m/s) [26].

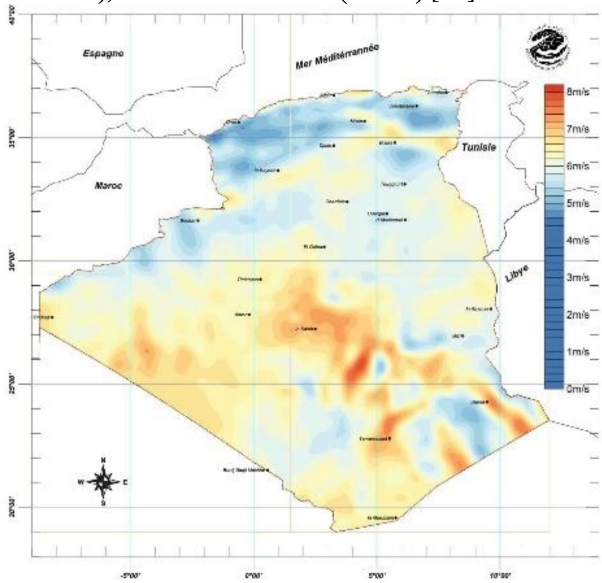

Fig. 13. Average Annual Wind Map at 50m (Period 2001-2010)

Algerian highlands experience considerable amount of wind powers, therefore a city such as M'Sila is suitable for wind energy applications.

Geographical coordinates:

- Longitude: 35.66°
- Latitude 4.5°
- Altitude: 442 m

The monthly, seasonal and annual wind energy potential will be assess using a 600 kW wind energy conversion systems installed at 50 m above ground level [29]. Energy calculations requires the wind turbine power coefficient curve, the rotor swept area and hub height.

TABLE XVI. WIND TURBINE PARAMETERS

Model	Fuhrländer FL600
Rated power	600 kW
Rotor diameter	50 m
Hub height	50 m
Swept area of rotor	1962 m²
Cut-in-win speed	3 m/s
Rated wind speed	14.5 m/s
Cut-out-wind-speed	19 m/s

The wind speed data at the location in Algerian highlands have been analyzed in a study taking into account the monthly and seasonal variations [30].

TABLE XVII. MONTHLY VARIATIONS OF MEAN WIND SPEED AND POWER DENSITY IN M'SILA

Elevation	10 m		50 m	
Parameters	**V (m/s)**	**P (W/m²)**	**V (m/s)**	**P (W/m²)**
Jan	4.12	277.06	5.77	533.77
Feb	4.31	206.65	6.09	439.40
Mar	4.97	281.16	6.91	581.85
Apr	4.70	163.49	6.66	384.39
May	5.14	178.29	7.24	424.77
Elevation	**10 m**		**50 m**	
Parameters	**V (m/s)**	**P (W/m²)**	**Parameters**	**V (m/s)**
Jun	3.97	80.93	5.80	216.19
Jul	3.48	59.37	5.17	163.73
Aug	3.24	46.10	4.86	132.40
Sep	3.69	70.91	5.43	190.58
Oct	3.10	74.21	4.59	183.37
Nov	3.73	238.76	5.28	460.61
Dec	4.11	269.57	5.91	528.25

It is observed that the monthly mean wind speed at 10 m varies between 3.10 m/s in October and a maximum value of 5.14 m/s in May, while at the hub height the monthly wind speed varies between 4.59 and 7.24 m/s. Furthermore, at 10m, the mean power density varies between 46.10 W/m² in August and 281.16 W/m² in March. Speed covers a large range of variation in autumn, winter and spring seasons, which spans [0–19 m/s], whereas in summer the higher limit of the speed range is 11 m/s. The analysis shows M'Sila situating in central highlands as a good site for wind energy with an annual amount of around 2.4 GWh. Furthermore, the population density in the area is 53 inhabitants per km² [35] which puts no obstacles against setting wind turbine farms in it.

M'Sila is only one of many places in Algerian highlands that experience such potential in wind energy, which leaves the door open for considering areas with similar characteristics as production sites that might contain even a higher potential for wind energy [31].

Going farther south, the Sahara has even more win energy potential, making the annual amount calculated previously a lower limit for energy production from wind in the Algerian desert.

D. Biomass Energy Potential

At the national level, the quantity of household and similar waste produced in 2013, was 10.3 million tons. It is estimated the potential of biogas that this quantity could generate around 716.8 million m^3 biogas [32] which is equivalent to 1.43 TWh of electricity (biogas: 2 kWh/m^3) [38].

Regulations from the MEM which support using of biomass from energy crops rapidly caused an increase in interest for connection agriculture and energy sector. This is seen as a first step in stimulating much faster the use of biomass in Algeria.

Biogas is considered to be a relatively cheap energy source. In addition, disposal of biogas by combustion is absolutely necessary to protect the environment; in particular, to protect the atmosphere against emission of unburned methane contained in biogas. A gradual growth of the use of biogas, particularly from landfills, was initiated by the UREERMS (Solar Equipment Experimentation Unit in the Sahara Area) which is seen as a step forward in the use of biogas in Algeria. A very promising alternative for burning is the gasification of biomass.

When it comes to electricity generation, it depends on the type of waste used. Different wastes have different calorific value, which depends on the waste composition.

A material can burn without supporting fuel when it has a calorific value of 14.4 MJ/kg as a lower limit. To calculate the overall calorific value of the waste, the calorific value is measured otherwise the composition needs to be analyzed. If there is no chemical reaction by mixing the different materials together, a weighted average of the different calorific values is a good approximation. If both the amount and the calorific value of the waste are known, it is possible to design the size of the incinerator and flue gas treatments system. The composition of municipal solid waste influences the incineration process. The heat value of some materials contained in the waste and their moisture content affects the capacity of the process. In particular, the plastics presence negatively affects the incineration process.

Waste used in biomass energy has lower density per unit due to the water containment, compared to coal for example, making it inefficient for transport. However, waste purification has become a standard in pre-generation processing, making it reliable.

Therefore biomass energy can be considered as one of the primary energy sources but in careful use as it might be less harmful to the environment when restricted than oil and gas.

E. Obstacles & Side-effects

The biggest obstacle to any large-scale renewables plan for the Sahara is political. There would have to be political buy-in from all parties concerned, including groups currently branded as terrorists.

Considering building generation stations in the Sahara for solar and wind energy has some side-effects on the environment. A study [35] indicated that an intensive installation of solar panels and wind turbines could increase rainfall and vegetation, creating a feedback loop which further greens the environment both of the Sahara and the adjacent Sahel, an impoverished dryland running from Senegal to Djibouti.

Wind farms at large scale also create more rainfall. Their blades "cause significant regional warming on near-surface air temperature… with greater changes in minimum temperature than maximum temperature," says the study. "The greater night-time warming takes place because wind turbines can enhance the vertical mixing and bring down warmer air from above to the lower levels, especially during stable nights."

Other issues that would also need careful consideration include the risk of sandstorms which could damage installations or impair their efficiency. Maintenance of such a vast solar/wind system could be a huge challenge, and very costly if roads were to be built in the desert.

Finally, transmitting energy and storing its excess require extensive research for optimal storage use and network construction, as the country is still developing and although rich in natural resources, the Algerian economy is incapable of further unnecessary expenditure.

VI. Transmission and Additional Costs

A. Station Allocating For Minimum Transmission Costs

Since the Algerian authorities should be aiming to both transmit renewable energies both nationally and internationally, and as the area of the country is the largest continently, transmission lines can be more expensive than necessary if generation stations are geographically misplaced.

As mentioned before, there are 3 network grids in Algeria. Most of residential demands are in the north where most of the population allocates. Therefore generation stations for local distribution should be built as close as possible to the north. In addition, the country already contains transmission lines connecting the north to the production stations in the southern areas.

For international exportation, Algeria is considered the portal that connects Africa and Europe, implying that building transmission lines can be profitable in both directions: north to Europe across the Mediterranean Sea, and south toward neighboring African countries such as Mali, Niger, and Chad. It is interesting to notice that exporting electricity generated from solar energy across southern borders is very practical as the stations can be built very close to the borders reducing the cost of transmission, due to the static amount of solar radiations and hours of sunshine from east to west of the Algerian desert.

Concerning wind energy, as established earlier, the highlands are characterized with a considerable potential to generate energy from wind. Hence, the same argument goes for wind energy stations as they can be allocated in the highlands near the northern grid for distribution, as well as near the southern borders from east to west due to high wind speeds (fig.13) which would serve in energy exportations as a source of supply that is second to solar energy.

When it comes to biomass energy, there exists already a generation-transmission-distribution system. The concern for biomass energy in Algeria is to scale it. The waste that is used in generation comes mostly from forests and agriculture, which means it is available in the north part of the country, spanning the land from the coast to the highlands. Therefore transportation is not a big concern.

B. Additional Costs

Lastly, costs of renewable energy applications are not remotely near the expense of energy production from coal and fossil fuels. The real cost of that energy is, in fact, 170 percent higher. Each kWh of coal-generated electricity comes with an additional 5.6 cents of damages to our well-being. This includes about 3.4 cents in adverse health impacts, according to a recent National Academies of Science report. The remaining 2.2 cents, based on the U.S. government's social price of carbon calculations, results from climate change-related damages [36]. Therefore projects in this field have been considered an attractive financial profit potential.

VII. Coverage Plan

Energy demanded in Algeria is mostly electricity and natural gas. Out of the three main sectors, the residential sector depends on both: electricity for cooling during the summer, and natural gas for heating during the winter. The transport sector depends heavily on fossil fuels, while the industry sector is mostly electrified.

According to the Algerian energy ministry, the total electricity production in the country is 67 bn kWh annually, which is mainly generated by steam, gas, and combined cycle gas turbines. The data reached an all-time high of 8,661.900 GWh in Jul 2019 as the fluctuation in electricity consumption can be explained by the rising need of building cooling during the summer.

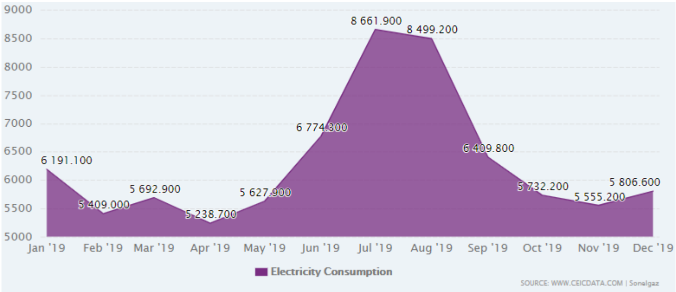

Fig. 14. Electricity consumption per month in Algeria (2019) in GWh [37]

On the other hand, natural gas consumption, which is mainly used in heat, electricity generation, and vehicles fuel, rises during the winter due to the higher heating needs.

The energy demands have lower standard deviations in the transport and industry sectors as consumption is constant throughout the year. Therefore the fluctuations in demands are seen in the residential sector, which requires currently different energies to meet the seasonal needs of climate adaptation.

An initial observation leads to stating that the fluctuation of both electricity and gas consumption is complementary. In other words, the rise of gas consumption is met with the decay of electricity consumption during the winter, and vice versa during the summer.

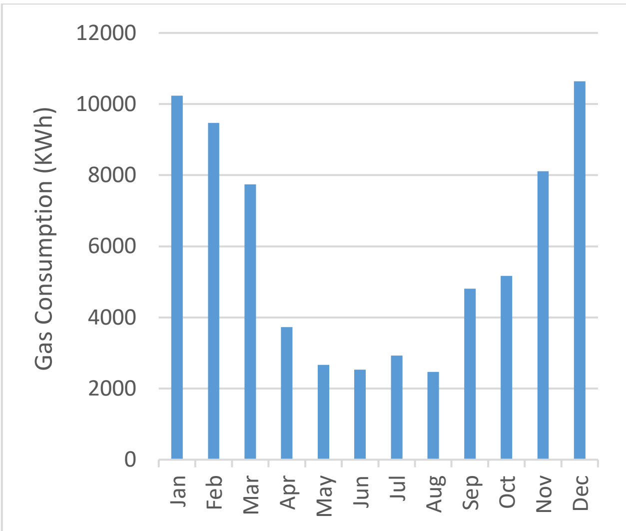

Fig. 15. Average monthly gas consumption (kWh) per Algerian households [38]

When it comes to daily fluctuations in energy demand, electricity load goes up around noon during the summer as cooling is more needed, and it also experiences a peak after the end of the typical working day (household's activities). The amount of energy consumed in buildings air-conditioning as gas is set to be reduced when heat pumps replace the currently used gas-heaters by a factor of 3-5.

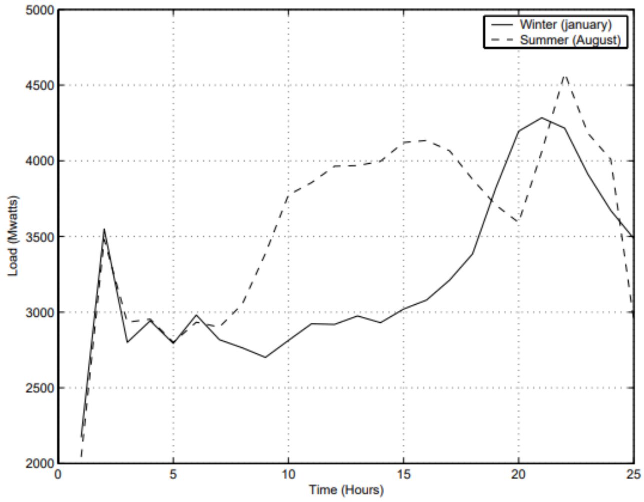

Fig. 16. Typical summer and winter daily (working) electricity load in Algeria [39]

Although the country contains and abundance in solar energy due to its desert, electricity demands as shown before peaks after sunset. When switching from gas heaters to heat pumps, electricity consumption would experience higher rates during winter, due to the outdated structure of most buildings that leaks thermal energy, making consumption high for heating, therefore becoming similar to current cooling demands during summer.

The renewable energy program launched by the government (power of 22 GW) will cover 30% of the electricity production for national consumption (74 GW to cover 100%).

74 GW is equal to 1,480 GWh overnight (20h), and 648 TWh annually. Biomass and wind energies have the potential that can supply powers of 2 GW and 17 GW respectively, covering 26%. Solar energy is set to cover the remaining 54.87 GW.

Biomass is predictable and can be consistent. However wind and solar energies experience fluctuations throughout the seasons of the year. It is expected to generate 4.5 TWh per trimester.

A southern site, for instance Tamanrasset, with a monthly hours of sunshine above 2000 hours during winter and above 3000 hours during summer with high temperatures, is a suitable generation location for solar energy.

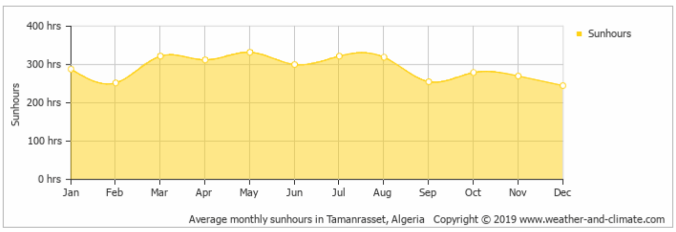

Fig. 17. Monthly hours of sunshine in Tamanrasset [40]

The daily radiations in the Sahara desert are almost 4 kWh/m² during the winter, and goes up to 7.5 kWh/m² during the summer.

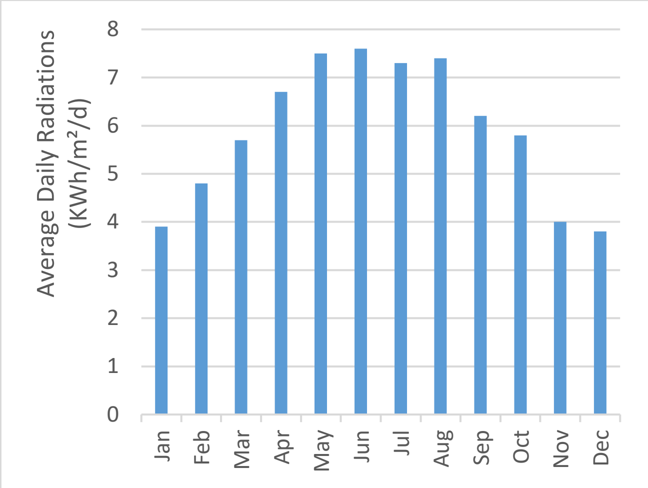

Fig. 18. Average daily solar radiations per month in Sahara desert [41]

When it comes to wind energy fluctuations, highlands still hold a high potential as mentioned previously.

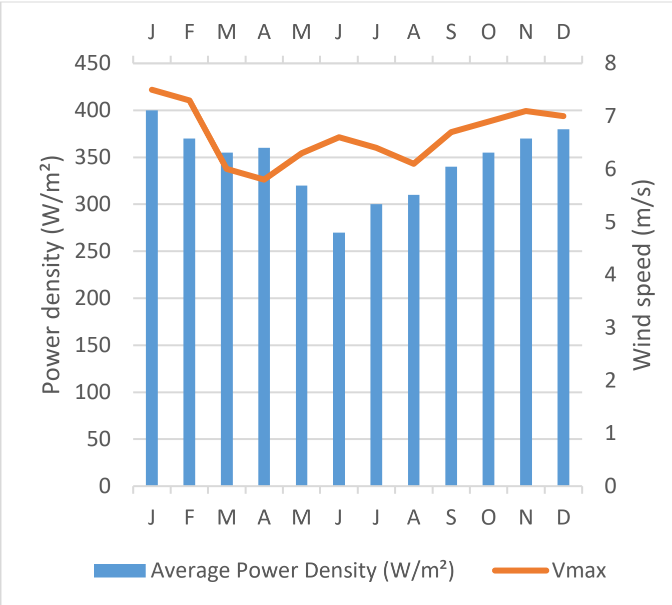

Fig. 19. Annual wind speed and power density in Algerian highlands [42]

25 km² of solar panels would generate the following:

Trimester	Solar Radiations (W/km²/trim)	Solar Energy (TWh)	Demand (TWh)	Difference (TWh)	D – Biomass (TWh)
Dec-Feb	405	10.125	17.406	-7.281	-2.781
Mar-May	585	14.625	16.557	-1.132	3.368
Jun-Aug	675	16.875	23.884	-7.009	-2.509
Sep-Nov	477	11.925	17.336	-5.411	-0.911

Biomass can be saved from the 2nd trimester to be used in the 3rd and 4th trimester. Therefore wind energy can be set to cover the remaining needs of the 1st semester with a power of 1.4 GW.

Although storage of 2.8 TWh is sufficient to be integrated in addition to a 1.5 TWh storage for overnight consumption, a bigger storage is needed due to the fact that regardless of the season, electricity consumption rises during the evening.

If biomass were to be used in heating, wind energy plants need to be up to the power of 6 GW, and a storage of 5 TWh is needed to cover for the last two semesters.

VIII. Renewable Energy Projects

There have been many projects aimed at developing renewable energies from in Algeria. The following are some of the most important initiatives and possible implementations in this field in the country:

A. *Governmental Plans*

Algeria is embarking on a new sustainable energy era. The updated Renewable Energy Program consists of installing renewable power of the order of 22,000 MW by 2030 for the domestic market, distributed by sector as follows: in the first place photovoltaic solar energy with an installation capacity of 13,575 MW followed by wind energy with an installation capacity of 5,010 MW, and thirdly the CSP with 2,000 MW. Such integration of clean energy is set to reduce emissions in the country [26-43].

TABLE XVIII. Avoided Emissions (Million tons of CO_2)

years	2015	2020	2025	2030
Avoided Emissions (Million tons of CO_2)	1.1	32.1	95.9	193.3

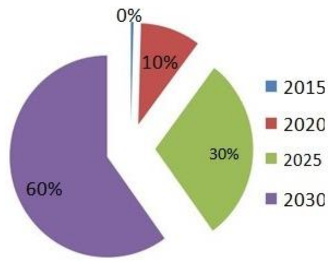

Fig. 20. Avoided Emissions Portions (2015-2030)

B. *DESERTEC Project* [44-45]

In the autumn of 2009, a consortium of companies formed the Desertec Industrial Initiative (such as E.ON, Munich Re, Siemens and Deutsche Bank) all signing up as ‘shareholders’. It was formed as a largely German-led private-sector initiative with the aim of translating the Desertec concept into a profitable business project, by providing around 20% of Europe’s electricity by 2050 through a vast network of solar- and windfarms stretching right across the Middle East and North Africa (MENA) region. The generators would be connected to Europe via transmission cables. The tentative total cost of this project has been estimated at €400 billion ($472 billion).

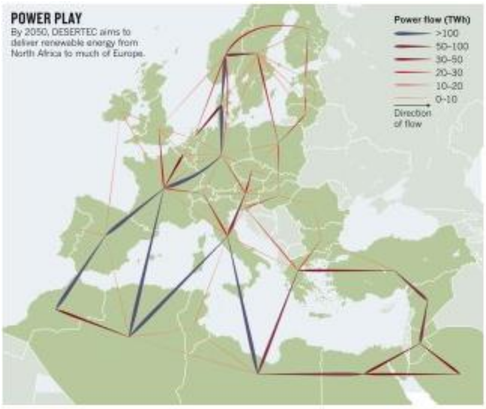

Fig. 21. a map of the most cost-effective distribution of renewable-energy sources in 2050, based on simulations run by the Fraunhofer Institute for Systems and Innovation Research in Karlsruhe, Germany.

There are a number of constraints that faced the implementation of the Desertec project, such as:

- The cost of investments to build power bridges across the Mediterranean is expected to be 2 million euros per kilometer (400 MW cables)
- Security risks associated with the risks of securing investments and laws, the transfer of energy from political and economic threats, and energy infrastructure.

C. *Sahara Solar Breeder (Alg-Jap)* [46]

Sahara Solar Breeder (SSB) is a project which proposes a plan of international partnership in aimed to gradually construct over the coming decades a “Global Clean Energy Super-highway” starting in the Sahara desert in North Africa. SSB will help migrate from fossil-fuel-based energy paradigm to a more sustainable and clean one as it helps to overcome global energy challenges, and reduce climate change and other environmental problems.

The research and experimental period lasted until 2016, over a period of five years at a value of $5 million for the power generation of 100 GW until 2050. The cost of research and installation may be large, but the cost of extracting silicon is low compared to extracting traditional energies.

At the University of Science and Technology, Oran, a new technique for the production of Silicon was developed, as announced by the Algerian-Japanese Program Manager (SSB) for solar technologies, it was stated that Sahara’s sand is 71% Silicon. The exploitation allows the development of manufacturing solar panels in Algeria. Extracting the Silicon contained in a rock called "diatomace" (available in a significant amount in the Siq or “Mascara”) is the core technique.

D. *The Maghreb-European Project in Solar Hydrogen Energy* [47]

The partnership between the countries of Southern Europe and Algeria can be strengthened in the upcoming years through the Moroccan-European project of solar hydrogen, in which the Center of Renewable Energies Development in Algeria covers in the Maghreb area. The northern Mediterranean countries is entrusted to the European Company for Hydrogen Technologies. The project was created by the Algiers Declaration at the World Hydrogen Energy Conference on 14 June 2006. The Maghreb-European project on solar hydrogen aims to achieve the following objectives:

- The development of high-efficiency technologies for hydrogen production by solar energy, as well as hydrogen production.
- Development of hydrogen transport technology over long distances: natural gas pipelines, maritime transport.
- Assess, compare and validate the safety of high-quality technology from the perspective of its industrial development.
- Forming effective experts in the fields of research, development and manufacturing in order to contribute to the development of this new energy.

In 2006, the Algerian research team concluded that the project could be launched by the establishment of a solar power plant near the city of Ghardaia (the gas field Hassi R’Mel) because the site contains the needed characteristics, namely: a solar reservoir, huge quantities of exploitable water, and gas pipeline network Trans-average through which hydrogen can be transported.

E. *Creating Private Suppliers*

There is the possibility of implementing a two-way grid system, which may turn the costumers into suppliers. This grid is designed so that houses in the south having solar energy panels that generate their domestic electricity, become the supplier in case of excess in generated electricity.

This initiative mainly targets the southern population of the country, as there is more profit potential in the south, which in return encourages a more balanced population-distribution, on top of the 50% reduction in electricity cost.

The national company of electrical and gas production would benefit from this project as well as suppliers, as maintenance costs are emitted when it comes to the energy generated by suppliers.

IIX. Conclusion

As a conclusion, the Algerian economy’s future is highly dependent on the integration of renewable energies as it plays a huge factor in the stability of not only the economy but the country’s as a whole. Some of the outcomes and benefits of renewable energies integration in Algeria have been presented throughout this thesis, emphasizing more on its importance.

The implementation of renewable energies would result in a more sustainable way of electricity production mainly, as much as it would offer more stability to the country’s economy and overall. It is estimated that it can easily cover the current and the future demands of energy in the country due to its potential, especially when it comes to solar and wind energy.

The potential in Algeria as previously presented is very high. The country hosts different climates, with a wide topography. Solar energy alone can cover the demand of energy in Algeria, if implemented in the great desert. Wind energy is also a reliable source in the country.

Energy can be exported, thus creating a new market and expanding the span of profits in the energy industry that would be embodied in the projects and initiatives in this field.

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