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Estimates of Hydrogen Production Potential from Renewable Resources in Algeria

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Abstract:

This study was conducted to estimate the potential for producing hydrogen from renewable resources (solar photovoltaic, wind and geothermal energy) in Algeria and to create maps that allow the reader to easily visualize the results. To accomplish this objective, we analyzed renewable resource data both statistically and graphically utilizing Geographic Information System (GIS), a computer-based information system used to create and visualize geographic information. The study will evaluate the availability of hydrogen production potential from these key renewable resources.

ملخص

وقد أجريت هذه الدراسة لتقدير إمكانية إنتاج الهيدروجين من مصادر الطاقة المتجددة (الطاقة الشمسية وطاقة الرياح) في الجزائر وإنشاء الخرائط التي تسمح للقارئ بسهولة تصور النتائج. ولتحقيق هذا الهدف، قمنا بتحليل بيانات الموارد المتجددة على حد سواء إحصائيا وبيانيا باستخدام نظام المعلومات الجغرافية (GIS) ونظام المعلومات الحاسوبية المستخدمة في إنشاء وتصور المعلومات الجغرافية. فإن دراسة تقييم توافر إمكانات إنتاج الهيدروجين من هذه الموارد المتجددة الرئيسية.

Summary

Symbol	Definition	Unit
$\mathbf{E_{PV}}$	Annual energy produced by the photovoltaic	GWh/m²/year
$\boldsymbol{G}$	Annual horizontal solar irradiation	kWh/m²/year
$\boldsymbol{C_P}$	Coefficient of performance of the wind turbine	-
$\boldsymbol{\rho}$	Density of air	kg/m^3
$\boldsymbol{C_e}$	Efficiency factor	-
$\boldsymbol{\eta_m}$	Efficiency of the gearbox	%
$\boldsymbol{\eta_g}$	Efficiency of the generator	%
$\boldsymbol{\eta_2}$	Electrolyser losses	%
$\boldsymbol{\eta_1}$	Electrolyser operation efficiency	%
$\mathbf{E_{el}}$	Energy generated by the wind generator	GWh/km²/year
$\boldsymbol{M_{hyd}^T}$	Hydrogen mass	Tons/km²/year
$\boldsymbol{P}$	Kinetic energy	Kw
$\boldsymbol{LHV_{H2}}$	Lower heating value of hydrogen	kWh/kg
$\boldsymbol{\eta_{PV}}$	Module reference efficiency	%
$\boldsymbol{\eta_{PC}}$	Power conditioning efficiency	%
P_{el}	Power generated by the wind turbine	GWh/m²/year
$\boldsymbol{E_{hyd}^T}$	Renewable energy production	kWh
$\boldsymbol{A}$	Swept surface of the wind turbine	m²
$\boldsymbol{V}$	Wind speed	m/s

List of figures

chapter I : Assessment of solar and wind potential and electricity production

Chapter II: Estimation Of Hydrogen Production

List of tables

General introduction

The world consumption of energy has increased even more rapidly. The International Energy Agency forecasts that the global demand for energy is expected to increase 53% by 2035 [1]. Conventional energy sources includes oil, gas and coal are the main resources for world energy supply (cover roughly 80%). Fossil fuels are easy to exploit to generate energy because they only require a simple direct combustion. However their use leads to increased undesirable production of greenhouse gas, contributing to global warming. More importantly, fossil fuel resources are finite, their reserve depletion times for oil, gas and coal of approximately 35, 37 and 107 years respectively [2].

Today, the greatest challenge is how to manage and to meet the rising demand in sustainably, economically and securely responsible ways, including dealing with greenhouse gas emissions. The transition to renewable energy based hydrogen systems appears to be an interesting solution and provides an opportunity to address the challenges.

Renewable hydrogen is a promising energy carrier for the future energy supply, it benefits as an environmentally friendly, versatile, and efficient fuel. Hydrogen may be produced from renewable energy sources through a variety of pathways and methods [3].

Attention around the world has focused on the promise hydrogen economy. In order to study the feasibility of the transition towards a hydrogen economy, as a major step we must evaluate and estimate the potential of renewable hydrogen for each country. For this, several authors have been estimated the hydrogen production potential from key renewable sources (solar, wind, geothermal and biomass) in many country in the world [4].

Algeria plays a key role in world energy markets as a leading producer and exporter of natural gas. Algeria’s energy mix in 2012 was almost exclusively based on fossil fuels, especially natural gas (93%) [5]. However, the country has enormous renewable energy potentialities in solar as well as in geothermal and wind energy.

The transition of energy from traditional fossil fuel based economy towards a sustainable hydrogen economy in the next years could fundamentally transform Algeria’s energy policy, creating opportunities to increase energy security though the use of variety of renewable energy sources for hydrogen production while reducing environmental impacts and a lever for economic and social development, particularly through the establishment of wealth and job creating industries [6].

The main objective of the present study is to assess and provide a comprehensive picture of hydrogen production potential using solar and wind energies in Algeria.

To accomplish this, our task will be divided into two sections. In the first chapter we describe the global energetic situation in Algeria, including an analysis of the oil and gas sector and the electrical consumption statistics, also water and renewable energy resources. Then we present the followed methodology to investigate the wind speed and solar irradiation characteristics in Algeria. The study is performed following two steps. In the first step, the study is based on the analysis and modeling of the statistical data of RETScreen. In a second step, a GIS tool, more specifically, an ArcGIS Spatial Analyst is used to produce maps of wind and solar energy, therefore the electrical potential are calculated after the introduction of the meteorological results in the photovoltaic and wind turbine models, finally the electrical potential of wind and solar will be presented.

In the second chapter the methodology for the assessment of the renewable hydrogen potential is presented. The aim of this section is to highlight suitable regions that have high annual hydrogen production from solar and wind energies. The assessment of renewable hydrogen production by solar and wind energy are analyzed both statistically and graphically using a Geographic Information System (GIS), a computer based information system used to create, manipulate, analyze, and visualize geographic information. Finally, a comparative study between solar and hydrogen production potential is presented.

1. Introduction

Algeria plays a very important role in the world energy markets, both as a significant hydrocarbon producer and as an exporter, as well as a key participant in the renewable energy market [7]. In the recent years, Algeria started a new energy strategy by paying more attention to developing its clean energy resources, and launching ambitious programs to develop and promote energy efficiency. This programs lean on a strategy focused on developing and expanding the use of inexhaustible resources, such as solar and wind energy in order to diversify energy sources, and prepare Algeria for tomorrow through combining initiatives, and the acquisition of knowledge. Studies of renewable energy sources performed in Algeria during recent years show that it has an important potential for power generation from solar and wind energy sources, for the domestic market as well as for export to the European market [8]. However these resources are still commercially under exploited, the assessment of these energies is needed to estimate the real potential of power generation from renewable energies in Algeria.

In this section of study, we will focus on the methodology followed to assess the power generation from renewable energy sources starting by the estimation of wind and solar energy potential in Algeria, which is different due to the varied nature of the resources, and due to the geographical sites specifications, climatic conditions and technological limitations of each resource. Once the solar and wind potential for each region is evaluated, a geographical representation of the resulting renewable energy potential is presented and interpreted.

2. Algeria Strategic location

Algeria's geographical location has several advantages for extensive use of most of the renewable energy resources. Algeria is situated in the centre of north Africa between 38–35° latitude North and 8–12° longitude East, with a surface of 2,381,741 km^2 that contains a wide range of different natural resources dispersed throughout its vast surface. Benefiting from political stability, Algeria's economy continued to perform solidly in 2013, growing by 3% (3.3% in 2012). Growth was driven by private demand and investment by public enterprises, which offset a downturn in public expenditure and exports, especially oil and gas. After stabilizing at 10.0% between 2010 and 2012, unemployment fell slightly in 2013, standing at 9.8% in September [9].

Inflation returned to its pre 2012 level, falling from 8.9% to 3.3% thanks to a prudent monetary policy, fiscal consolidation and government measures to control and improve distribution channels for consumer goods. Algeria’s economic growth slowed in 2013 to 3% (3.3% in 2012) as oil and gas output dropped and, to a lesser extent, public expenditure was reduced as part of the government’s fiscal consolidation measures. The main drivers of growth were private demand and investments by public enterprises. Excluding oil and gas, the economy grew by an estimated 5.9%, down from 7.1% in 2012 [9].

2.1. Oil and natural gas sector

Algeria, whose economy is reliant on petroleum, has been an OPEC member since 1969. Hydrocarbon production forms a very important part of Algeria's economy accounting 60% of government revenues, 95 % of export earnings. Its crude oil production stands at around 1.1 million barrels/day, but it is also a major gas producer and exporter, The country produced almost 1.8 million bbl/d of total petroleum and other liquids in 2013, which includes crude oil, condensate, natural gas plant liquids, and refinery processing gain [10].

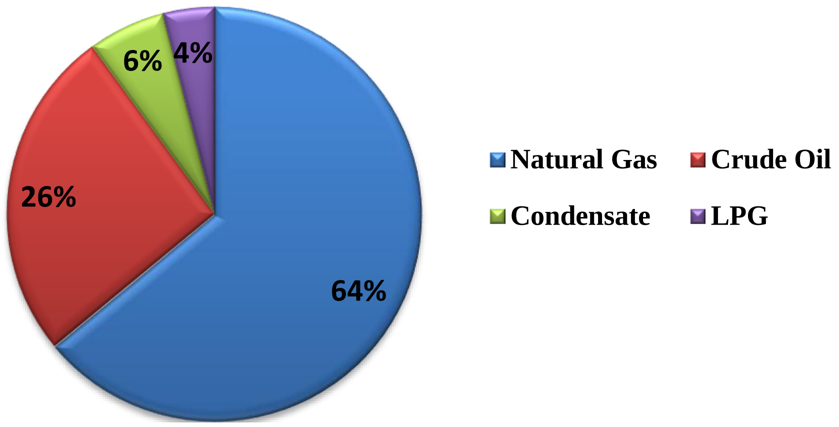


Figure 1 : Total Petroleum Production [10]

The largest and oldest oil field, Hassi Messaoud, contributed more than 40% of total crude oil production, which averaged 1.2 million bbl/d in 2013, according to OPEC Algeria has the 17th largest reserves of oil in the world, and it is the leading natural gas producer and the second oil producer in Africa.

Algeria was the first country in the world to export liquefied natural gas in 1964, it is the second largest natural gas supplier to Europe, it exports natural gas via pipelines and on tankers in the form of liquefied natural gas. It has three transcontinental export gas pipelines: two transport natural gas to Spain and one to Italy. Besides, Algeria is estimated to hold the third-largest amount of shale gas resources in the world.

Algeria's national oil and natural gas company, Sonatrach, dominates the country's hydrocarbon sector, owning roughly 80% of all hydrocarbon production. By law, Sonatrach is given majority ownership of oil and natural gas projects in Algeria. The vast majority about 72% of Algerian crude oil exports are sent to Europe. The United States was the single largest destination until 2013 when U.S. imports fell to 29,000 bbl/d, 75% less compared with 2012 [5].

Most of Algeria's domestic petroleum consumption, which averaged 380,000 bbl/d in 2013, derives from domestically refined products. Algeria's petroleum consumption has increased by an annual average of 5% over the past decade, income from oil and gas rose in 2011 as a result of continuing high oil prices, though the trend in production volume is downwards.

2.2. Electricity Sector

Algeria's electricity generation capacity reached 15.2 gigawatts (GW) at the end of 2013, up from 12.9 GW at the end of 2012 and 11.4 GW at the end of 2011, according to Sonelgaz, the country's public utility in charge of electricity generation and distribution.

Sonelgaz has brought additional capacity online to keep up with demand needs, the vast majority of generation capacity comes from gas-fired and combined-cycle plants, although the share of renewable energy in Algeria's generation mix is growing but still limited (Figure 2) [11].

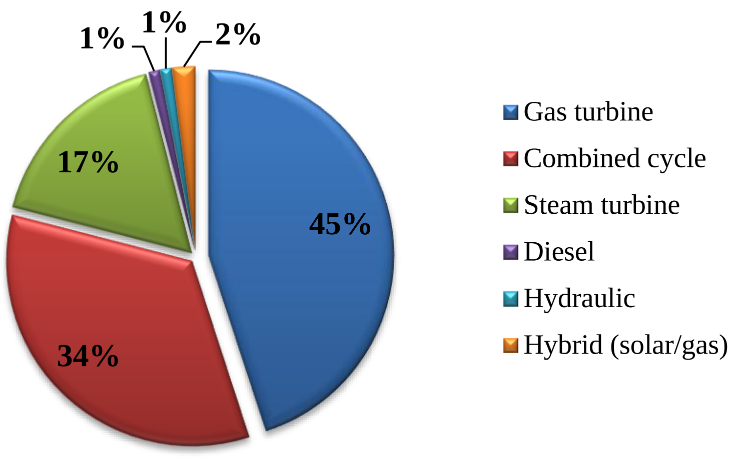


Figure 2: Electricity production by technology [11]

Net electricity consumption was 44 billion kW in Algeria in 2012, Algeria’s electricity consumption has increased by an annual average of roughly 10% from 2009 to 2012.

The vast majority of generation capacity comes from gas-fired and combined-cycle plants, although the share of renewable energy in Algeria's generation mix is growing but still limited. According to the Electricity and Gas Regulation Commission (CREG), The country's electricity and gas market regulator, the national electricity system consists of an interconnected network that distributes power to Northern and Southern parts of the country. About 99% of Algeria's population is connected to the national grid [12].

Algeria's power demand peaks during the summer months, and demand is expected to reach 12.5 GW in the summer of 2014. Algeria's peak demand is expected to grow to 20 GW by 2017.As a result, Sonelgaz plans to add more than 12 GW of generating capacity by 2017/2018.

Present reserves of oil and natural gas can only cover consumption at this rate for the next 50 years in the case of oil, and for the next 70 in the case of natural gas. Therefore, one of the fundamental priorities for a country such as Algeria is to exploit it wide range of renewable energies and pay more attention to the friendly energy conversion technologies.

2.3. Renewable energy projects in Algeria

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 such projects to other countries . Indeed, the integration of renewable energies into the national energy mix constitutes a major challenge in the preservation of fossil resources, the diversification of electricity production ways and the contribution to sustainable development in the program for development of renewable energies 2011-2030 adopted by the government in February 2011, renewable energies are placed at the heart of energy and economy policies led in Algeria [8].

The renewable energy program is defined through different phases:

- Installation of a total power capacity of 110 MW by 2013 ;
- Installed power capacity to reach 650 MW by 2015 ;
- Installed power capacity to reach about 2600 MW by 2020 and a possibility of export of 2000 MW;
- An additional capacity of about 12000MW is expected to be installed by 2030 and a possibility of export up to 10 000 MW.

The division of this program by technology sector, appears as follows:

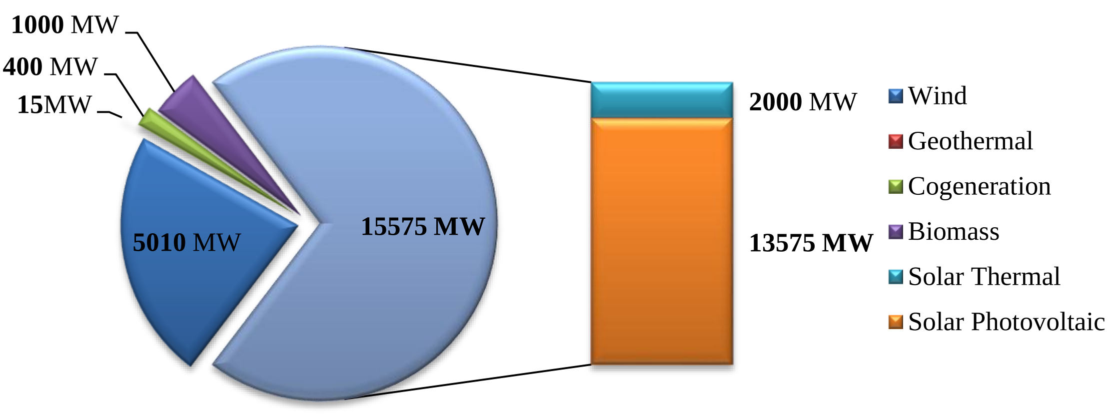


Figure 3 : Partition of renewable energy program[8]

Achieving this program will allow to reach by 2030 a contribution of 40 % of renewable energy in the national report of electric production, the program aims to reach by

2030; a contribution of 22000 MW from renewable electricity production for the national market, 4500 MW will be realized before 2020 [8].

Currently, Algeria is engaged in two major projects that provide a place for solar and wind energy, hybrid gas-solar plant of 150 MW is located in Hassi R'mel which the cost is 350 million Euros, a solar technology park that will generate electricity from the sun with a capacity of 6000 MW by 2015 and a 10 MW wind farm in Tindouf, these projects are being implemented by the group New Energy Algeria (NEAL). The commissioning of the hybrid plant combining solar and natural gas in Hassi R'mel is part of the program of four hybrid units in Algeria and extends over an area of 152 ha. It will use giant parabolic mirrors on an area of 18 ha with solar panels of 100m to generate power. It will allow Algeria to be the pioneer in the Mediterranean in the field of renewable energies [11].

CEEG company (subsidiary of SONELGAZ), launched an international tender to conduct a wind farm with a capacity of approximately 10 MW in Tindouf, a large development project of solar water heaters market, funded by the PNUE, was launched in 2008. It is the installation of 10 000 m² of solar collectors.

The group Sonelgaz instructed its engineering company CEEG to undertake a project to build a manufacturing of photovoltaic modules in the scope of the industrial area of Rouiba, through a mandate with the client (Rouiba Lighting Company). The envelope that will be allocated to the creation of this first manufacturing plant for photovoltaic modules is 100 million dollars. This future entity, which commenced operations in 2012, will be an annual capacity of 50 MW. It will be financed entirely by Sonelgaz and installed within the company's website Rouiba Lighting over an area of 4 ha [11].

Three other central hybrid solar / gas of 400 MW each are scheduled for 2015; a wind farm with a capacity of 10 MW, located in Adrar, is under tendering. The project is the first project of its kind in Algeria and will operate on a hybrid wind / diesel technology. Two other wind farm projects of 10 MW are planned in Timimoun (2012) and Bechar (2015).

2.4. Water resources in Algeria

Algeria, with a surface of 2.4 million km², is the largest country of northern Africa. Most of this surface is occupied by the Sahara, unfit to agriculture, but rich with mineral resources. More than 90 % of the population lives in the North, that includes a coastal band along the Mediterranean Sea, plains, mountains and high lands. The annual amount of rain, in the North, varies between 300 and 1000 mm. In the Sahara and south the Saharian Atlas, the annual amount of rain is below 100 mm. Algeria has 17 major hydrographic basins and shares the Medjerda basin with Tunisia, and Tafna, Draa, Guir and Daoura basins with Morocco [13].

The annual amount of rain is 100 billion m^3, of which 80 % evaporate into the atmosphere. The water resources are estimated at 19.3 billion m^3/year, of which 12.4 billions of surface water and 6.9 billions of underground water. Only 6 billion could be mobilized by dams. For the moment only four billions are mobilized by nearly 110 dams (Figure 4) [14].

In wide territories; underground water often offers natural characteristics in conformity with the standards required by many uses, in particular the drinking water., from the 6.7 billions of ground water resources, 5.1 billion are located in Sahara. The rest, 1.6 billion m3, is already mobilized at a rate of 80 %, principally by wells and boreholes.

The aquiferous system of the North Sahara, extending 1 million km², is shared by Algeria, Tunisia, and Libya (Figure 5). The groundwater aquifers are fed by the winter rains and sometimes by infiltration from the Oueds. Algeria, Tunisia, and Libya have launched efforts to coordinate the management of these water resources [13].

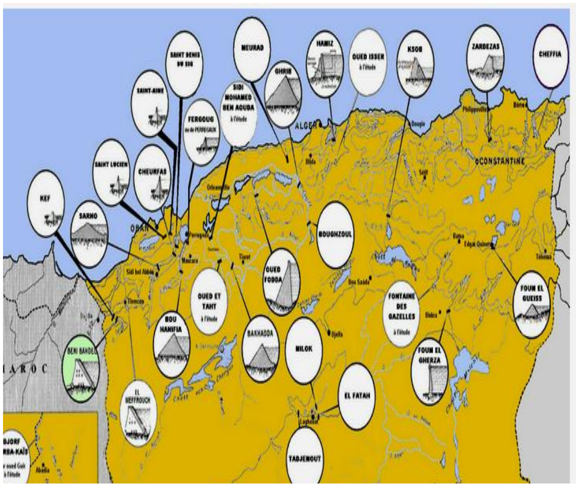


Figure 4: Algeria's 110 dam[13]

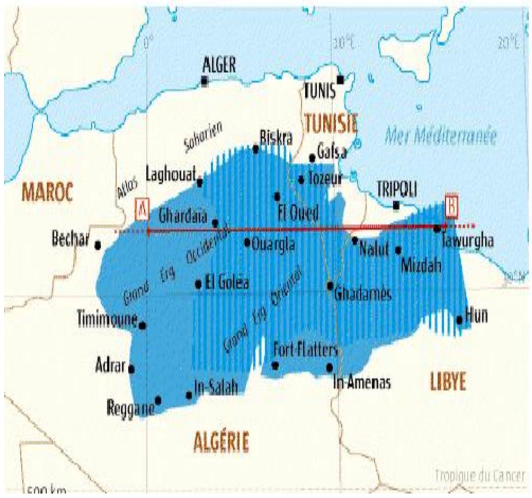


Figure 5: The Albian Aquifer[13]

From all these statistics we can see the variety of natural resources that Algeria is endowed with, however taking into account the technological evolutions and the economical changes and needs, the need to diversify the energy resources is becoming a necessity.

3. Meteorological data

The first step to evaluate the hydrogen production using renewable energies, is to analyze the solar and wind potential in Algeria. For this, the definition of the meteorological data such as solar radiation, wind speed, is needed.

3.1. Solar irradiation data

Today, the most common technologies for utilizing solar energy are photovoltaic and solar thermal systems. One of the main influencing factors for an economically feasible performance of solar energy systems (besides of installation costs, operation costs and lifetime of system components) is the availability of solar energy on ground surface that can be converted into heat or electricity . Therefore precise solar irradiation data are of utmost importance for successful planning and operation of solar energy systems. Solar irradiation means the amount of energy that reaches a unit area over a stated time interval.

Solar radiation can be divided into direct and diffuse radiation, together these components are denoted as global irradiation. The distinction between direct and diffuse radiation is important as different technologies utilize different forms of solar energy [15].

Total solar radiation data is considered the most important parameter in solar energy application, particularly for sizing photovoltaic systems. In this study, the assessment of these data have been recorder for a period of 10 years (2003-2013), in 47 meteorological stations in the Algerian territory and 22 stations from the neighbor countries (Tunisia, Morocco, Mauritania, Libya, Niger and Mali).

3.2. Wind speed data

Wind was one of the first energy sources to be harnessed by early civilizations. The world’s first automatically operated wind turbine, which was built in Cleveland in 1888 by C.F. Brush, was 18 m tall and had a 12 kW turbine. Nowadays the use of wind energy in electricity generation is widely spread and new units with nominal capacity of thousands of megawatts are being installed each year. The total wind power capacity installed worldwide has exceeded 120 GW in 2008.

The ever increasing interest for wind energy, coupled with its uncertain nature, makes the estimation of wind energy perhaps the most difficult and crucial part of a wind farm project [15]. For the assessment of the wind resource in Algeria we use the average wind speed (m/s), this data is collected from 48 local stations and 22 stations from neighboring countries.

The real potential of renewable resources in Algeria will be presented in the wind and solar energy maps for the whole Algerian territory using meteorological data. For both estimation of solar and wind potential, the meteorological data available in the RETScreen software are used (Annex 1). The software integrates a number of databases to assist the user, including a global database of climatic conditions (horizontal solar irradiation, wind speed, ambient temperature, humidity ...etc.) obtained from 6700 ground-based stations and NASA's satellite data; benchmark database; project database; hydrology database and product database [16].

3.3. Validation of RETScreen database

This study was conducted on the meteorological database of the RETScreen software (Annex 1), to validate our results we had to compare the data collected from both, the RETScreen software and the local National Office of Meteorology (ONM), for Ouargla region.

In order to simulate the daily solar irradiation of Ouargla region, a mathematical program has been developed based on mathematics models[17]. This program is able to calculate direct, diffuse and global daily average solar irradiation. The monthly sunshine duration measurements are obtained from the National Office of Meteorology, these data were recorded for a period of 10 years (2003-2013).

For the wind speed ; it was recorded at the height of 10 meters. The comparison of solar irradiation data and wind speed data from both The National Office of Meteorology [18] and the RETScreen software for Ouargla region is presented in the Table1 and Table 2 , respectively.

Table 1: Validation of RETScreen database (solar irradiation data)

Month	RETScreen Solar radiation (kWh/m²/j)	ONM Solar radiation (kWh/m²/j)	Error
January	3.04	3.43	0.4
Febraury	4.35	4.52	0.17
Mars	5.62	5.22	0.4
April	7.06	7	0.06
Mai	7.25	7.04	0.21
Juin	7.69	7.12	0.57
July	7.91	7.08	0.83
August	7.42	7.03	0.39
September	6	6.9	0.9
October	4.33	4.91	0.58
Novembre	3.3	3.9	0.6
December	2.66	3.19	0.53
Annual	5,54	5,61	0.07

Table 2: Validation of RETScreen database (wind speed data)

Month	RETScreen wind speed (m/s)	ONM wind speed (m/s)	Error
January	2.8	3	0.2
Febraury	3.3	3.4	0.1
Mars	3.9	4.4	0.5
April	4.4	5	0.6
Mai	4.9	5.4	0.5
Juin	4.5	4.6	0.1
July	4.3	5	0.7
August	4.1	4.5	0.4
September	4.1	4.3	0.2
October	3.5	3	0.5
Novembre	2.5	3.2	0.7
December	2.7	2	0.7
Annual	3.73	3.98	0.25

The comparison has shown an average absolute error of 0.06 - 0.83 (kWh/m²/j) for the solar annual horizontal irradiation, and an error of 0.1 - 0.7 (m/s) for the wind speed measurements. The error between the annual solar irradiation of both data sources represents 1.24% and 6.28% for the annual wind speed. The result of this comparison shows a slight difference between the collected data, and that defines the RETScreen software as a validated source of meteorological database.

4. The assessment of solar and wind energy potential

The determination of the available wind and solar potentials in the whole Algerian territory is based on the data of the RETScreen based on the meteorological measurement stations which are not sufficient to estimate the wind and solar potentials in other locations where no measurement stations are available. For this reason, prediction methods are needed in order to predict the wind and solar potential for each point of the territory [4], an interpolation method is required to find out the potential accessible anywhere in Algeria.

Numbers of method are available to construct an interpolated surface between available point's data measurement. One of these of the spatial interpolation methods is the inverse distance weighting (IDW) method, it is easy and straightforward to interpret, it is based on the idea of the assumption that the attribute value of an undefined point is the weighted average of known values within the neighborhood points, and the weights are inversely related to the distances between the sampled points and the ones to be predicted.

Once the renewable energy potential for each region is interpolated using the IDW method, a geographical representation of the resulting potential from solar and wind is mapped using the ArcGIS software (Annex 2). This software is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. the Geographical Information System can show many different kinds of data on one map. This enables people to more easily see, analyze, and understand Algerian renewable resources map [19].

4.1. Solar resource analysis

Data from 69 stations; 47 in the Algerian territory and 22 in the neighboring countries has been recorded to generate seasonally maps that shows the variation of the average horizontal solar irradiation for each season. These 22 extra data will help us to get a precise results of the solar irradiation in the bordering regions of the map.

From these maps we can observe the developing of solar irradiation throughout the year (Figure 6), the amount of solar irradiation varies regionally with the changing seasons, and hourly due to daily variation in sun's elevation.

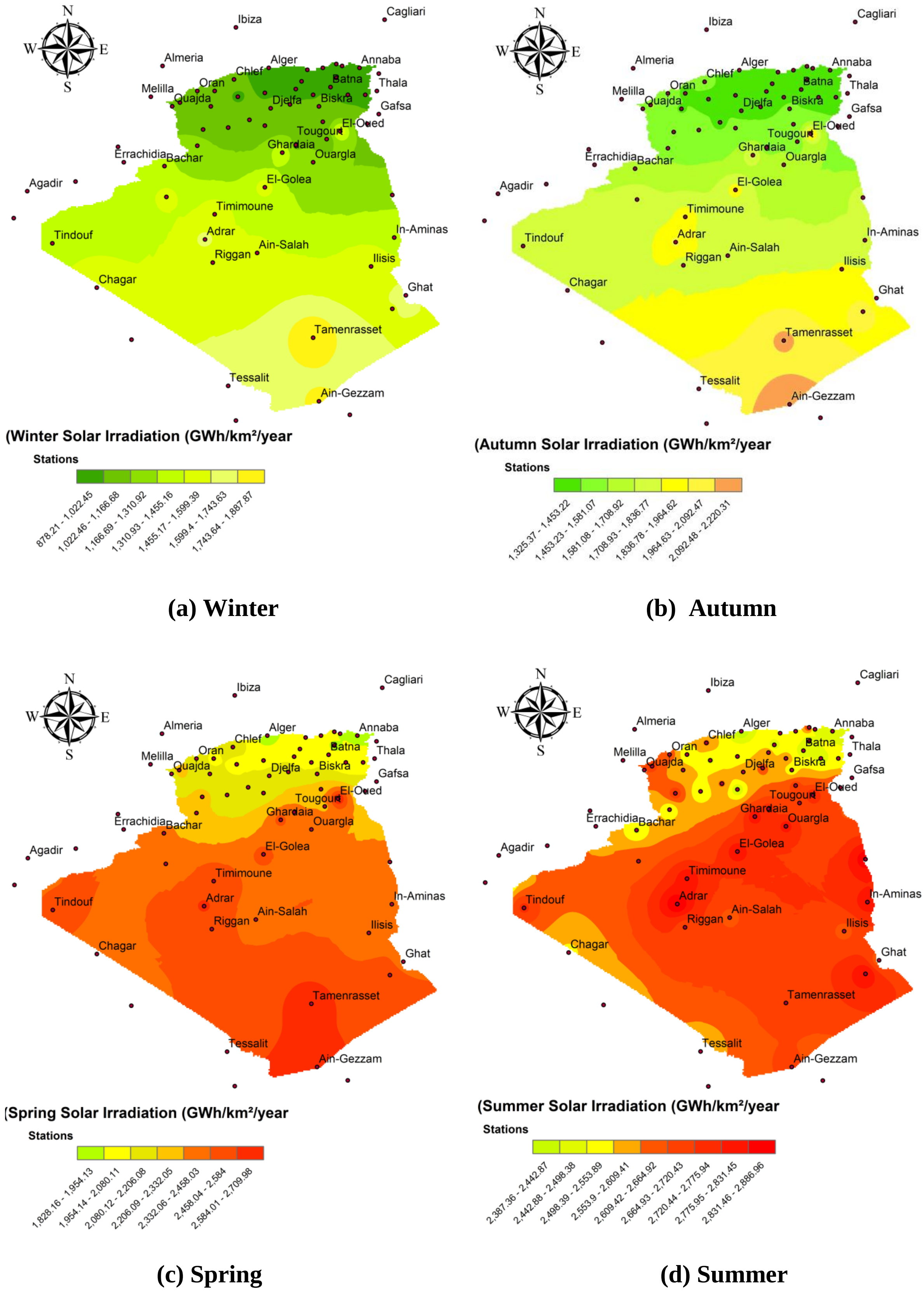


Figure 6: Seasonally average daily horizontal solar irradiation in Algeria

In winter and autumn the main obtained solar energy can be seen in the extreme South and Southwest of Algeria, in Tamenrasset region where it reaches 2117 kWh/m²/year in autumn and 1888 kWh/m²/year in winter, and in Adrar region we consider a 1638 kWh/m²/year of solar irradiation in winter and 1980 kWh/m²/year in autumn. The North part of the Sahara shows an average irradiation between 1600 – 1200 kWh/m²/year, when in the high plains and the North of the country it is less then 1000kWh/m²/year due to winter climate conditions.

However, spring and summer seasons show the real potential of the vast Algerian desert where the solar irradiation reaches its maximum throughout most of its regions by an average of 2600 kWh/m²/year, for example the 557 906 km² of Tamenrasset region records a respectable average of 2700 kWh/m²/year, in the North part of the Sahara we consider an average of 2800 kWh/m²/year in Ouargla region, and the highest recorded solar irradiation was recorded in Adrar region where it reaches 2887 kWh/m²/year. The high plains and the Northern regions still represent a considerable potential where the average solar irradiation varies between 2500 – 2300 kWh/m²/year in summer and 2200 – 1800 kWh/m²/year in spring.

Therefore, one key point to know the amount of incident solar irradiation on the horizontal surfaces is to analyze the annual solar energy map as shown in Figure 7. The annual solar irradiation in Algeria represents the most important value that expresses the overall solar potential (Figure 7).

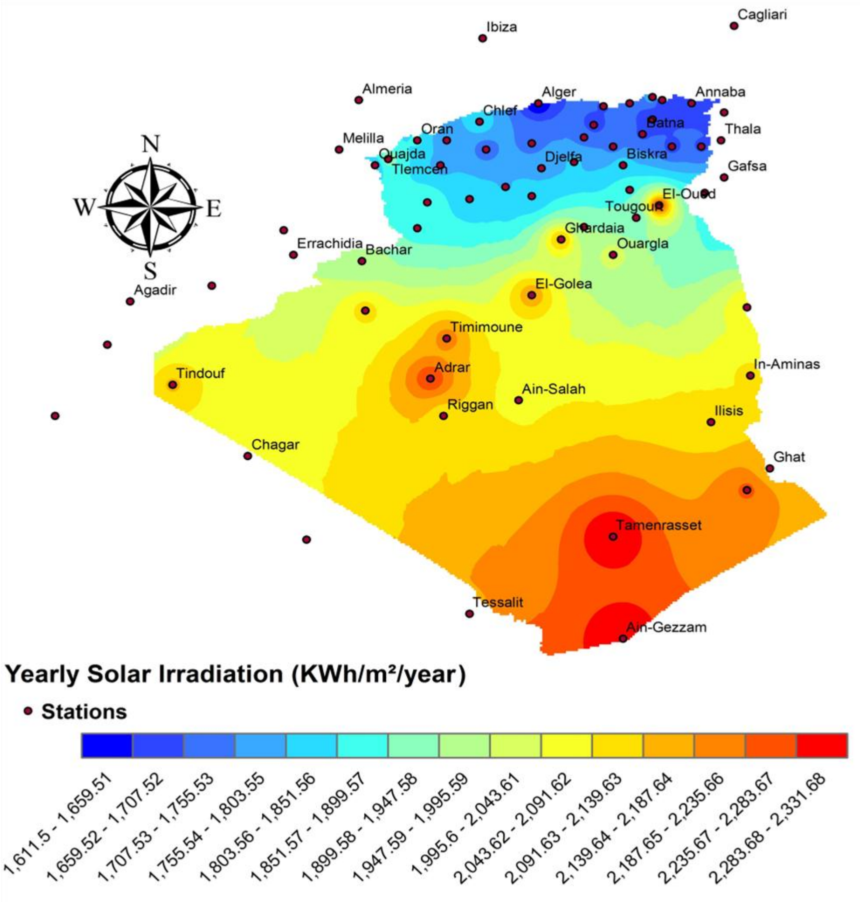
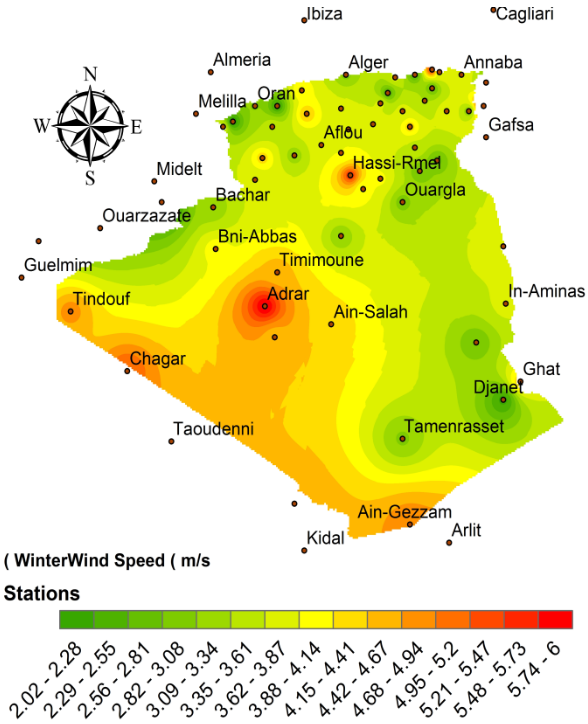


Figure 7: Annual horizontal solar irradiation map of Algeria

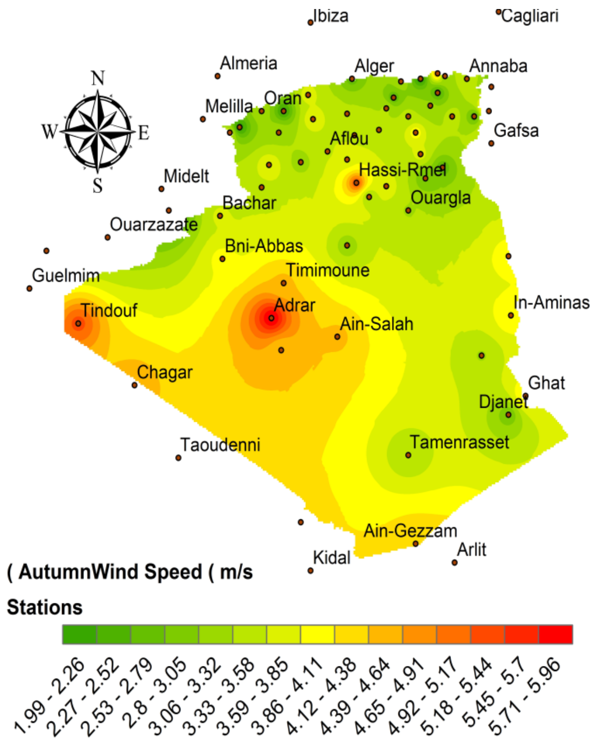
The annual horizontal solar irradiation map of Algeria promotes the promising overall solar energy, with an average of 5.3 kWh/m² daily solar exposure and 1908 kWh/m²/year within the whole Algerian territory. The vast Algerian Sahara with its 1.9 million km² which presents the main solar potential, records an average of 6 kWh/m² daily and it exceeds the 2200 kWh/m²/ year.

4.2. Wind potential

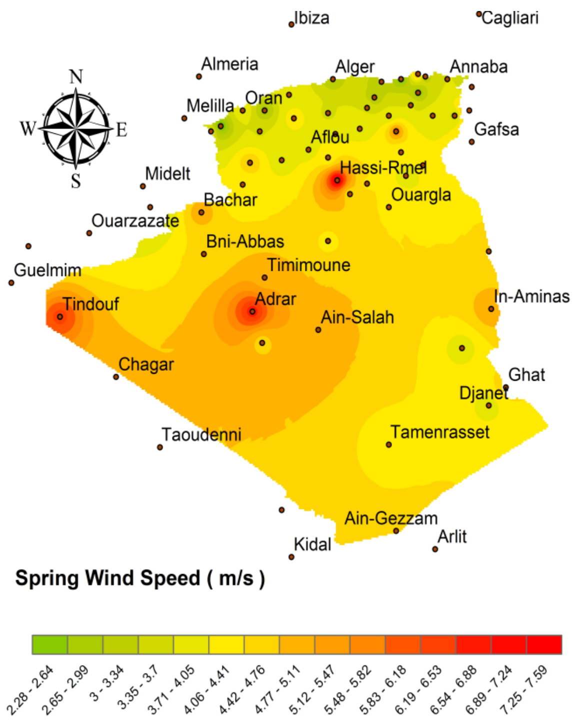
In this study we used wind speed data from 70 meteorological stations, 48 in the Algerian territory and 22 in the neighboring countries, these data were obtained at a height of 10 meters, and recorded for a period of 10 years (2003-2013). Data from The foreign measurement stations help us to get a more precise interpolated surface of the wind potential in the bordering regions of the country. The seasonally variation of wind speed as presented in Figure 8, provides information about the availability of wind speed during different months of the year.



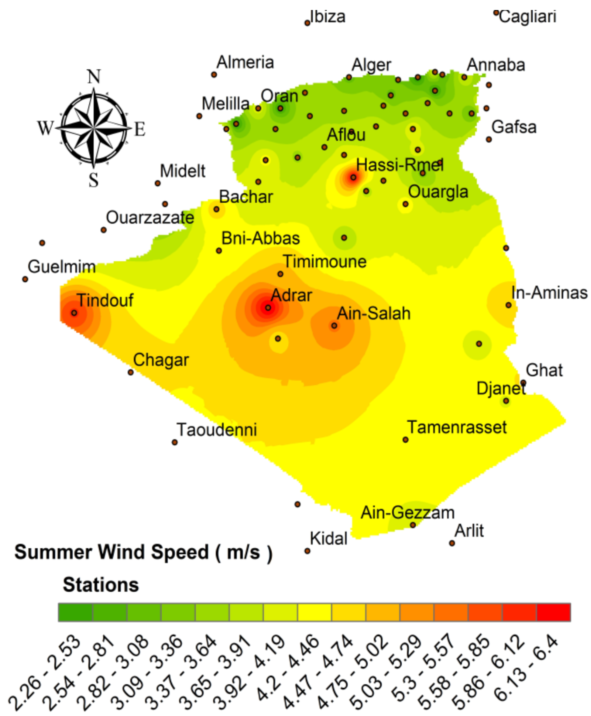
(a) Winter



(b) Autumn



(c) Spring



(d) Summer

Figure 8: Seasonally average wind speed in Algeria

We notice from seasonally wind speed map the effect of the changing seasons on the average wind potential, as we can see from these maps (Figure 8) the main obtained wind potential is well considered in the Southwestern regions of the country as well as the Northern part of the Sahara exactly in Hassi R'mel region where the maximum wind speed was recorded.

During the autumn and winter seasons from September to Mars, the overall wind speed is slightly modest throughout the Algerian map and it’s centralized in the southwest part, in Adrar it reaches 6 m/s, Tindouf 5.3 m/s, and Hassi R'mel respectively record 5.2 m/s average. In winter the maximum wind speed is measured in the Southwest region where it exceeds the 6 m/s in Adrar and Tindouf , and about 5.5 m/s in Hassi R'mel, however the wind speed varies in the rest of country in less than 4 m/s.

Nevertheless the spring and summer seasons show a great wind potential essentially in the South part of Algeria, where it reaches its maximum in Hassi R'mel region with an average wind speed of 8.2 m/s recorded in the month of may. The Southwest region present the main active wind potential, as always in the Tindouf, Ain Saleh , Adrar and Timimoun regions where the wind exceeds the 6m/s.

For a full estimated wind potential in Algeria, the annual wind speed is displayed in Figure 9, the annual wind speed represents an important parameter that expresses the average wind potential throughout the whole year.

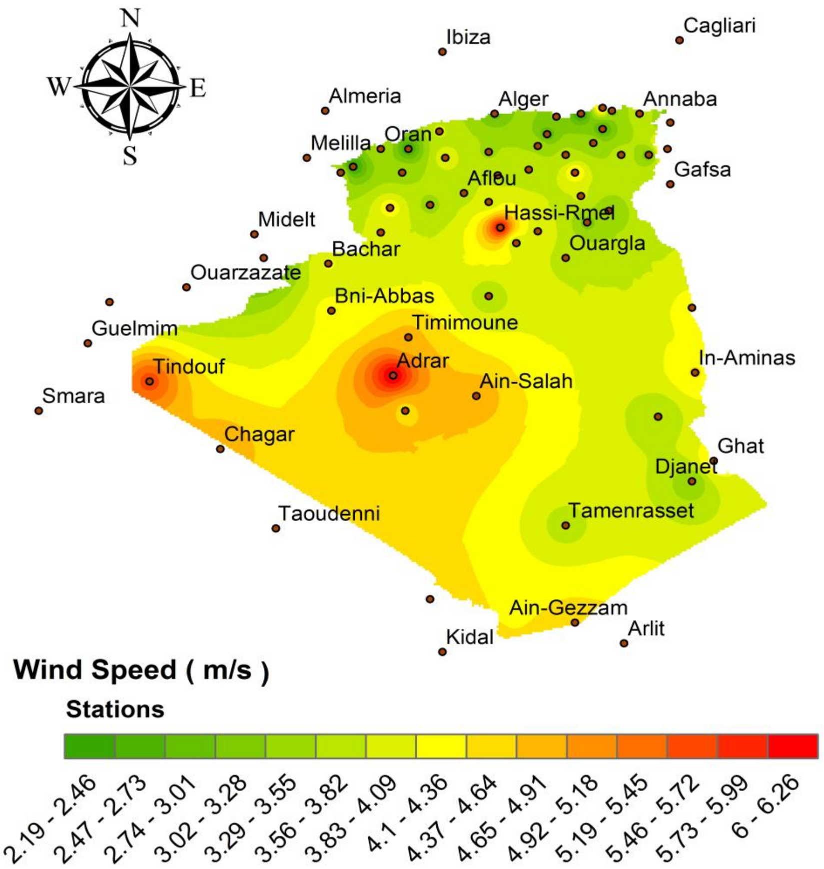


Figure 9: Annual wind speed map of Algeria

We can notice that the average annual wind speed varies across the Algerian territory between 1.8 and 6 m/s. as we can see from this map that the Southwest region represents a very significant wind potential, the region of Adrar has the max of annual wind speed estimated by 6.3 m/s, the region of Hassi-R'Mel records also a high wind speed value estimated by 6.1 m/s, in the far West the region of Tindouf presents also a respectable wind speed of 5.7 m/s annually.

In the central Sahara; Ain-Salah, Timimoun, El-Golea and Ghardaia regions, wind speed varies between 3.6 and 4.8 m/s, in Southeast in In-Aminas region wind speed reaches 4.4 m/s. However, In the high plains wind speed records medium values between 3 – 4.3 m/s, a bit higher in the west of the country exactly near El Mechria. The average wind speed in the coastal line region is about 4m/s. The lowest speed of 1.3 m/s was observed for the region of Tizi-Ouzou, So for the Maghnia region (Northwestern area), we observe that wind potential is below 1.5 m/s.

These wind potential results compared with the results recorded from different measuring stations in the neighboring countries like morocco where wind speed reaches 4.6 m/s annually in Mellila, and in Tunisia we record 4.7 m/s annually in Toseur, and in Mauritania it exceeds the 4.9 m/s annually in Chagar, these results promote the huge potential of wind energy in Algeria compared to the neighboring countries.

5. Modeling electricity production potential

The estimation of hydrogen production using renewable energies in Algeria depends primarily on the estimation of the electricity production potential from wind and solar energies, this estimation is based on the introduction of the collected solar irradiation and wind speed data in specific mathematical models to obtain the electrical potential distribution in Algeria. This process is achieved using MATLAB software, in order to assess the electrical production potential.

5.1. Modeling of photovoltaic panels

Photovoltaic panels generate electricity directly from sunlight via an electronic process that occurs naturally in certain types of material, called semiconductors. Electrons in these materials are freed by solar energy and can be induced to travel through an electrical circuit, powering electrical devices. The annual energy produced by the photovoltaic panel can be expressed as follow [20]:

$$E_{PV} = \eta_{PV} * \eta_{PC} * G \tag{1}$$

$\boldsymbol{G}$ Annual horizontal solar irradiation, kWh/m²/year

$\boldsymbol{\eta_{PC}}$ Power conditioning efficiency, %

$\boldsymbol{\eta_{PV}}$ Module reference efficiency, %

5.2. Wind turbine model

The power contained in the wind as a kinetic energy P (kW) is expressed as (Diaf et al., 2006):

$$P = \frac{1}{2} * \rho * A * V^3 \tag{2}$$

$\boldsymbol{A}$ Swept surface of the wind turbine, m²

$\boldsymbol{\rho}$ Density of air, kg/m^3

$\boldsymbol{V}$ Wind speed, (m/s)

The wind turbine can recuperate some of the kinetic energy of the wind, and it represents the power generated by the wind turbine :

$$P_{el} = \frac{1}{2} * \rho * C_e * A * V^3 \quad (3)$$

$\boldsymbol{C_e}$ Efficiency factor , which depends on the wind speed and architecture of the system

It is determined from the performance of the transformation unit:

$$C_e = C_P * \eta_m * \eta_g \quad (4)$$

$\boldsymbol{C_P}$ Coefficient of performance of the wind turbine (C_{P-max}=0.593)

$\boldsymbol{\eta_m}$ Efficiency of the gearbox, %

$\boldsymbol{\eta_g}$ Efficiency of the generator, %

In this study, we take $C_e = 0.45$. Therefore, the energy generated by the wind generator is expressed by :

$$E_{el} = P_{el} * \Delta t \quad (5)$$

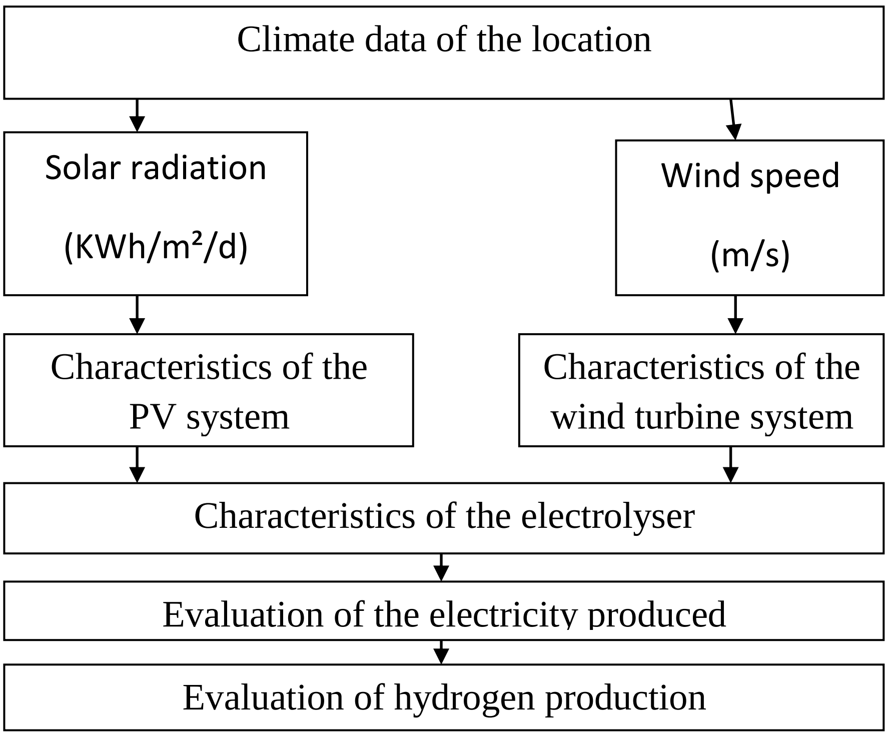


Figure 9: Diagram for the evaluation of the production of hydrogen

6. Estimation of renewable electricity production

6.1. Solar electricity production analysis

The electrical energy results obtained from the mono-crystalline photovoltaic panels of 250Wc rated power, with surface of 1.63 m² and an efficiency of 15.28% (Elysun, 2010) presented in the above section.

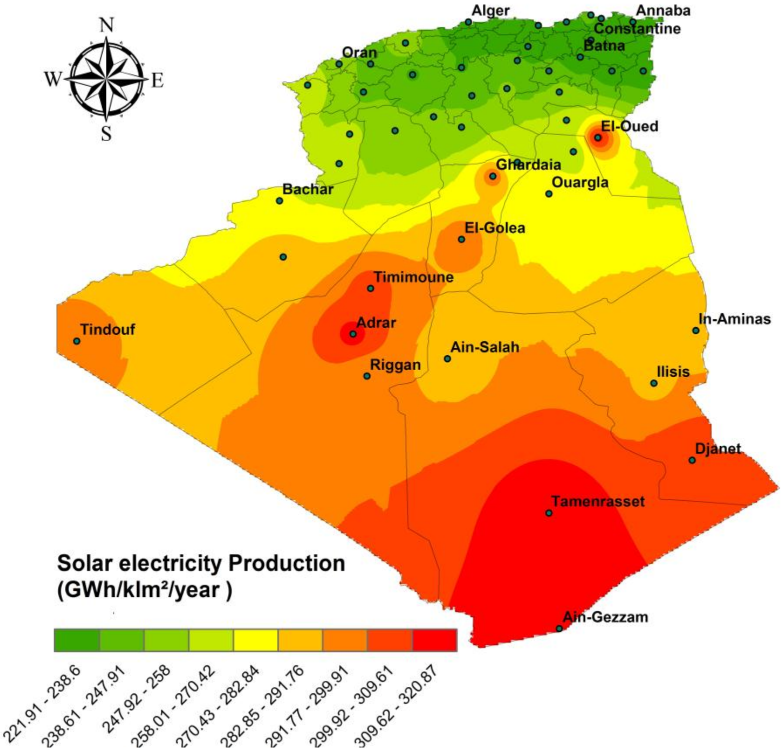


Figure 10: Solar electricity production

The geographical distribution of power generation in Algeria is presented in Figure 9. The result of the solar electricity production shows that all territory of Algeria can produce a comprehensive amount of solar energy varies between 220 and 310 GWh/km² annually. Also, the map allow us to discern three main zones depending on the geographical distribution of solar electricity (Figure 11).

Table 3: the electrical production from solar energy according to the three zones

Zone	Regions	Electrical production (GWh/km²/year)
Zone A	Laghouat-Tebessa-Khenchla-Souk Ahras -Guelma- Oum Elbouaghi-Batna-Biskra- Djelfa- Tiaret- Saida- Sidi Bel Abbas- Mascara-Rélizane- Tissemssilet- Médéa-M'sila- Sétif- Bordj bou Arreridj-Bouira- Blida- ain Defla- Annaba- Mostaganem- Chlef- Tipaza- Alger-Boumerdes- Tizi Ouzo- Béjaia- Jijel- Skikda- Taref- Elbayadh	<254.82
Zone B	Naama, Ain timouchent, Bachar, Sidi Bel Abbas, Ghardaia, Oran, Tlemcen, Ouargla, El Oued	255.91-284.87
Zone C	Adrar, Tindouf, Ilizi, Tamenrasset	>285.01

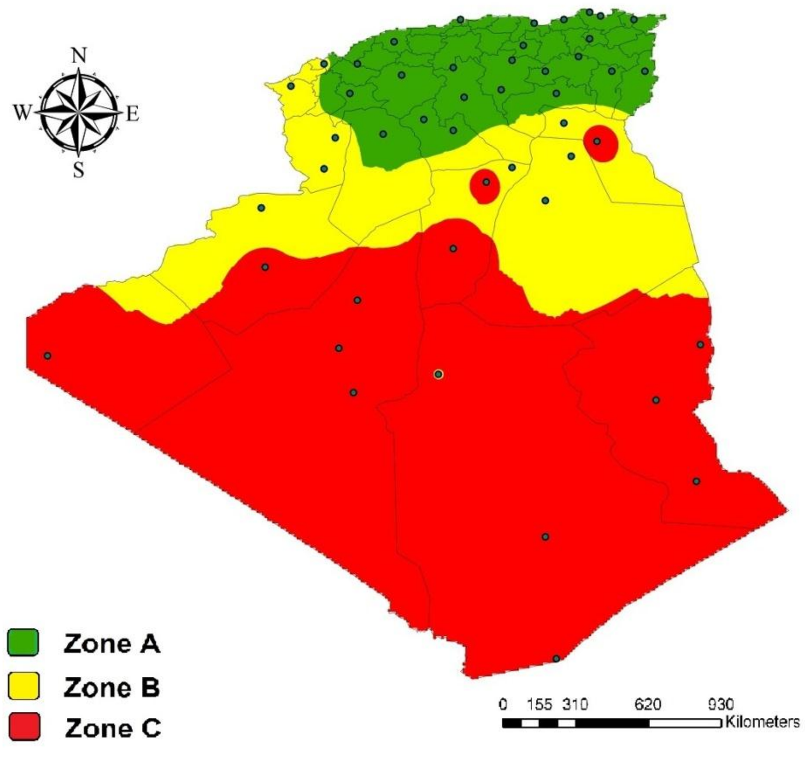


Figure 11: Repartition of Algerian territory in three zones according to the spatial distribution of solar electricity potential

Zone A shows a less amount of solar energy production comparing to the other regions and that is due to climatic conditions and seasonally changing solar radiation which affects the PV system production, however regions like Chlef, Biskra and El bayad represent possible locations for a respectable amount of solar energy exploiting. The assumed electricity production in Zone B varies from 255.91 to 278.87 GWh/km² annually. Zone C which is the largest region represents one of the most promising place for solar electricity production not only in Algeria but in the world with high solar radiation values the big Algerian Sahara can produce considerably 285.01 to 320.87 GWh/km² annually of solar electricity.

To understand the evaluation of electricity production throughout the year we analyzed the monthly production for chosen sites of the three zones, which are the most produced region in each zone.

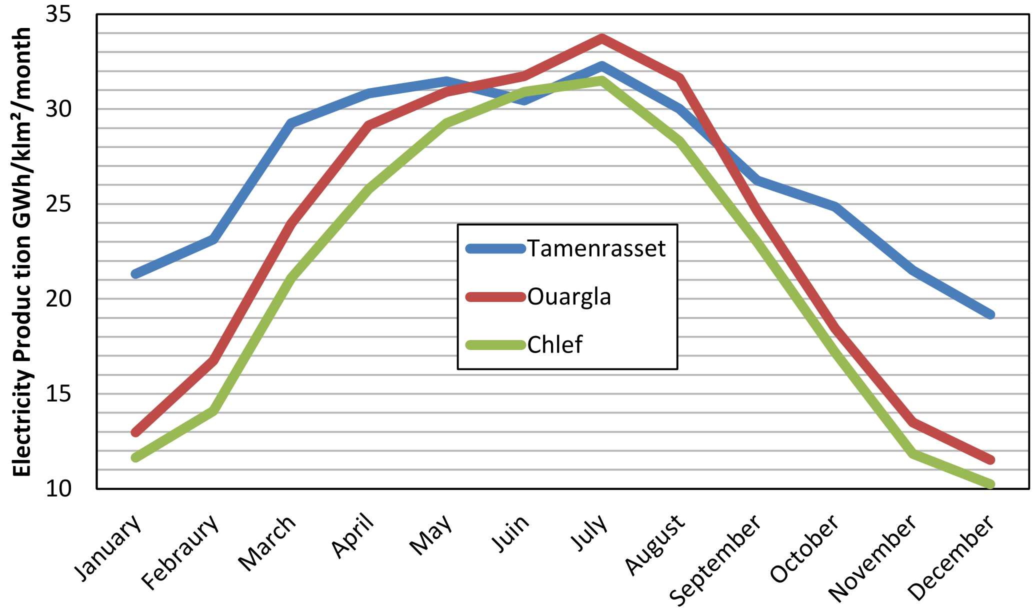


Figure 12: Monthly Solar Electricity Production of Tamenrasset, Ouargla and Chlef

The electricity production reaches its maximum in the summer season where it exceeds the 30 GWh/km² monthly, the region of Tamenrasset shows a high amount of energy generation throughout the whole year, the production rate doesn't get under the 19 GWh/km² until December, the production rate holds high values during the whole year.

Electricity production in the regions of Ouargla and Chlef is clearly affected by the changing seasons, where the production rate doesn't keep regular pace, the electricity generation starts increasing from April until it reaches its maximum in July where the region of Ouargla records the highest amount of electricity production of 33.72 GWh/km², the production rate decrease severely after the summer season until it gets under the 12 GWh/km² limit in December.

The evaluation of the solar electricity production in Algeria shows high potentials of solar energy exploitation widely observed in the south of the country with a power generation that exceeds the 300 GWh/km² yearly a large scale Hydrogen production from solar energy is largely possible.

6.2. Wind electricity production analysis

The electrical energy results obtained from the wind turbine model of 1.5 MW rated power for the 48 stations are presented in the Figure 13.

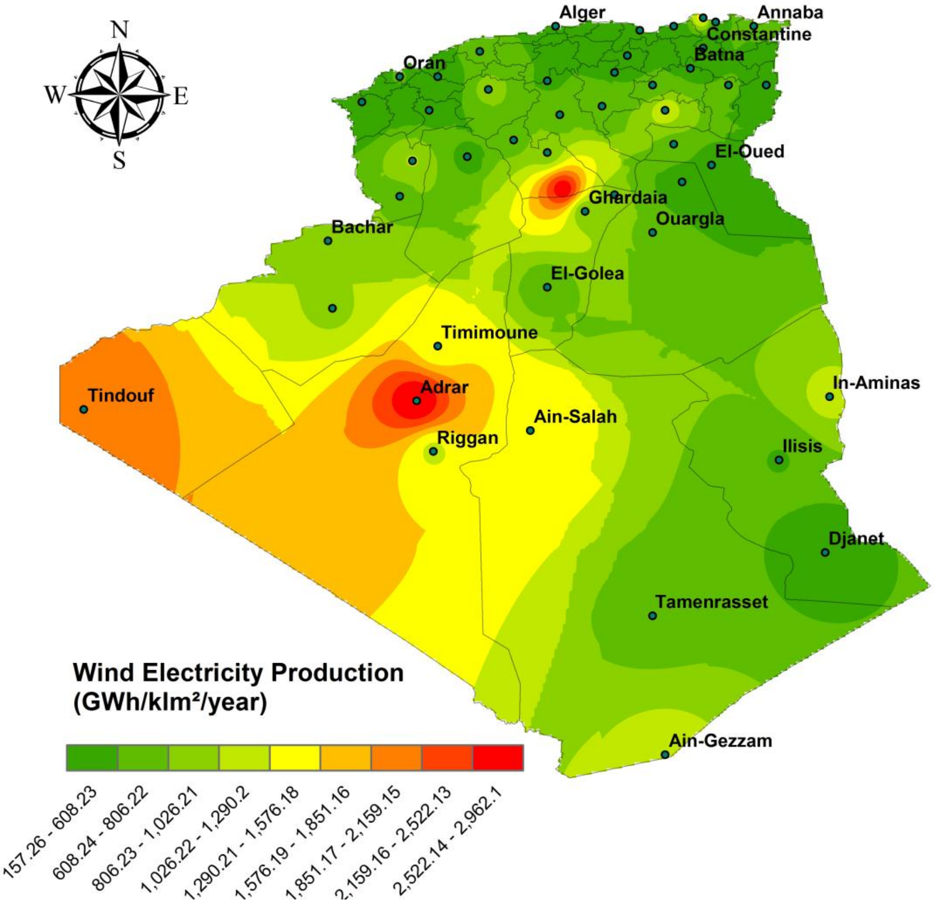


Figure 13: Wind electricity production

As seen from the presented map (Figure 13), wind electricity potential is irregularly dispersed throughout the territory, the Southern part of Algeria is considered as regions with a high electricity potential, and we can be seen scattered in the southwest as well as in central region and the coastal line in Skikda, this irregularly partition is due to disproportionately distribution of wind potential in the Algerian territory. Also, the presented map allow us to discern three main zones depending on the geographical distribution of wind electricity (Figure 14).

Table 4: The electrical production from wind energy according to the three zones

Regions	Wilayas	Electrical production (GWh/km²/year)
Zone A	Saida- Sidi Bel Abbas- Mascara- Rélizane- Oran- Ain Temouchent- Mostaganem- Tlemcen- Médéa- M'sila- Sétif- Bordj Bo Arreridj- Bouira- Blida- Ain Defla- Tipaza- alger- Boumerdes- Tizi Ouzo- Béjaia- Jijel- Tébessa- Khenchla- Souk Ahras- Guelma- Oum Elbouaghi- Batna- Constantine- Mila- Annaba- Taref-El Oued- Illisi- El bayadh	> 671
Zone B	Tiaret- Tissemsilet- Chlef- Bachar- Naama- Djelfa- Biskra- Ouargla- Ghardaya- Tamenrasset	687-1198
Zone C	Adrar –Tindouf- Laghouat- Skikda	< 2963

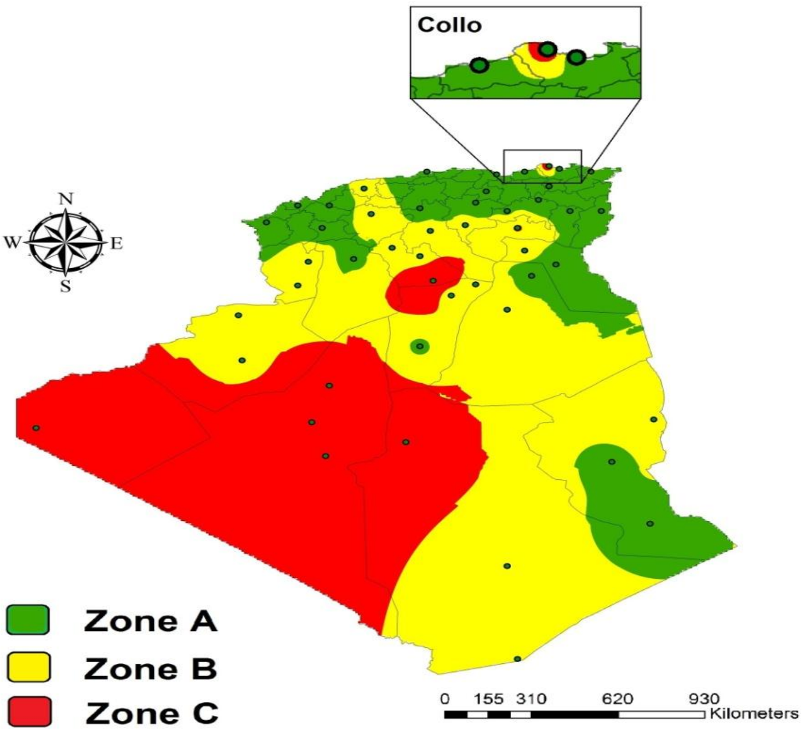


Figure 14: Repartition of Algerian territory in three zones according to the spatial distribution of wind electricity potential

Zone A which its estimated wind electricity production potential varies between 156 and 671 GWh/km² yearly is considered as the less wind production potential region, it is widespread in an irregular distribution that represents the regions with a less wind speed potential. The estimated energy production in this region is mainly considered in the wilayas of Khenchla, Msila and Tebessa. The zone B which represents the largest regions, has a production potential that varies between 687 and 1198 GWh/km² annually. The region with the highest estimated wind energy production potential is Zone C with a production rate that varies between 1491 and 2963 GWh/km² annually, it includes the regions with the highest wind speed potential like the Southwest region and the wilaya of Laghouat exactly in Hassi R'mel region where the estimated wind electricity production is about 2820 GWh/km² yearly and it comes second after the Wilaya of Adrar with 2963,36 GWh/km²/year of wind electricity production. Collo in Skikda represents also a respectable wind energy potential area with 1491,39 GWh/km² annually.

The estimated electricity production from wind turbines in the rest of the country varies in less than 1100 GWh/km² yearly which remains highly respectable and promotes wind electricity exploiting.

7. Conclusion

From the previous results we conclude that Algeria has a great potential of wind electricity potential production, highly estimated in the Southwest region where the Wilayas of Adrar and Tindouf represents a promising areas of a large scale wind turbine farm, not only in Algeria but in the North of Africa, wind electricity potential is also well considered in Laghouat exactly in Hassi R'mel region, the southwestern Wilayas of Tindouf and adrar can produce a huge amount of wind electricity that reaches 5094.45 GWh/km² annually that represents the overall production of the zone B.

Solar electricity potentials are also promising and can be exploited in the large Algerian south which is endowed with high solar radiation potentials that enables it to be a convenient place for a large scale of solar energy exploitment. This potential reaches its maximum in the huge Wilayas of Tamenrasset and Adrar.

Through these results we conclude that a large scale hydrogen production is well convenient in Algeria specially in the southern regions where electricity potentials reaches its highest values as well as the availability of the Albian aquifers that meets the needs of water for a large scale electrolysis operation.

1. Introduction

Hydrogen gas or H_2 is an abundant element on earth, but because it readily binds to other elements it is rarely found in isolation, it can be found in substances such as water, hydrocarbons, alcohol, and biomass. Hydrogen is not a primary energy source, because it is not naturally occurring as a fuel. It is, however widely regarded as an ideal energy storage medium, due to the ease with which electric power can convert water into its hydrogen and oxygen components through electrolysis and can be converted back to electrical power using a fuel cell. Hydrogen as an energy vector can increase the penetration of renewable and intermittent sources and it can serve as an energy vector that may allow reaching 100% renewable energy supply.

Hydrogen offers a range of benefits as a clean energy carrier if produced by ‘‘clean’’ sources, which are receiving ever greater attention as policy priorities. Creating a large market for hydrogen as an energy vector offers effective solutions to both emissions control and the security of energy supply.

In this section of the study we will be interested in explaining the importance of hydrogen as a future fuel as well as an energy carrier, also we will focus on hydrogen production methods and its fields of application. Finally we will analyze the hydrogen production potential using wind and solar energy in Algeria using the already obtained results.

2. Hydrogen Energy

Neither the use of hydrogen as an energy vector nor the vision of a hydrogen economy is new. Until the 1960s, hydrogen was used in many countries in the form of town gas for street lighting as well as for home energy supply. The idea of a hydrogen-based energy system was already formulated in the aftermath of the oil crises in the 1970s (AFH_2, 2011).Moreover, hydrogen is an important chemical feedstock, for instance for the hydrogenation of crude oil or the synthesis of ammonia.

Being a secondary energy carrier that can be produced from any primary energy source, hydrogen can contribute to a diversification of automotive fuel sources and supplies and offers the long term possibility of being solely produced from renewable energies.

Hydrogen could further be used as a storage medium for electricity from intermittent renewable energies such as wind, solar, biomass, hydraulic power as far as the security of supply or greenhouse gas emissions are concerned, any advantage from using hydrogen as a fuel depends on how the hydrogen is produced [21].

2.1. Renewable hydrogen as future fuel

Hydrogen is not an energy source. It is not primary energy existing freely in nature. Hydrogen is a secondary form of energy that has to be manufactured like electricity. It is an energy carrier. The majority of the experts consider that renewable hydrogen has a great role to play as an important energy carrier in the future energy sector.

Hydrogen is currently produced industrially in large quantities from fossil fuels, primarily natural gas. The world hydrogen production is approximately 500 billion cubic meters or 44.5 million tons per annum, representing around 2% of primary energy demand.

The use of hydrogen as a fuel for transportation and stationary applications is receiving much favorable attention as a technical and policy issue. Hydrogen gas is being explored for use in internal combustion engines and fuel cell electric vehicles. Fuel cells are in the early stages of commercialization and offer a more efficient hydrogen use. Many of the world's major car manufacturers have presented fuel cell vehicles as demonstrations, and are even beginning to lease small numbers of vehicles to the first selected customers. A hydrogen fuel cell vehicle offers advantages over hydrogen-fueled internal combustion engines or fuel cells powered by other fuels. Hydrogen can be used in fuel cells which can achieve a high electric efficiency. The total energy efficiency may even exceed 90% if the waste heat can be used. Hydrogen and fuel cells are often considered as a key technology for future sustainable energy supply.

2.2. Renewable hydrogen as an electric bridge

In the future, hydrogen could also join electricity as an important energy carrier. An energy carrier moves and delivers energy in a usable form to consumers. Renewable energy sources, like the sun and wind, can't produce energy all the time but they could, for example, produce electric energy and hydrogen, which can be stored until it's needed. Hydrogen can also be transported (like electricity) to locations where it is needed.

Hydrogen is now in the same position than electricity a little over century ago, when it replaced the direct use of the power from a steam engine . However, hydrogen does not replace electricity in the future, but they will work together in some kind of synergy. Electricity will be converted to hydrogen when energy storage is needed and hydrogen will be converted back to electricity when e.g. a fuel cell vehicle needs power to its traction motor . The implementation of hydrogen will help to overcome the storage difficulty of renewable energy. A renewable hydrogen system with electrolyzer, storage and fuel cell can be used to provide households with a reliable power supply. In fact, hydrogen has been regarded by many as a popular carrier of renewable energy in remote locations .

3. Hydrogen production methods

Hydrogen can be produced from diverse energy resources, using a variety of process technologies. These energy resource options include fossil, nuclear, and renewable energies. Ideally, hydrogen should be produced using renewable energy that produces little to no greenhouse gas emissions [3]. In this section, a study of possible hydrogen production methods from renewable and non-renewable sources is undertaken.

3.1. Hydrogen from Fossil fuels

Hydrogen can be derived from any hydrocarbon fuel, including oil, coal, or natural gas. Steam reformation of methane using natural gas as the feedstock is the dominant technology used to produce industrial hydrogen worldwide. In general, steam reformation can be used with any light hydrocarbon such as methane, butane, propane, etc. However, the use of natural gas as the feedstock for this process has several drawbacks.

Gasification of coal and other hydrocarbons, though less mature than steam methane reforming, this method is also relatively well established, with more than 15 gasifier systems in place worldwide, mostly to produce hydrogen for ammonia fertilizer.

In contrast to steam reformation, gasification processes can also be used with a variety of heavier hydrocarbons, including heavy residual oils and other low-value refinery products, as well as coal. However, making hydrogen from coal or heavy oil would generate large amounts of carbon emissions [22].

3.2. Hydrogen from Biomass

Biomass, one of the non-intermittent renewable energy sources, is the focus of much attention for the production of hydrogen. This technique can be used to produce hydrogen in a number of ways. These typically involve heat (thermochemical processes) or anaerobic digestion using fermentative bacteria (biochemical processes). Biomass based hydrogen production could potentially make use of a variety of domestic feedstocks, including dedicated energy crops as well as crop and livestock wastes or residues [22].

3.3. Hydrogen from Nuclear

Nuclear power can be used for electrolysis, or to supply heat to reduce the energy requirements associated with steam reformation of natural gas, or in a thermochemical process for dissociating water molecules. The uranium used to power nuclear plants is a relatively abundant domestic resource, but substantial hurdles exist to the expansion of nuclear power. Nuclear energy is an attractive potential source of hydrogen for the hydrogen economy.

3.4. Hydrogen from renewable energy resources

In contrast to those production methods, renewable energies are a desired energy source for hydrogen production due their diversity, regionality, abundance, and potential for sustainability. Renewable hydrogen is mainly an economic option in countries with a large renewable resource base and/ or a lack of fossil resources, for remote and sparsely populated areas or for storing surplus electricity from intermittent renewable energies. Hydrogen can be produced by splitting water into its constituent elements using a process known as electrolysis, which requires electricity.

One advantage of electrolysis of water is that nowadays; it is compatible with large variety of available renewable energy technologies namely, solar, hydro, wind, wave, geothermal, etc. In addition, water electrolysis benefits of some additional advantages , among them the use of different scales (on-site and off-site), its greater maturity, compactness and high current density and small footprint.

3.5. Electrolyser technologies

An electrolysis cell uses electricity to split, water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2). In this way, electrical energy is transformed into chemically bound energy in the hydrogen molecules. This is the reverse of the process that occurs in a fuel cell.

$$H_2O_{liq} + \text{energy} \longrightarrow H_2 + {}^1/_2\ O_2$$

There are currently three types of water electrolyzer, classified according to the nature of the electrolyte and their operating temperature [20]:

Table 1: Electrolyzers technologies[20]

Type	PEM	Alkaline	SOEC
Operation temperature (°C)	80-100	50-100	800-1000
Operating pressure (bar)	1-70	3-30	-
Power consumption (kWh/Nm^3 H_2)	6	4-5	3-3.5
Energy efficiency (%)	80-90	75-90	80-90
Market status	Development	Marketed	Search

Polymer electrolyte membrane (PEM) electrolysis is the electrolysis of water in a cell equipped with a solid polymer electrolyte (SPE), that is responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes. The PEM electrolyzer was introduced to overcome the issues of partial load, low current density, and low pressure operation currently plaguing the alkaline electrolyzer. PEM electrolysis is a promising alternative for hydrogen production to be used as energy storage coupled with renewable energy sources [23].

4. Renewable hydrogen production installation

A system of hydrogen production from renewable power has been proposed in this study. It consists of a renewable energy sources, an AC/DC converter and a PEM electrolyser (Figure 1). In this system, the AC output of the sources is converted to a DC voltage suitable for electrolyser operation through an AC/DC converter. In fact, the electricity generated from renewable sources can be turned into hydrogen using the electrolysis process, hydrogen can then be stored until it can be transferred into electricity or used as fuel.

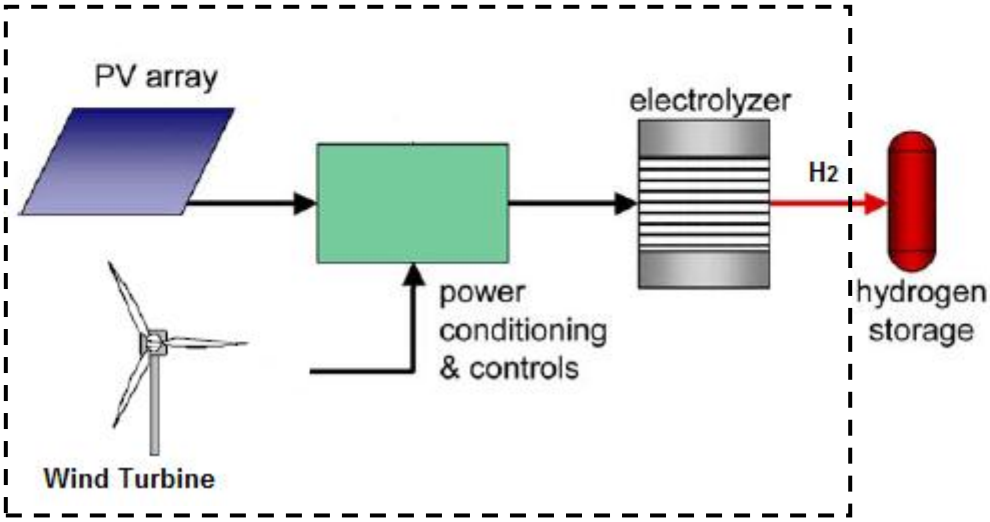


Figure 1 : Schematic diagram of hydrogen production chain from wind and solar energies

In this study two different configurations are presented, for each one; the system mainly consists of tow subsystems; eclectic power source and PEM electrolyzer (Annex 3). Solar photovoltaic panels and wind turbine are used to produce electricity. This electricity is used to operate electrolyser in which water splits into oxygen and hydrogen.

4.1. Electrolysis modeling

The generated solar and wind energy is sent to the electrolyser to drive the electrolysis process of water. The results of this study are based on the use of a proton exchange membrane electrolyzer (PEM). PEM electrolysis is a viable alternative for generation of hydrogen in conjunction with renewable energy sources. it can generate hydrogen (and optionally oxygen) at pressures up to 200 bar, with very little additional power consumption, which may be attractive for the application where hydrogen needs to be stored or used at elevated pressure [23]. For this, we consider an electrolytic production rate of 52.5 kWh/kg of hydrogen (which is equivalent to about 75% in efficiency) [4].

The energy transferred to the electrolyser is defined as :

$$E_{H_2} = \eta_1 * \eta_2 * E_{RES} \quad (1)$$

$\boldsymbol{\eta_1}$ Electrolyser operation efficiency, %

$\boldsymbol{\eta_2}$ Electrolyser losses, %

$\mathbf{E_{RES}}$ Renewable electric source production, kWh/km²/year

The hydrogen mass (Tons/km²/year) can be calculated as follow:

$$M_{H_2} = E_{H_2} / LHV_{H_2} \quad (2)$$

$\mathbf{LHV_{H2}}$ Lower heating value of hydrogen, kWh/kg

5. Estimation of hydrogen production from renewable resource

For the annual renewable hydrogen production evaluation, we are based on the data presented in chapter 1, the model for calculating annual renewable hydrogen production potential is given in equation (2). An overview of the calculation steps is given in Figure 2.

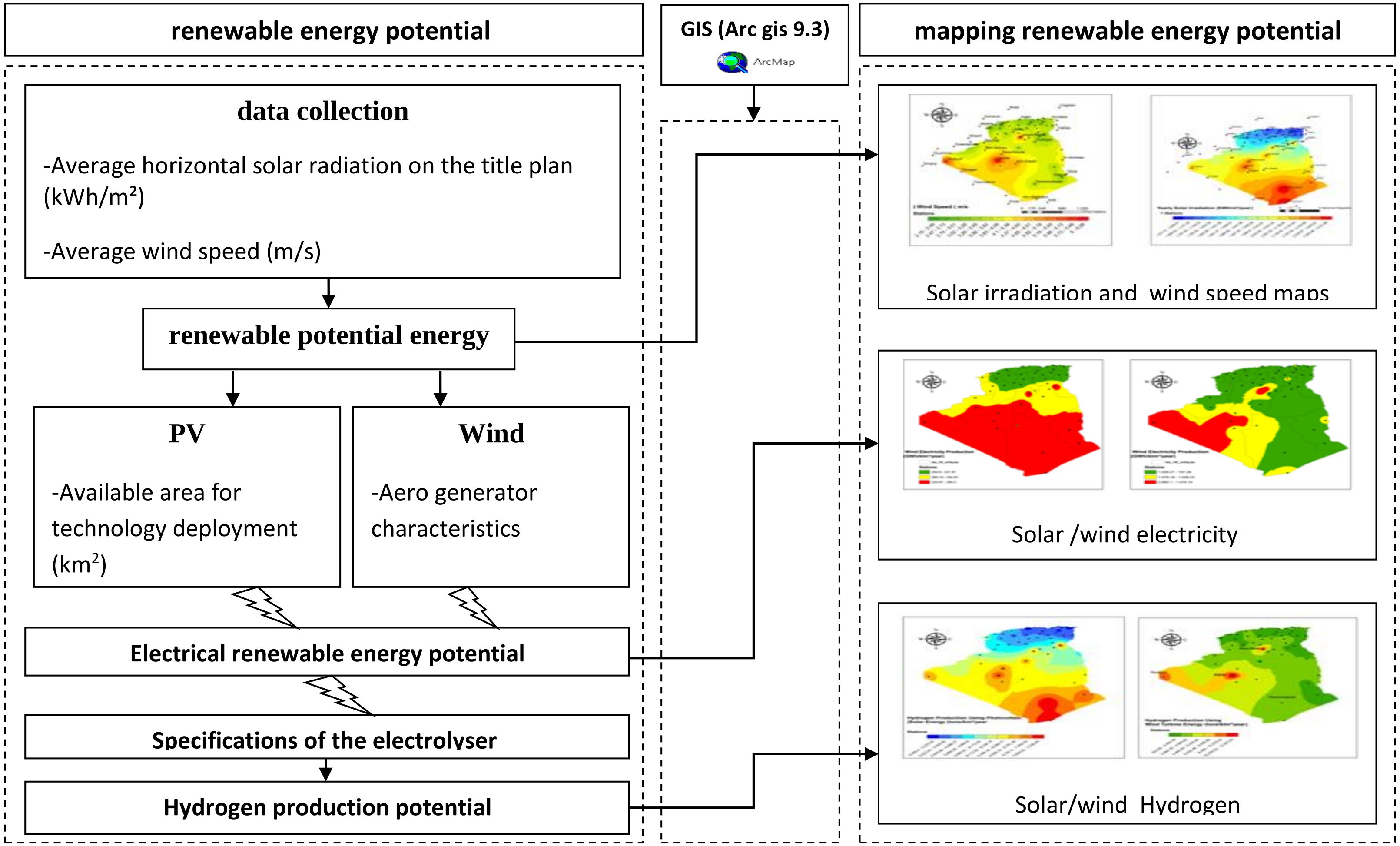


Figure 2: Flowchart representation for the evaluation of the renewable hydrogen production potential in Algeria using Geographic Information System (GIS)

5.1. Solar hydrogen production analysis

The potential of solar electricity is introduced in the electrolyzer explained in the above section, to obtain the hydrogen mass production in Algeria using solar electricity. The obtained results are presented in Figure 3 for the Algerian map of hydrogen production potential.

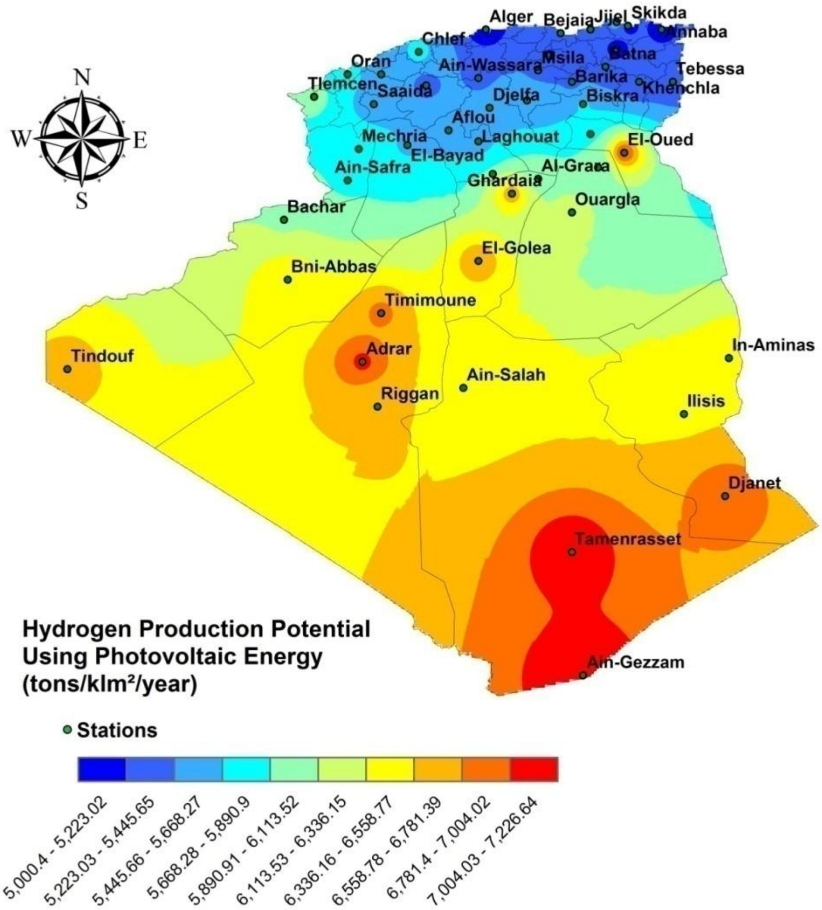


Figure 3 : Hydrogen production potential using photovoltaic solar energy in Algeria (Tons/km²/year)

Solar electricity and hydrogen production potential are directly proportional, the region which has the higher electricity production potential has the more estimated hydrogen production. As seen in Figure 3 that shows hydrogen production potential distribution in Algeria, generally areas that represents a high hydrogen production potential are mainly observed in the Southern part of Algeria. From the Northern region of the Sahara to the extreme South , hydrogen based on solar energy is widely possible.

The average hydrogen production in Zone A is 5392.66 tons/km² yearly, a higher electricity potential enables a higher hydrogen production possibility, Chlef represents the higher estimated amount of hydrogen production in zone A with 5738.92 tons/km²/year, however its small surface of 4791 km² can represent a technical challenge for the solar and hydrogen exploitation plants installation. Regions like Biskra and El-Bayadh with an estimated hydrogen production of 5688.22 and 5647.80 tons/km² yearly ,respectively, are considered as a promising areas for a large scale hydrogen production potential in this zone due to available surface that they have.

The average hydrogen production in zone B is about 5970.38 tons/km²/year, it is largely considerable due to the high solar electricity potential that this zone have, regions like Ouargla and Bachar with an estimated hydrogen production of 6280.92 and 6098.45 tons/km²/year respectively are the most promising for a large scale installation of hydrogen production from solar energy not just for the promising solar energy potential but also for the large available surface for plants installation.

Zone c with an average estimated hydrogen production potential of 6788.28 tons/km² yearly is one of the most promising areas for hydrogen production using solar energy, it includes regions endowed with a high solar electricity potential , and vast surface ready for exploitation, like El Oued with an estimated hydrogen production of 7064.75 tons/km² yearly , and Adrar with 7055.95 tons/km² yearly. Tamenrasset is the most promising wilaya for solar electricity exploiting and also for hydrogen production with a surface of 557906 km² it is Algeria's biggest region, which can produce 7218.13 tons/km² of hydrogen yearly.

5.2. Wind hydrogen production analysis

A promising option for clean hydrogen production by electrolyser is exploiting wind energy by using wind turbines for electricity production which is sent for water electrolysis.

Hydrogen mass production results are obtained after the introduction of wind electricity potential in the PEM electrolyzer. The obtained results are presented in Figure 4 for the Algerian map of hydrogen production potential using wind electricity.

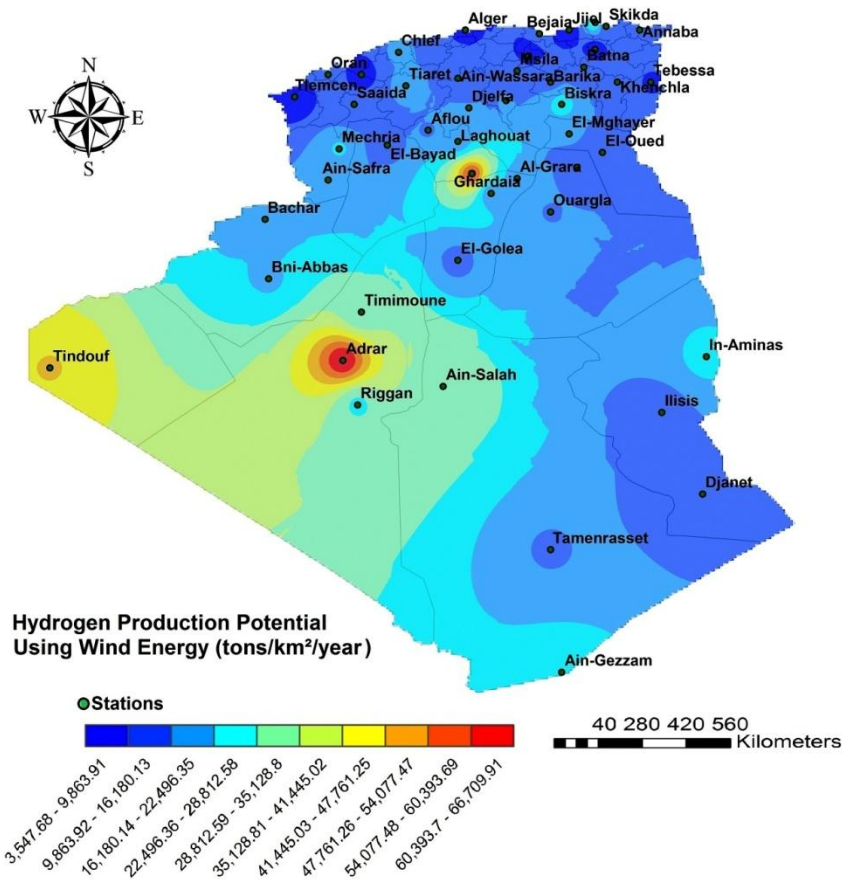


Figure 4: Hydrogen production potential using wind energy in Algeria (Tons/km²/year)

Electricity production and hydrogen production potential are directly proportional, the higher the electricity production potential the area has, the more estimated hydrogen production it presents. As seen before and unlike solar energy, wind energy potential is largely scattered in an irregular geographical distribution, this partition enables different regions to be suitable for wind based hydrogen production.

At variance of photovoltaic system wind turbines produce more energy and that promotes more potential for large scale hydrogen production, as seen from the figure above, Zone A has an average of 10004.13 tons/km² of hydrogen yearly, the highest estimated hydrogen production potential in this zone can be observed in the wilayas of Khenchla in the east by 15132.19 tons/km²/year and Oran the west by 14233.72 tons/km²/year , also in M'sila and the wilaya of Ilizi which can produce up to 13476.23 tons/km² of hydrogen yearly.

Zone B represents the second attractive zone for hydrogen production by an average of 18758 tons/km²/year, the mainly promising regions in this zone are Bachar and bBskra which their estimated hydrogen production potential exceeds 20000 tons/km² yearly, with a surface of 162 200 km². Bachar represents an attractive area for a large scale hydrogen production benefiting from its vast surface for the installation of a wind farm project.

Zone C that includes Adrar, Tindouf, Ghardaia and Skikda represents the highest wind energy and hydrogen production potential region in Algeria, by an average hydrogen production of 52965.58 tons/km²/year, this most promising potential is well observed in the southwest region like the regions Tindouf and Adrar, this last one that lays upon a surface of 427 368 km² shows the highest estimated hydrogen production potential in Algeria with 66742.46 tons/km² yearly which means 66.7 kg/m², this promotes the real potential of a large scale of hydrogen production using wind turbines, also the region of Hassi R'mel in Laghouat region is also promising for this kind of projects with 63532.29 tons/km²/year.

The windy region of collo promotes the coastal wilaya of skikda to be also a promising area a hydrogen production installation using wind turbines, due to its estimated hydrogen production of 33059 kg/m² annually.

6. Comparison between solar and wind hydrogen production potential in Algeria

As seen in the previous results, hydrogen production using renewable energies, is mainly related to the solar and wind energy potential which affects directly the electrical potential from each source, therefore the estimated hydrogen production and the the renewable electrical potenial are directly proportional, however the distribution of hydrogen production from solar and wind behaves differently, and that is due to the varied nature of the source, and due to the geographic site specification, climatic conditions and technological limitations of each resource in the largely scattered surface of the Algerian territory. Figure 5 shows the comparison of the estimated production potential from both resources for each region.

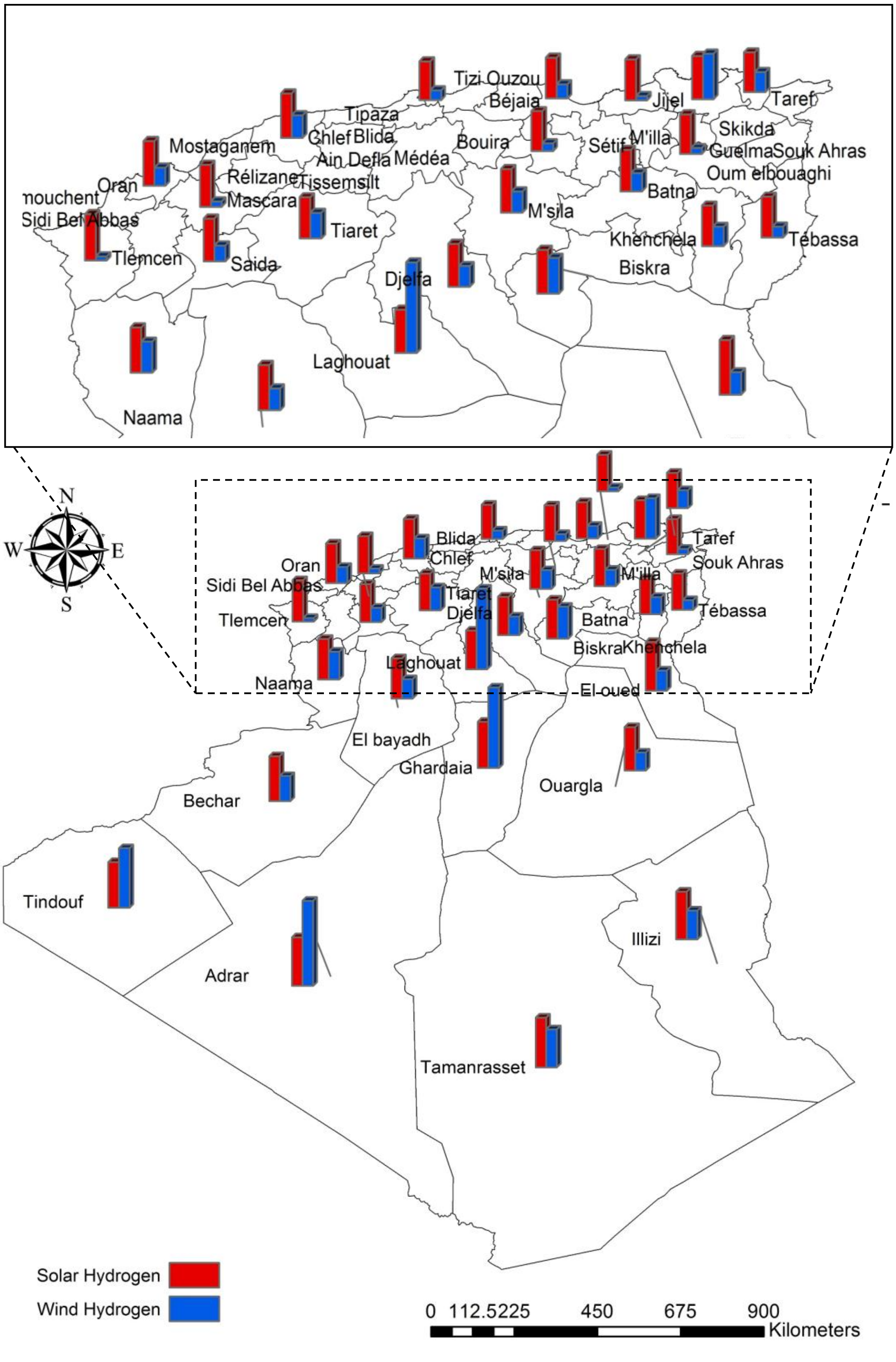


Figure 5 : Comparison of solar and wind hydrogen production potential in Algeria

As seen from Figure 5, solar based hydrogen production potential varies in a quite small interval from the highest estimated potential in Adrar by 7055.95 tons/km² yearly to the lowest obtained potential in Algiers by 4992.84 tons/km² yearly comparing to the estimated wind based hydrogen production which varies differently in a quite large interval, the highest estimated hydrogen production was obtained in Adrar by 66742 tons/km² yearly to the lowest obtained value in Tlemcen by 3520.63 tons/km² yearly.

regions of high solar and wind potential promotes a high potential of hydrogen production, Algeria's large Saharian regions present the most attractive region for hydrogen production based on both solar and wind energy. The wilaya of Adrar with its vast surface shows a high potential of hydrogen production from wind and solar, this advantage enables the this region to have a more variety of options in the future of hydrogen production using renewable resources.

The regions of Bechar , Tamenrasset, Illizi, Ouargla and El Oued have the potential to produce more hydrogen from solar then wind, however the wilayas of Adrar, Ghardaia and Laghouat are more suitable for wind based hydrogen production than solar.

In the North part, solar based hydrogen is more convenient to wind based hydrogen specially in the Western region of the country where the wilayas of Tlemcen, Oran and Naama present some high values in this part of the country with an estimated annual hydrogen production based on solar energy of 6012.10 tons/km², 5881.15 tons/km² and 5763.76 tons/km² , respectively. Algiers shows and estimated production potential of 4992.84 tons/km² of solar based hydrogen yearly and 7945.27 tons/km²/year of wind based hydrogen.

In the Northeastern region, the wilaya of Skikda is widely observed for its wind based hydrogen production potential, with 33589.99 tons/km²/year.

The huge difference in results of hydrogen production from solar and wind is due to the capacity factor which represents the amount of functional hours, wind turbines represents a 100% capacity factor functioning 24/24h unlike photovoltaic panels with an average of 9/24h of functioning hours.

7. Conclusion

This analyzed results show that hydrogen production using renewable energies in Algeria is widely promising, the exploiting of solar or wind energy for hydrogen production is relatively linked to the available renewable resources in each region.

The huge available solar and wind hydrogen potential that reaches in the Southern region of Algeria its highest solar based hydrogen of 7055.95 tons/km² yearly and 66742 tons/km² yearly of wind based hydrogen in the wilaya of Adrar. however the lowest estimated hydrogen production from wind is obtained in Tlemcen by 3520.63 tons/km² yearly. and the lowest solar based hydrogen production potential is in Algiers by 4992.84 tons/km² yearly.

In the south solar and wind energy are both convenient however in the north, solar based hydrogen is more probable for a large scale exploitation installation.

General conclusion

Despite being a hydrocarbon-rich nation, Algeria represents the most endowed country with solar and wind energy, and it is making concerted efforts to harness its renewable energy potential to diversify it power generation sources, hydrogen is of paramount importance. It permits the country not only to increase and to diversify its energy mix but also to keep its share of the energy market at the international level and to meet its domestic demand that is becoming more and more important.

In this study we analyzed the overall hydrogen production potential using two renewable energies, starting by solar and wind renewable potentials, from collecting the available meteorological data to create reflective maps that expresses the huge renewable electric and hydrogen potential in Algeria.

The electric wind potential is highly recommended for exploiting in the Southwestern region, and in the Wilaya of Laghouat (middle region), where the wind electricity production of these regions can reach 10 TWh/km² yearly and it exceeds the rest of the country's wind electricity production.

Whereas solar electricity potential is also promising and well considered in much of the country, especially in the Southern region which enabled by one of the highest rates of solar irradiation of any country about 6 kWh/m² daily and it exceeds the 2200 kWh/m²/ yearly. For that solar electricity is well considered in the South of Algeria that can produce 285.01 to 320.87 GWh/km² annually of solar electricity specially in Tamenrasset and Adrar regions.

The availability of water aquifers in the big Algerian Sahara is added to All these advantages that promote hydrogen clean production from solar and wind electricity, hydrogen production and the electrical potentials are directly proportional, for that hydrogen production from wind electricity is highly recommended in the Southwestern region as well as the Wilaya of Laghouat exactly in Hassi R'mel region that can produce up to 63532.29 tons/km²/year, added to the estimated production of Adrar by 66742.46 tons/km² /yearly.

Solar based hydrogen is well considered in Tamenrasset, Adrar, Ghardaia and El Oued regions, if exploited, these regions can produce more hydrogen than the rest of the country have the potential to, and can fulfill the national needs for the future hydrogen consumption.

In the upcoming years, the exploitation of these renewable energies potential in a large scale hydrogen production will make Algeria one of the biggest world suppliers of electricity as well as the revolutionary energy vector of hydrogen.

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<u>Annexe I :</u> The RETScreen software

The RETScreen Software is the world's leading clean energy decision-making software. It is provided completely free-of-charge by the Government of Canada as part of Canada's recognition of the need to take an integrated approach in addressing climate change and reducing pollution. RETScreen is a proven enabler of clean energy projects worldwide.

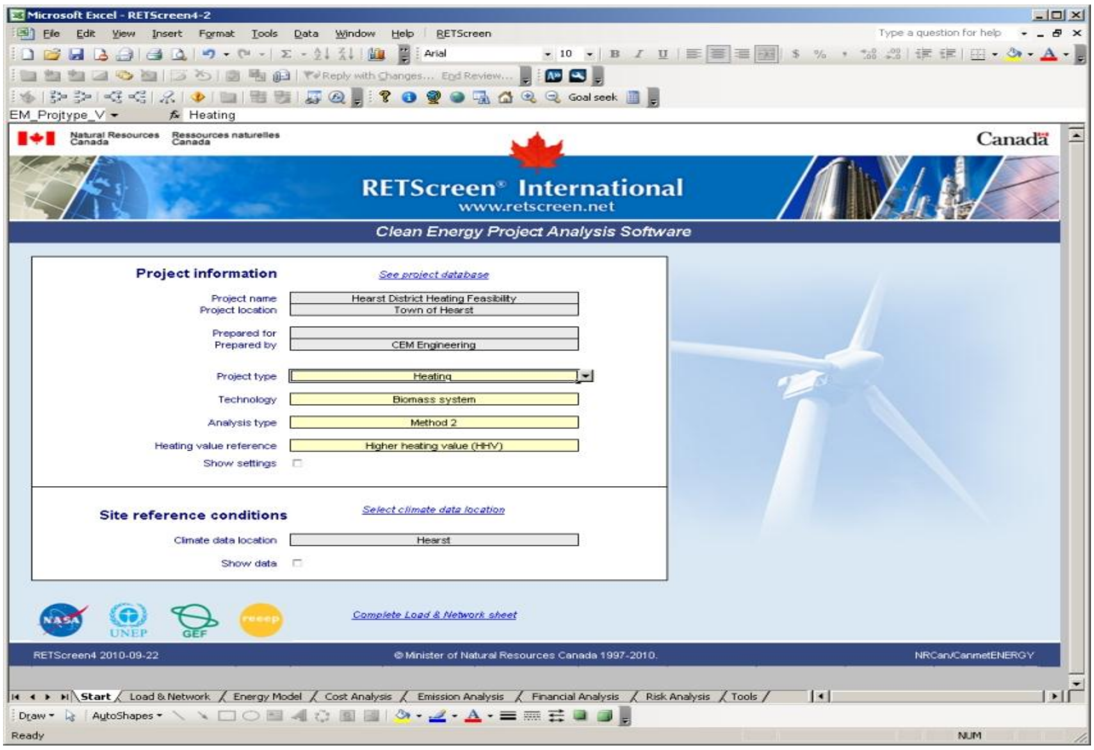

Figure : RETScreen interface

The software integrates a number of databases to assist the user, including a global database of climatic conditions obtained from 6,700 ground-based stations and NASA's satellite data; benchmark database; project database; hydrology database and product database. [NASA Collaboration Benefits International Priorities of Energy Management By: Denise M. Stefula]The software also includes clean energy policy & legal toolkits, as well as a large amount of multilingual and multimedia free training material[W].RETScreen is the most comprehensive product of its kind, allowing engineers, architects, and financial planners to model and analyze any clean energy project. Decision-makers can conduct a five step standard analysis, including energy analysis, cost analysis, emission analysis, financial analysis, and sensitivity/risk analysis.

Annexe II: ArcGIS software

ArcMap represents geographic information as a collection of layers and other elements in a map. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, a symbol legend, and so on.

The main application in ArcGIS is [ArcMap](), which is used for all mapping and editing tasks as well as for map-based query and analysis. A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information.

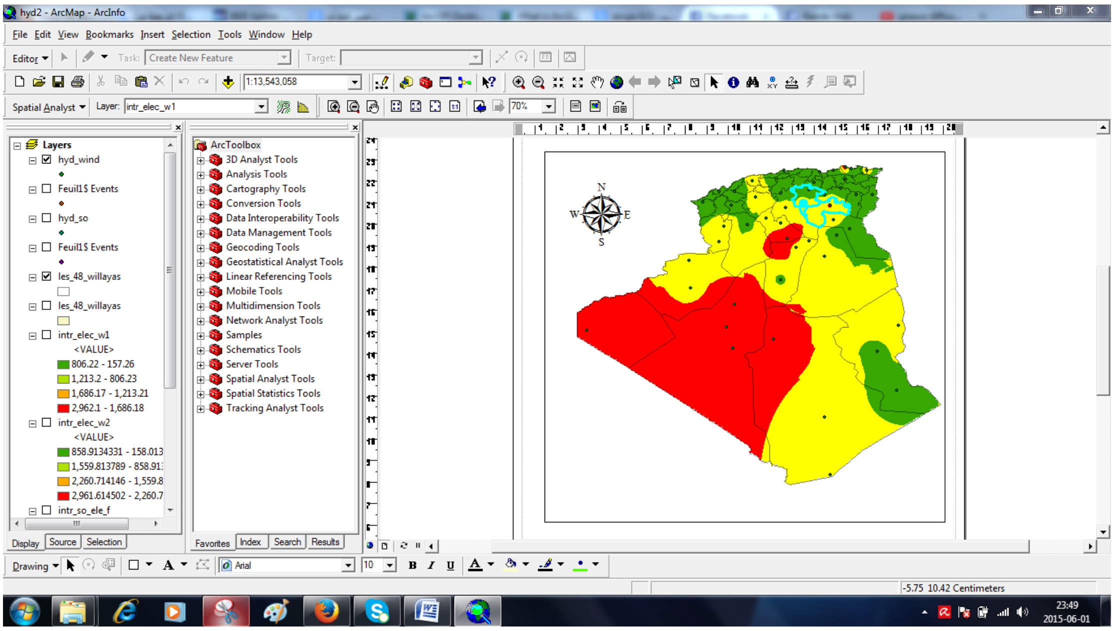

Figure: ArcGIS interface

ArcMap represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend. There are two primary map display panels in ArcMap: the data frame and the layout view. The data frame provides a geographic window, or map frame, in which you can display and work with geographic information as a series of map layers. The layout view provides a page view where map elements (such as the data frame, a scale bar, and a map title) are arranged on a page. You can learn more about data frames and map layouts below.

Annexe III: PEM electrolyzer

A proton exchange membrane (PEM) water electrolysis cell is a device which produces hydrogen and oxygen gas by using DC electricity to electrochemically split water. The cell is named for the electrolyte, which is a solid conductive polymer. The most commonly used proton exchange membrane is based upon a perfluorosulfonic acid (PFSA) type material, although there are several lower cost alternative membranes under development.

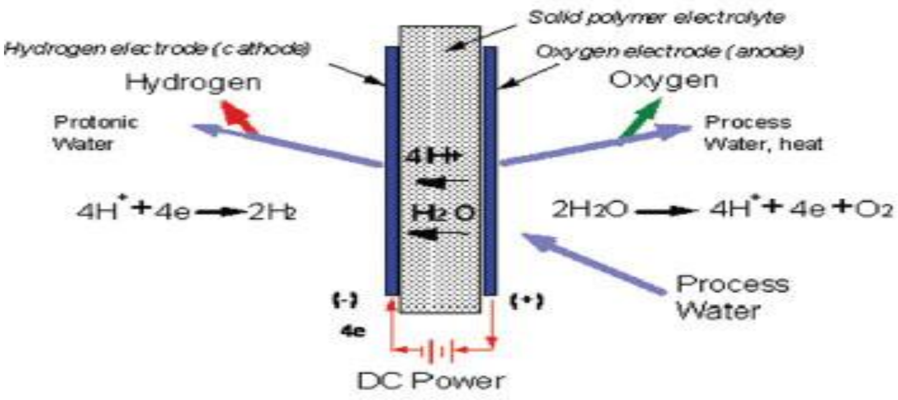

Figure: Illustrates the PEM electrolysis reaction.

In the electrolysis cell, the water enters the anode and is split into hydrogen ions (protons), electrons, and oxygen gas. The protons are conducted through the membrane while the electrons pass through the electrical circuit. The oxygen is carried from the cell with excess water flow. At the cathode, the protons and electrons recombine to form hydrogen gas. The flow of protons also results in water being dragged across the membrane to the cathode. The extent to which this water is removed from the hydrogen down stream of the cell determines the hydrogen purity.

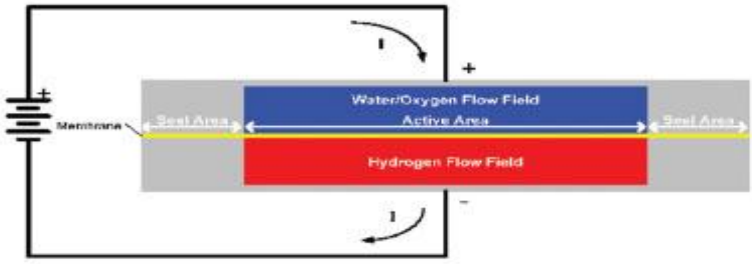

Figure : The electrolysis half-reactions are shown in the equation

Abstract:

This study was conducted to estimate the potential for producing hydrogen from renewable resources (solar photovoltaic, wind) in Algeria and to create maps that allow the reader to easily visualize the results. To accomplish this objective, we analyzed renewable resource data both statistically and graphically utilizing Geographic Information System (GIS), a computer-based information system used to create and visualize geographic information. The study will evaluate the availability of hydrogen production potential from these key renewable resources.

ملخص

وقد أجريت هذه الدراسة لتقدير إمكانية إنتاج الهيدروجين من مصادر الطاقة المتجددة (الطاقة الشمسية وطاقة الرياح) في الجزائر وإنشاء الخرائط التي تسمح للقارئ بسهولة تصور النتائج. ولتحقيق هذا الهدف، قمنا بتحليل بيانات الموارد المتجددة على حد سواء إحصائيا وبيانيا باستخدام نظام المعلومات الجغرافية (GIS) ونظام المعلومات الحاسوبية المستخدمة في إنشاء وتصور المعلومات الجغرافية. فإن دراسة تقييم توافر إمكانات إنتاج الهيدروجين من هذه الموارد المتجددة الرئيسية .