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Suitable sites for solar hydrogen production: a case study.

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Dedication

First of all, we thank God for everything. Praise be to God, who has enabled us to finish these years of study. We don't miss to thank everyone who taught us even a letter. This work is a dedication to:

Our parents for everything they gave us, may God protect them for us.

To all our brothers and sisters.

As well as to all our friends, whether religion introduces us to the university or outside it. Thank God.

Appreciation

In the beginning, we thank God who enabled us to complete this work. We thank the Supervisor of memoir **Dr. S. Rahmouni**, Lecturer B, MCB. who supervised us all this time and accompanied us in completing this work.

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Dr. A. Gouareh, Lecturer A, MCA, President.

Dr. D. Messaoudi, VPRS laboratory, examiner.

I would like to thank all those who have contributed directly or indirectly to the accomplishment of this work.

Abstract

Suitable sites for solar hydrogen production: a cas study.

Green hydrogen, or as it is called the fuel of the future, is an important destination to reduce dependence on various forms of fossil fuels. Our study is concerned with choosing the appropriate location for establishing a green hydrogen production facility in Algeria, using a geographical information system(GIS). Algeria is one of the countries with considerable resources for the production of solar hydrogen. Through our study analyzing, synthesizing and integrating Algeria data through a multi-criteria GIS approach, it was discovered that more than half of its total area is capable of establishing solar hydrogen production project.

Key words: solar energy, hydrogen, Algeria, GIS, Multi-Criteria Analysis.

ملخص

المواقع المناسبة لإنتاج الهيدروجين الشمسي: دراسة حالة.

الهيدروجين الاخضر او كما يسمى بوقود المستقبل هو وجهة مهمة للحد من التبعية لأشكال الوقود الاحفوري المختلفة. دراستنا هده تتعلق باختيار الموقع المناسب لإنشاء منشأة لإنتاج الهيدروجين الأخضر في الجزائر ودلك باستخدام نظام المعلومات الجغرافية. تعد الجزائر واحدة من الدول التي تتمتع بموارد ضخمة لإنتاج الهيدروجين من خلال الطاقة الشمسية فمن خلال دراستنا التي تمثلت في تحليل وتركيب ودمج البيانات الخاصة بالجزائر عبر نهج GIS متعدد المعايير تم الاكتشاف بان أكثر من نصف مساحتها الاجمالية قابلة لإقامة مشاريع انتاج الهيدروجين الشمسي.

الكلمات المفتاحية: الطاقة الشمسية, هيدروجين, الجزائر,نظم المعلومات الجغرافية, تحليل متعدد المعايير.

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Nomenclature

Symbol	Definition	Unit
M_{H2}	hydrogen mass	[kg]
E_{ely}	The energy required by the electrolyzer	[kWh]
Spv	photovoltaic area	[m^2]
Nmodules	The number of solar panels	/

General Introduction

General Introduction

Currently, the majority of the global energy demand is supplied by fossil fuel resources. With the continuous world growing population, the energy consumption is expected to rise more and more. Thus, by considering their non-renewable origin, it is necessary to plan a future energy scenario in the scarcity of fossil fuels. This necessity is even more important due to the increasing levels of greenhouse gas (GHG) emissions associated with the intensive consumption of fossil fuels, which have led to the advancement of climate change [1].

To deal with these issues, the market is interested in developing alternative fuels to diversify the energy supply. Specifically, the technological interest is focus on renewable energy sources such as solar and wind energy. Indeed, after years of significant development efforts, electricity from photovoltaic (PV) systems and from wind turbines is partly economically competitive with fossil fuel based electricity at many locations [1].

Hydrogen is considered as one of the most important natural elements because of its important properties that distinguish it from other elements. The latter has different types. In our work, we talked about green hydrogen, which is considered the fuel of the future because of its advantage that it has zero carbon emissions.

Algeria has very huge and different natural resources. Among them is the great solar wealth due to its vast area and huge desert. This is what makes Algeria one of the most important countries in the world that can contribute to reducing greenhouse gas emissions. It contributes to the global trend towards renewable energies.

Our work is to determine the appropriate location for the establishment of a green hydrogen facility in Algeria using the geographical information system(GIS) based on various data.

Our dissertation is divided into three chapters:

Chapter 01 talks about the properties of green hydrogen and how to produce it in different ways. It also talks about how to store it, the different methods of transporting it, and its various fields of use.

Chapter 02 Geographic information system (GIS) based on multi-criteria analysis. A review of the most important elements of the geographic information system. And identification of the various multi-criteria.

Chapter 03 In which we are talking about choosing the appropriate place for the completion of the green hydrogen facility in Algeria, using the Geographic Information System.

This is done by relying on several inputs geospatial data of the study area.

Finally, we conclude our work by presenting the results obtained. And make a set of suggestions about future work.

Chapter01:

Green hydrogen as a form of future energy.

1.1. Introduction

The trend towards sustainable energy has become an inevitable necessity in order to reduce the risks posed by fossil energy sources. Green hydrogen is considered a fuel of the future that countries are racing towards because of its many advantages, perhaps the most important of which is that it is a 100% environmentally friendly fuel.

In this chapter we will talk about Hydrogen production methods and the applications of hydrogen.

1.2. Hydrogen properties

Molecular hydrogen (H2) can be the key for addressing many environmental challenges given the fact that it is a non-polluting energy carrier, so for that can be called the Energy of the 21st Century. Hydrogen is the most common and simpler chemical element in the Universe, but its occurrence in the molecular form is rare. In our planet, hydrogen presents itself mostly combined with oxygen and carbon to form water and organic compounds, and therefore it must be separated and extracted [1].

Molecular hydrogen is characterized as a non-colored, tasteless, odorless, very light (14.4 times lighter than air) and extremely flammable gas at normal temperature and pressure (1 atmosphere and 0°C respectively). Other physical characteristics are displayed in Table (1. 1).

Table1.1: Hydrogen properties [1].

Characteristics	Value	Unit
Molecular weight	2.02	g/mol
Density	0.09	kg/m3
Specific energy ● **Higher heating value** ● **Lower heating value**	 142 120	 MJ/kg MJ/kg
Melting point	- 259.20	°C
Boiling point	- 252.77	°C
Critical pressure **Critical temperature**	13.0 - 240.0	bar °C

1.3. Hydrogen production

The production of hydrogen requires physical-chemical processes to synthesize and isolate this molecule. When produced from RES, H2 is commonly referred to as green hydrogen, when produced from fossil fuels or from sub products of industrial processes it is designated as brown and grey hydrogen, respectively. The term "blue hydrogen" has been used for H2 produced from the reformation of natural gas followed by capture and storage of the emitted CO2. Worldwide, 96% of hydrogen in utilization has been produced from fossil fuels and only 4% has been produced from RES. Hydrogen can be created using different sources [2].

1.3.1. Hydrogen from fossil sources

There are four processes for producing hydrogen from natural gas: steam reforming (using water as oxidant and source of hydrogen), partial oxidation (using oxygen as oxidant), autothermal reforming (using both water and oxygen as oxidants) and dry reforming (using CO2 as oxidant). The main difference between these methods regards their hydrogen to carbon monoxide ratios: steam reforming has the highest ratio (H2/CO = 3), followed by partial oxidation (H2/CO = 2) and dry reforming (H2/CO = 1). For what concern the enthalpy of the reactions involved (Eqs. 1.1–1.3), steam reforming and dry reforming are endothermic processes,

Steam reforming

$$CH_4 + H_2O \rightarrow 3H_2 + CO \qquad \Delta H_r = +206\ kJ/mol \qquad (1.1)$$

Partial oxidation:

$$CH_4 + \frac{1}{2}O_2 \rightarrow 2H_2 + CO \qquad \Delta H_r = -36\ kJ/mol \qquad (1.2)$$

Dry reforming:

$$CH_4 + CO_2 \rightarrow 2H_2 + 2CO \qquad \Delta H_r = +247\ kJ/mol \qquad (1.3)$$

Then the syngas is fed into a WGS reactor to increase the quantity of hydrogen, culminating in a steam with H2 and CO2.

The final step of the process, gas purification, requires the H2 rich steam to be submitted to pressure swing adsorption, from which the pure hydrogen gas is obtained.

The heat necessary for the reaction in the SMR process can be supplied by concentrated solar thermal energy, therefore minimizing the associated CO2 emissions. The energy efficiency of hydrogen production achieves 70 - 85% in industrial scale [3,6].

1.3.2. Hydrogen from renewable energy sources

Electrolysis is the most common route of production of hydrogen from RES, followed by biomass conversion. Below these two main processes are described.

1-3.2.1. Biomass

Biomass is a renewable organic material which includes forest residues, organic municipal solid waste and also animal wastes, agriculture crop residues and dedicated crops. There are two paths for conversion of biomass into hydrogen gas, thermo-chemical conversion and biological conversion. The most commonly used route is the thermo-chemical based on the pyrolysis/gasification process.

Normally the biomass has to be heated in a reactor at high temperatures and under pressure. This step oxidizes the material and produces a gas constituted by H2, CO, CH4 and CO2. The gas stream is subjected again to high temperatures in order to increase hydrogen content. Subsequently in a pressure swing adsorption (PSA) unit, in which the pressure and partial pressure are alternated to promote adsorption and desorption in order to remove existing impurities, it is produced hydrogen with a high purity level [5,6].

1.3.2.2. Electrolysis

Water electrolysis is an electrochemical process based on the use of direct electric current for splitting water into hydrogen and oxygen. An electrolyzer is composed of:

two electrodes (anode and cathode, positive and negative respectively) and a conductive liquid designed as the electrolyte, in which the electrodes are immersed. Typically, potassium hydroxide (KOH) is added to increase the conductivity of water [3,6].

The process is based on the passing of an electric current between anode and cathode through the electrolyte. In this way, the water will split in hydrogen, released from the cathode, and oxygen from the anode. The general chemical equation for the electrolysis reaction is (eq1.4):

$$2H_2O \rightarrow 2H_2 + O_2 \qquad (1.4)$$

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The electric current necessary for the process can be produced from renewable energy sources such as wind, biomass or sun. The H2 produced with this technology has a high level of purity given the fact that the product stream is dried, and the impurities have been removed. Here we highlight the most common electrolysis technologies such as alkaline electrolyzer and polymer electrolyte membrane (PEM), which differ in efficiency, operational conditions and the material used for electrolyte [6].

Alkaline electrolyzers are the most mature and established technology. They normally consist of a solution of water and 25% to 30% of KOH, although sodium chloride (NaCl) and sodium hydroxide (NaOH) are also used in the electrolyte. It's necessary to use a diaphragm for separating the electrodes, keeping the product gases apart and ensuring the efficiency and safety (Figure 1.1). This component has to be permeable to water molecules and hydroxide ions.

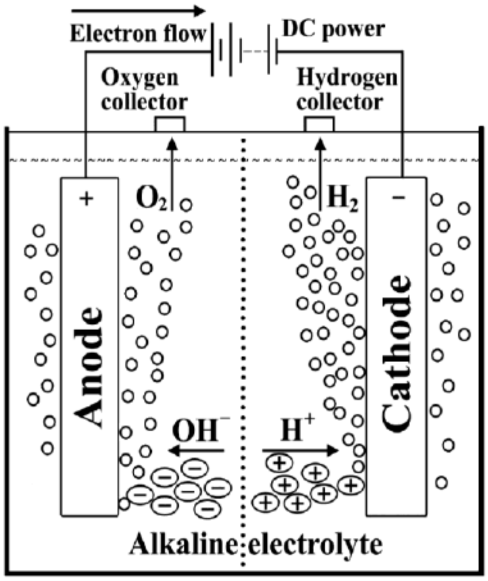


Figure 1.1: Schematic illustration of the alkaline electrolyzer cell [32].

The process initiates with the application of electric current between both electrodes. In the cathode the water molecules react with electrons to form OH- ions and H2. The hydroxide ions pass through the diaphragm towards the anode, where they release the electrons into the electric circuit and combine to form oxygen and water molecules [6].

Although alkaline electrolysis is the more mature technology, there remain 3 major limiting issues: operating with low pressure, the limited current density due the losses in the diaphragm, and the cross-diffusion of product gases [6].

Polymer electrolyte membrane is the process where H2 is obtained with highest purity. This system is constituted by a polymer membrane that only allows protons to pass, by the anode and the cathode catalysts, and the electrode layers where the current is applied. (Figure 1.2) shows a schematic representation of a PEM electrolyzer.

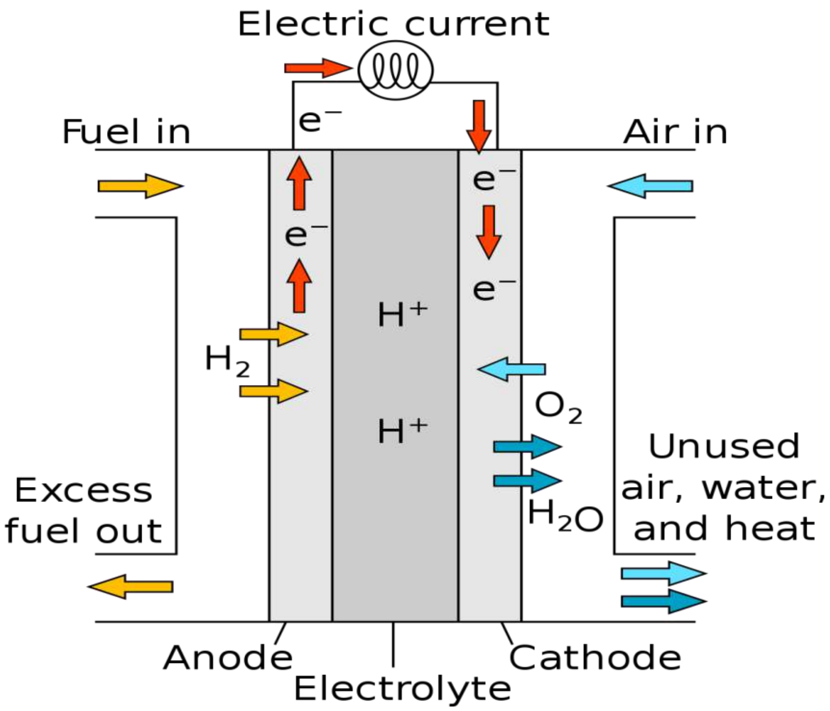


Figure1-2: Schematic illustration of the PEM cell [33].

This process favors the removal of liquids and gases from the catalyst surfaces. Thus, in the process, the water molecules dissociate into oxygen (O-) and hydrogen ions (H-) on the anode catalyst. The oxygen is removed, and protons pass through the membrane towards the cathode, where they receive electrons and are converted into hydrogen gas (H2). Nevertheless, this method is limited by the cost of the catalyst and the lifetime of the membrane [6].

1.4. Hydrogen storage

The various hydrogen storage options available today are

1.4.1. Gaseous hydrogen

currently available in 350 and 700 bar pressurized systems [7].

Density of hydrogen at different pressures

- 200 bar (~10-15 kg/m3)
- 350 bar (~20 kg/m3)
- 700 bar (~35-40 kg/m3)
- 1000 bar (~40-45 kg/m3) (not commercialized yet)

1.4.2. Cryogenic liquid hydrogen

cryogenic storage at very low temperatures (-253°C) in special insulated tanks (~71 kg/m3) [8].

1.4.3. Solid State [9]

- **Chemisorption of hydrogen** (Metal hydride storage)

- Gravimetric density mostly around 5-7 wt-%
- Maximum achievable volumetric density till date in Mg_2FeH_6 (~150 kg.m-3) with a gravimetric density of 5.5 wt-%

➢ **Physisorption of hydrogen** (Porous systems)

- Materials such as activated carbon, zeolites, silicas (aerogels), nanotubes, etc.
- Limited by their gravimetric density of ~1-3 wt-%
- Unreliable results

➢ **Chemical Storage** (reaction with water)

➢ A short summary of the above listed storage methods is presented in table 5.

Gravimetric density ρm, volumetric density ρv, operating temperature T and pressure P are also shown. RT stands for room temperature (25 °C).

1.5. Transport of hydrogen

Hydrogen can be transported three main ways, depending on the distance, volume, and state in which transporting

1.5.1. Pipelines

Tend to be the cheapest way to move hydrogen over longer distances. Constructing pipelines usually requires volume and demand certainty to justify investment. Additionally, existing natural gas pipelines can be repurposed provided they meet the technical criteria to reduce the risk of embrittlement. Repurposing of existing pipelines also enables blending of hydrogen within the existing natural gas networks for end uses where blended hydrogen can accelerate demand creation [10].

1.5.2. Trucks

Are also used to transport hydrogen in smaller volumes, both in gaseous and liquid form, for local distribution and longer journeys [11].

1.5.3. Tanker ships

Are beginning to be used for larger volume, longer distance transport, mainly moving liquid hydrogen (LH2), LHOCs, and ammonia. Shipping of hydrogen is currently expensive due to added conversion costs (liquefaction or chemical conversion) in addition to the necessary structural design to reduce risk of embrittlement [10].

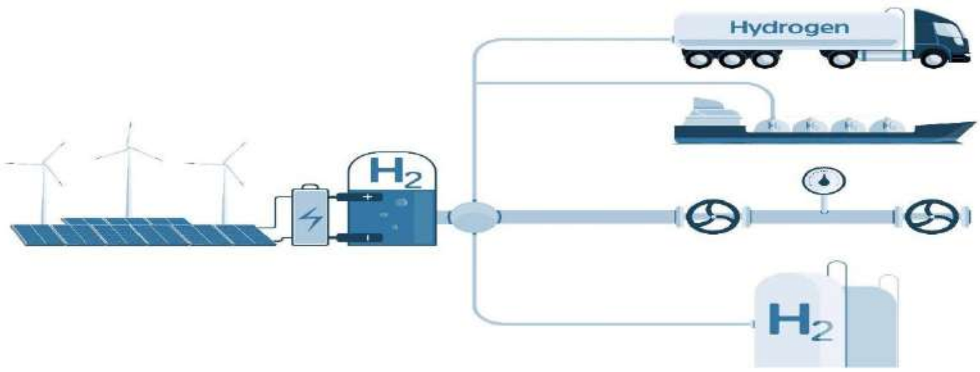


Figure1.3: Hydrogen transport methods [12].

1.6. Hydrogen applications

1.6.1. Historical Industrial Application

For decades, hydrogen has been used primarily by the chemical and refining industries. End applications include [11]:

- **Agricultural/Chemical Industry**
  Hydrogen is a fundamental raw material needed to produce ammonia (NH_3), also known as azane, an important part of fertilizers used in agricultural industries around the world. Ammonia can also be used as an affordable, environmentally-friendly refrigerant (R-717).
- **Petroleum Refining Industry**
  Hydrogen is commonly used in hydrocracking to create petroleum products, including gasoline and diesel. It is also used to remove contaminants like sulphur and to create methanol (CH_3OH).

1.6.2. Other Common Industry Applications of Hydrogen

Hydrogen also has a long history of use in several other industries. These include [11]:

- **Food**
  Hydrogen is used to turn unsaturated fats into to saturated oils and fats, including hydrogenated vegetable oils like margarine and butter spreads.

- **Metalworking**
  Hydrogen is used in multiple applications including metal alloying and iron flashmaking.
- **Welding**
  Atomic hydrogen welding (AHW) is a type of arc welding which utilizes a hydrogen environment.
- **Flat Glass Production**
  A mixture of hydrogen and nitrogen is used to prevent oxidation and therefore defects during manufacturing.
- **Electronics Manufacturing**
  As an efficient reducing and etching agent, hydrogen is used to create semiconductors, LEDs, displays, photovoltaic segments, and other electronics.
- **Medical**
  Hydrogen is used to create hydrogen peroxide (H_2O_2). Recently, hydrogen gas has also been studied as a therapeutic gas for a number of different diseases.

1.6.3. Hydrogen Energy Industry Applications

- Newly commercialized applications of hydrogen, like fuel cells, are opening all kinds of new opportunities in transportation and other energy-related industries. In some applications, hydrogen is used as an alternative combustible fuel. Notable growth areas include [11]:

- **Space Exploration**
  Liquid hydrogen (LH_2) fuel has played an important role in space exploration since NASA's Apollo program, when it was first used in in the secondary stage of the Saturn rockets. Today its use is expanding to include government and commercial organizations like United Launch Alliance, Boeing, and Blue Origin.
- **Aviation**
  Several experimental programs have utilized hydrogen fuel cells in projects like the Pathfinder and Helios unmanned long duration aircraft. Recently, Airbus unveiled concepts for hydrogen-fueled "ZEROe" aircraft that utilize liquid hydrogen to power modified gas turbine engines.
- **Global Logistics**
  Dozens of companies with large warehouse and distribution needs are turning to

hydrogen fuel cells to power trucks, forklifts, and more. Companies like Nikola Motors, Hyundai, Toyota, Kenworth Truck Co, and UPS have big aspirations for hydrogen powered trucks, vans.

- **Public Transportation:**
  Hydrogen fuel cells are also being considered for other public transportation applications including trains and buses. Several major cities including Chicago, Vancouver, London, and Beijing have experimented with hydrogen powered buses. Hydrogen-powered trains have now appeared in Germany, and in the next five years, other models are expected to come to Great Britain, France, Italy, Japan, South Korea, and the United States.
- **Personal Transportation**
  Nine of the major auto manufacturers are developing hydrogen fuel cell vehicles (FCVs) designed for personal use.
- **Power Generation**
  Hydrogen is already used for cooling power plant generators, but it also provides a promising means of electrical grid stabilization. Electrical energy can be turned into hydrogen through electrolysis, then stored and used in an end-use application like transportation.
- **Backup Power Generation**
  At a local level, stationary fuel cells are used as part of uninterruptible power supply (UPS) systems, where continuous uptime is critical. Both hospitals and data centers are increasingly looking to hydrogen to meet their uninterruptible power supply needs.

1.7. Conclusion

In this chapter, we talked about hydrogen as one of the future forms of energy. In it, we touched on several axes, such as the properties of hydrogen and methods of producing it. We also talked about ways to store hydrogen and its means of transportation. Finally, we talked about the different fields of using hydrogen

Chapter02:

Geographic information system (GIS) based on multi-criteria analysis.

2.1. Introduction

GIS (geographic information system) is a program that allows the storage, analysis, management, and downloaded of geographic data. Geographic data is used in geolocation and related information to assist in decision making process such as maps, aerial images and spatial data. GIS stores geographical data in spatial databases, and allows decision makers to effectively enter and edit this data.

In this chapter we explain GIS program and how it is used in spatial data analysis, and particular discuss a multi criteria method (MCDM) of data analysis using GIS program.

2.2. Geographic information system

In ancient times maps were used in many civilizations.

The invention of microprocessors in the last century has led to the development of manual cartographic data collection for example, we find GPS, aerial image and accurate scanning tools, the use of these system on desktop computers led to development of a system containing databases, the processing of satellite image, aerial image, the installation and inspection of many data. These processes led to the emergence of a sophisticated geographic information system.

For the first time, GIS was adopted into geodesy and natural science, but soon it turned out that can be applied into other research disciplines, like business or transportation. Further, the environmental modelling applications evolved into demographic and business activities analysis and the results could be used for decision making [12].

2.2.1. Definition of GIS

GIS stands for Geographic Information System, often defined as a computerized database management system for capture, storage, retrieval, analysis, and display of spatial data. Many different types of data can be integrated into GIS and represented as a map layer. When these layer are down on top of each other, spatial patterns and relationships often emerge [13].

To simplify, the goal of any GIS (technology and science) is to do data visualization, which are the key to the exploration to find an answer on certain question. In such a manner, data is the core of any GIS, and to be precise, spatial data coupled with attribute data [14].

2.2.2. Function of GIS

The functionality of GIS can be described at three level with an increasing complexity:

The first level of functionality is cartographic representation or spatial visualization. It is the simplest and most basic function of GIS. A map is a basic form of spatial visualization and representation of spatial data. Maps in GIS are digital form and called digital maps. A digital map in GIS is a set of data recording the proprieties and their geographical locations (often recorded as latitude and longitude) [15].

The second level is the management of spatial data commonly referred to as layers, defined as a set of data consisting of points, lines or silhouettes crossing and describing geographical reality on the earth's surface. The following figure is an example of spatial data base. The strength of GIS lies in the analysis and manipulation of these different layers of the convergence of these layers data.

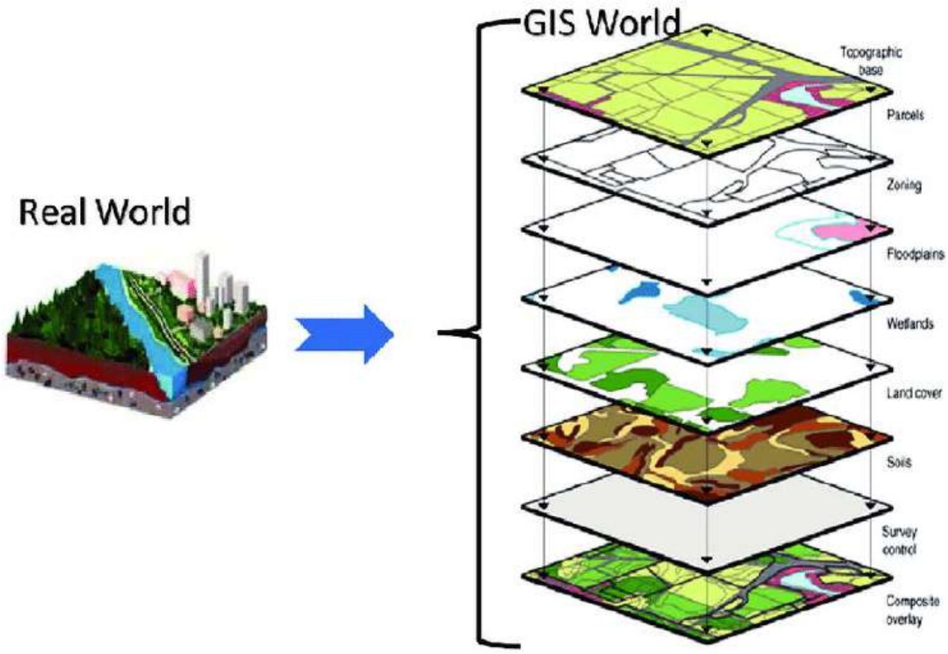


Figure (2.1): conceptualization of GIS data and layers [16].

The third level of fonctinonality is spatial analysis and modelling. Spatial analysis and modelling is location based. And the results of spatial analysis are also dependent on the location of features being analysed. Spatial analysis and modelling function in GIS allow users to defined and execute spatial and attribute procedures to conduct analysis in space and about place. The functionality of this level is commonly thought of as the heart of a GIS [15, 17].

2.2.3. Spatial data types in GIS

In GIS, tow spatial data sets are used: Raster and Vector

Raster is used to represent spatial data by a network of cells or pixels associated with each other, representing raster in the form of a group of colored pixels, where each pixel contains certain value or values, raster can be used to represent areal image, space imagery, digital altitude models and other data that reflect geographical characteristics equally in the regions.

Vector is used to represent spatial data by typical geographical objects such as points, lines and polygons, vector is used to describe geographical features more accurately and in more detail, where objects are represented by specific points in space and define spatial relationships between them, vector can be used to represent buildings, roads, rivers, state borders and any other elements that need accuracy and accuracy in representation.
The following figure represents models of the spatial data of raster and vector

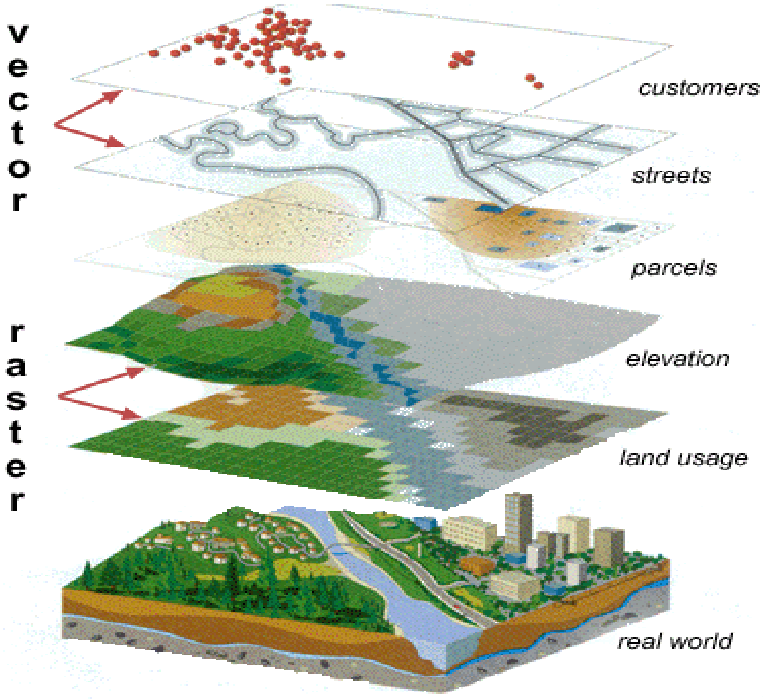


Figure (2.2): feature types and their representation in tow spatial data models in GIS [18].

2.3. Decision making

Decision making is the process of sufficiently reducing uncertainty and doubt about the alternatives to allow a reasonable choice to be made from among them [19].
The decision itself depends on "the nature of the problem, the policy of the decision makers and the overall objectives of the decision''. The possible types of action include: choice of alternative solution, ranking of the form the best to the worst ones or the assignment of the considered alternatives into predefined classes [13, 20].

2.4. Concept of decision problem

The concept of the decision making problem relates to the outcome of the latter and represents an important role in determining the correct manner of the decision making situation under consideration. Bernard Roy 15 categorized the decision making situations according to four major problematic and the way the decision aid should be envisaged [21]:

- ❖ The Description Problematic – decision aid focuses in providing an appropriate set of actions and a suitable family of criteria, without making any recommendation.
- ❖ The Choice Problematic – the aid intends to narrow down the number of actions to find a single alternative or possible smaller subset (usually containing the most fulfilling actions the predefined goals).
- ❖ The Sorting Problematic – In this problematic the aid seeks to assign each action a category from a set defined a priori. These categories can be related with the feasibility of the actions and the possibility of their implementation.
- ❖ The Ranking Problematic – The decision aid results in a complete or partial preorder of the set of alternative, after comparing them with each other.

2.5. Multi criteria decision making approaches

Multi-Criteria Decision Analysis (MCDA) is a framework used to help make decision when there are a variety of competing criteria to be observed. MCDA aims at highlighting these conflicts and deriving a way to come to a compromise in a transport process. Unlike methods that assume the availability of measurements, measurement in MCDA are derived subjectively as indicators of the strength of various preference. Preference differ from decision makers to decision maker, so the outcome depends on who making the decision and what their goals and preferences [22].

Are powerful tools used for evaluating problems and addressing the process of making decisions with multiple criteria. MCDA problems typically are quite complex, but the distinguishing characteristic is the fact that various conflicting criteria and the interactions between theme have to be modeled explicitly in order to again an understanding of the problem or to provide a solution to the problem. MCDA as a multi-disciplinary field of Operation Research (OR), uses mathematical approaches involving the following steps [23].

1. Structuring decision processes;
2. Defining and selecting alternatives;
3. Determining criteria formulation and weights;
4. Applying value judgment and evaluating the results to make decision in design or selecting alternatives with respect to multiple conflicting criteria.

2.5.1. Framework for MCDM

The definition of decision is vital after identifying the problem, as MCDM begins to mention the problem and continues to work steps in the figure (2.3) where the decision makers classifies and evaluates possible alternative with regarding the constraints to structure the decision making matrix.

MCDM processed with a generation of decision matrix that includes the scores of the alternatives according to the selected criteria [24].

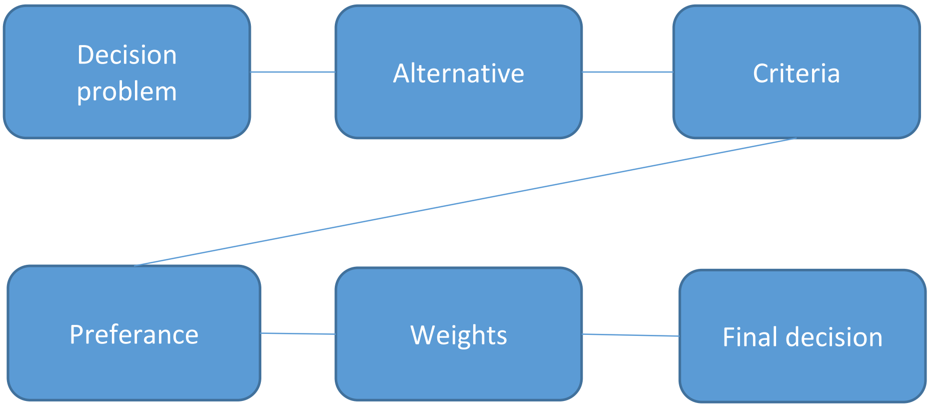


Figure (2.3): basic of decision process

2.5.2. Classification of MCDM methods

The MCDA consists of several methods consisting of multi-objective decision making (MODM) and multi-attribute decision making (MADM) where the basic distinction between two sets of methods depends on the number of alternatives under evaluation. MADM methods are designed for selecting discrete alternatives while MODM are more adequate to deal with mutli-objective planning problems, when a theoretically infinite number on continuous alternative are defined by a set of constraints on a vector of decision variables [25].

MCDA methods are classified by [26] because it directly reflects the scope of their application. Classified MCDA into four categorization

1. Elementary method;
2. The single synthesizing criterion approach;
3. The outranking synthesizing approach;
4. The mixed methods.

Table 2.1 shows the main methods belonging to each of these categories [26].

Table 2.1: MCDM classification by Guitouni and Martel (1998) [26].

Category	**Methods**
Elementary method	Weighted sum, lexicographic method, conjective methods, disjenctive method, maximine method
Single synthesizing criterion approach	Topsis, maut, mavt, smart utility theory additive (uta), ahpevamix, fuzzy weighted sum, fuzzy maximin
Outranking synthesizing approach	Electre, promethee, melchior, oreste, regime
Mixed methods	Qualiflex, materal & zaras method, fuzzy conjenctive/disjunctive method

2.6. GIS-MCDA integration

Combining spatial and geographical data (inputs) to obtain a volume change decision (outputs) is a solution to decision problems.

GIS is an excellent tool for acquisition, storage, manipulation and spatial analysis of geographical data, but has a luck to with spatial decision problems especially with conflicting objective in the decision-making process. Bellow some critics addressed to GIS technology. [27]

- ❖ Decision data like decision makers preference are not taken into account by current GIS;
- ❖ Assessment and comparison of different scenarios are not permitted by GIS. The solution given by GIS satisfy all criteria simultaneously;
- ❖ Analytic functionalities found is most GIS are oriented towards the management of data, but not towards an effective analysis of them.

MCDA is used to in GIS to help make spatial decision about the place.

MCDA aims to assess and analyze a range of potential alternatives using a variety of specific criteria. In the context of GIS, MCDA can be used to solve issues related to resource allocation, location of facilities, urban, development planning, risk analysis, environmental impact assessment, and other spatial issues.

MCDA and GIS can be combined in several steps, including identifying important criteria, collecting relevant data, developing an analytical model for evaluating alternative, generating results and analysis, and making the final decision.

2.7. Conclusion

In this chapter we discussed the evaluation of geographical system over time, after which we explained GIS and discussed MCDM methodology as a decision making tool. Finally, we explained the link between GIS and MCDM and its impact on decision-making in various fields.

In general, GIS can be used in supporting decision to improve understanding, planning, organization, predicting future events, improving process efficiency, making more targeted decisions and realizing spatial benefits related to business and projects.

Chapter03:

Choosing the appropriate site for green hydrogen in Algeria using the Geographic Information System.

3.1. Introduction

The establishment of a solar hydrogen production facility require carful site selection to ensure the best performance and effectiveness of the facility.

In this study, GIS software was used to analyze, store, display and incorporate geospatial data and understand the spatial relationships between different data and their analysis in the context of maps and geospatial data.

In our study on research on optimal area suitable for solar hydrogen production in Algeria as a whole, we have applied a multi-criteria approach based on the use of the GIS program to incorporate and modify these criteria.

3.2. Presentation of study area

Algeria is located in North Africa, astronomically between latitudes 19 D and 37 D north of the equator, and between lines 12 D east of the Greenwich line and 9 west of Greenwich line. And extends along the north coast of the African continent.

- ❖ It is bordered from the east by Tunisia and Libya.
- ❖ From the south by Niger and Mali.
- ❖ From the south by Mauritania and Western Sahara.
- ❖ And from the west by morocco.

The desert occupies more than half of Algeria total area. Temperatures vary depending on the geographical location, altitude and climate of the region, ranging from 15 to 25 degrees Celsius north in summer, while in the desert the exceed 50 degrees Celsius.

Internally, Algeria has a great geographical and environmental diversity, resulting in a great diversity of the country's infrastructure and roads.

Algeria population, agriculture and industrial growth have increased the demand for energy supply in recent times.

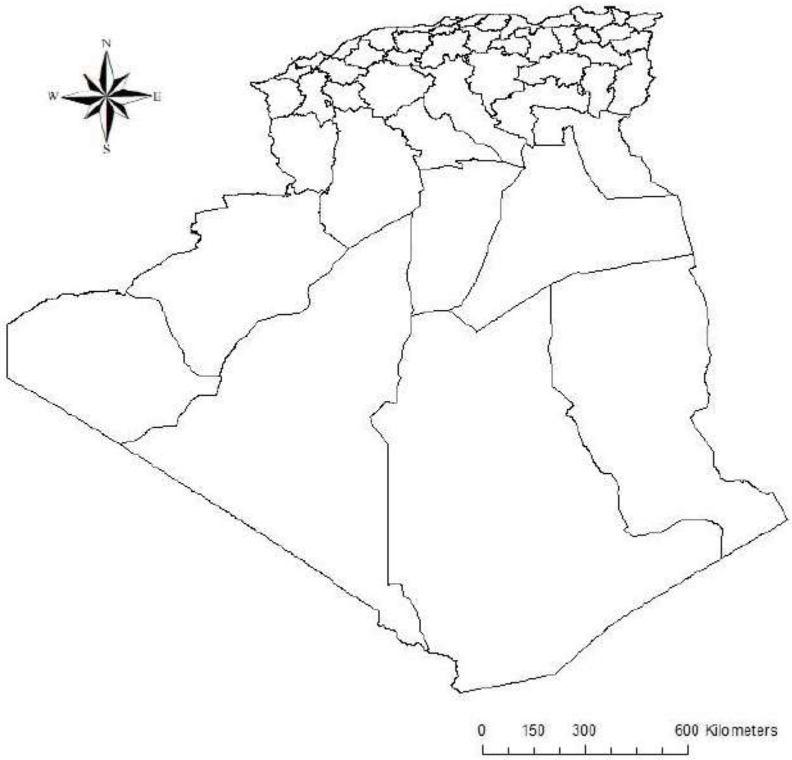


Figure3.1: administrative area of Algeria

The Figure (3-1) shows that most states are concentrated north, making it an area of urban overcrowding, resulting in a multitude of infrastructure, farmlands and roads.

3.3. Method and methodology of the work

A methodology has been developed using GIS program in this study to obtain the best suitable sites for the production of solar hydrogen solar in Algeria. Optimal location for solar hydrogen production have been identified based on the following steps:

- Select the main criteria and special sub-criteria obtained from different sources.
- Maps were collected and edited by GIS.
- Integrate these maps and finally get results.

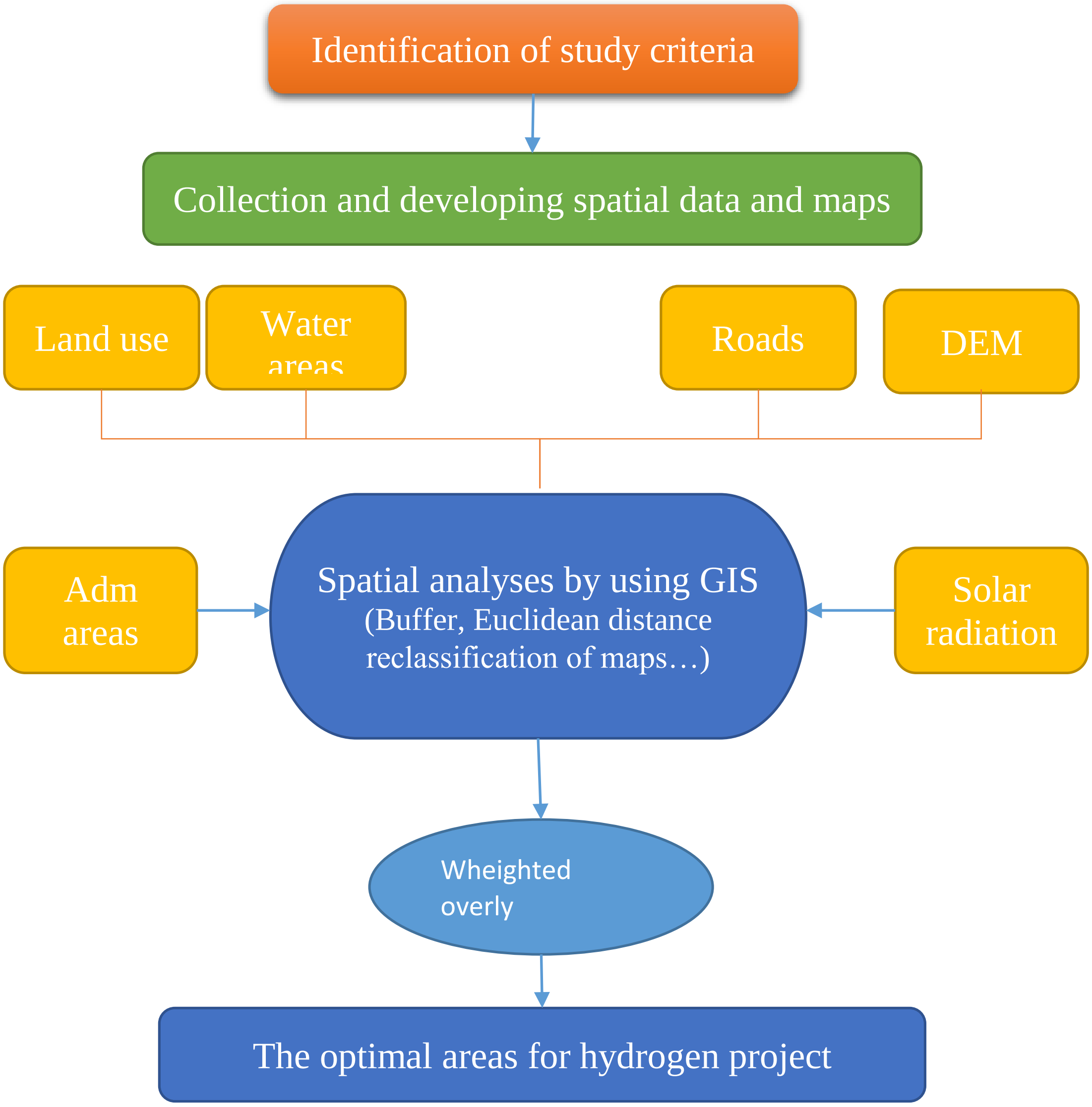


Figure (3.2) methodology of study

The figure (3.2) shows the methodology to be followed after obtaining the spatial data of the study area to reach the optimal area.

3.4. Technical criteria

In any renewable energy project, the technical standard must be chosen as one of the necessary criteria and must be taken seriously including the green hydrogen production project.

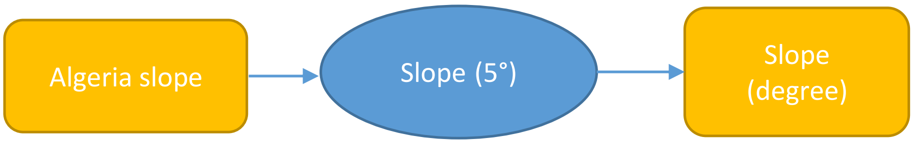
In our study, we relied on two technical criteria to highlight optimal areas for the establishment of the solar hydrogen production project.

3.4.1. Slope

Area with steep slopes are not suitable for construction of PV solar plants and hydrogen production sites due to the challenges they pose for accessibility, as it would be difficult for trucks and other modes of transportation to reach the site, increasing the costs and technical challenges [35].

When we got the DEM of the country of Algeria, we excluded all areas with a very steep level using the slope tool in GIS.

Slope of Algeria obtained from CGIAR CSI website [37].



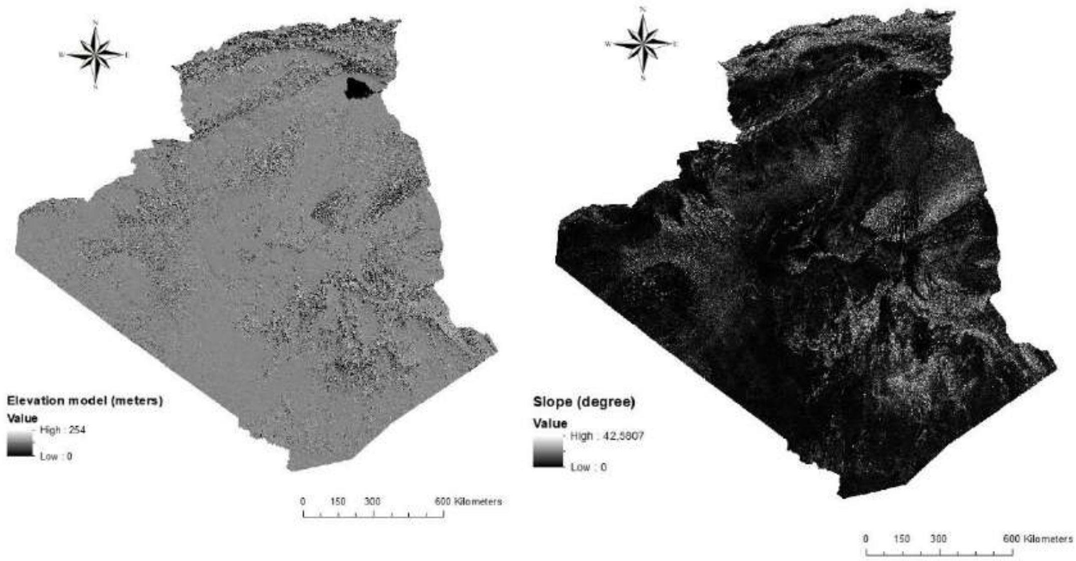


Figure3.3: map of elevation model and slope

The figure (3.3) shows the map of digital from 0 (m) to 254 (m) and the map of slope from 0° to 42.6°.

We note that most of the declines and high altitude are in the far north and some places on the south and east, while we have observed some flat lands or more equilibrium in the interior, central and far south.

3.4.2. Solar radiation

The data showed that the horizontal rate of solar radiation in Algeria ranged from 7.6 (KWh/m²/day) to 28.9 (KWh/m²/day).

Solar radiation data of Algeria downloaded from Solargis site [28].

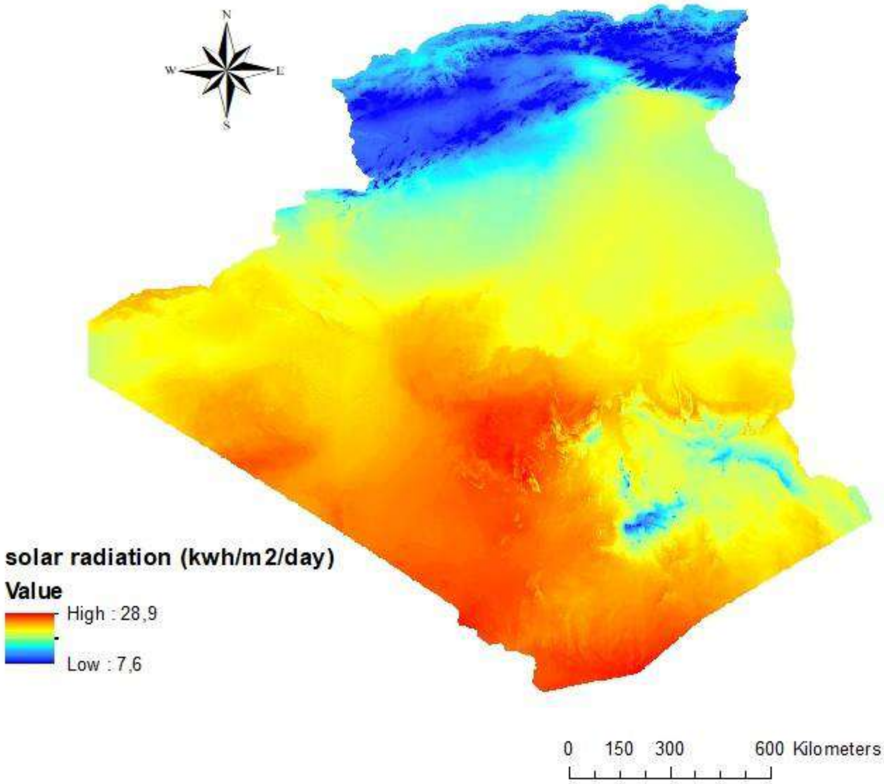


Figure3.4: the map of Algeria average daily solar radiation

The values of solar radiation in Algeria are divided by geographical location, as we have generally observed that the higher value of solar radiation are concentrated in southern desert regions while the lower values are in the northern regions.

3.5. Economic criteria

Economic feasibility is one of the most important criteria that need to be considered for the development of any project. The distance to roads are considered the sub criteria for the economic assessment of suitable green hydrogen sites in the study area [41].

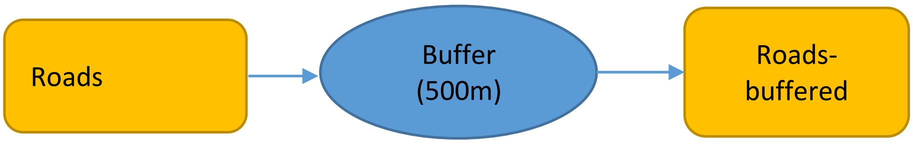
3.5.1. Distance from roads

Algeria road network currently consists of 1216 kilometers of traffic road east-west, and more than 141,000km of which more than 117,000 km is paved [36].

The decision makers also concern about traffic density near the station in order to estimate the demand later on. The potential sites near to primary and secondary road (within 500m away from roads) were taken in this study [37].

Algeria road network has been taken from the site Geofabrik [40].

We gave the places close to the roads a greater conveniences, by the buffer tool in GIS our study roads with a distance of 500 meters.



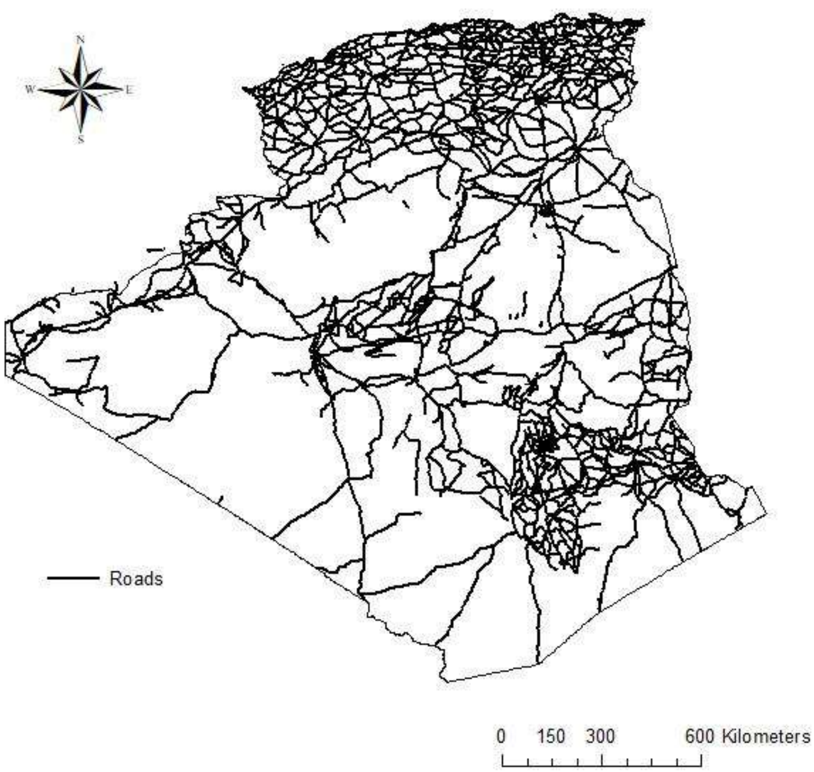


Figure3.5: map of the roads

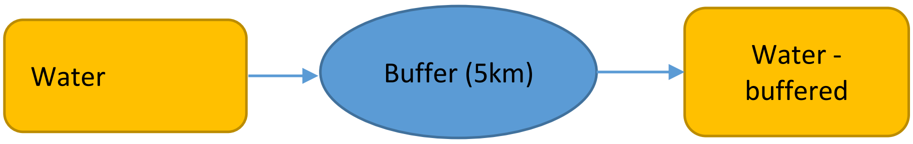
3.6. Environmental criteria

In any project there are environmental criteria to be taken and applied, especially since this project expresses clean, environmentally friendly energies, so the environmental aspect must be taken into account.

3.6.1. Distance from water areas

Water is an important feature in protecting environment. Moving away from these spaces is necessary, so we cut off the water areas from the map.

Using the tool buffer 5 kilometers away in GIS the water area was cut off.



The following figure sets out Algeria water areas

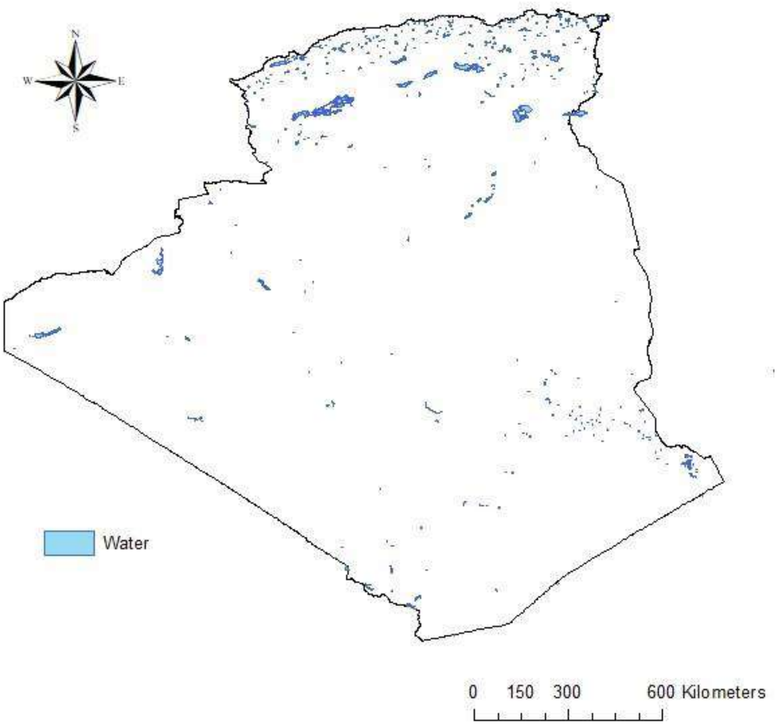


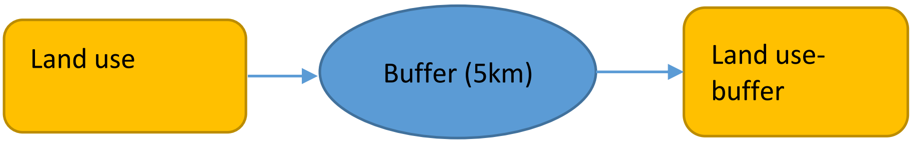
Figure 3.6: water areas in Algeria

3.6.2. Distance from land use

Representing all land used from residential, agricultural and infrastructure areas, these areas are restricted, inappropriate and distanced are necessary to preserve the healthy environment and public safety.

Land used data in Algeria have been downloaded from the open street map website [40].

Using the buffer tool in GIS we excluded these areas by five km



The following map illustrate the land use before and after treatment

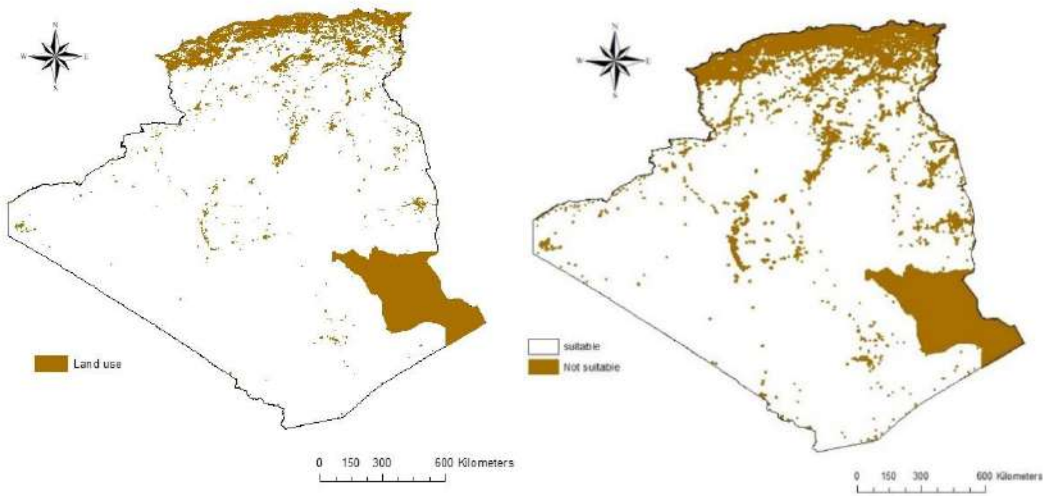


Figure3.7: map of land use before and after buffer

Most of the land used is based in the northern part of the area and therefore the possibility of establishing the project's in these territories is reduced.

3.7. Data description

The applicable data was obtained from the approved websites and modified for use in this study:

Table3.1: the criteria used and classifications in this study

Subcriteria	Geometry type	Scale	Source
Map of Solar radiation Kwh/m²/day	Point	1:13 897 900	Solar gis
Slope (degree)	Raster	1:13 897 900	CGIAR CSI
Map of roads (m)	Line	1:13 897 900	Geofabrik
Map of water (km)	Polygone	1:13 897 900	Gis open street map
Map of Land use	Polygone	1:13 897 900	Gis open street map

3.8. Collect and integrate criteria

The maps obtained after processing have been reintegrated and formulated in the same format, the process is applied by taken the same weight for each criteria in the spatial system to produce a single aggregated graduate and finally acquiring a map of suitable and not suitable areas for hydrogen project.

The following figure explain the process of integrating criteria

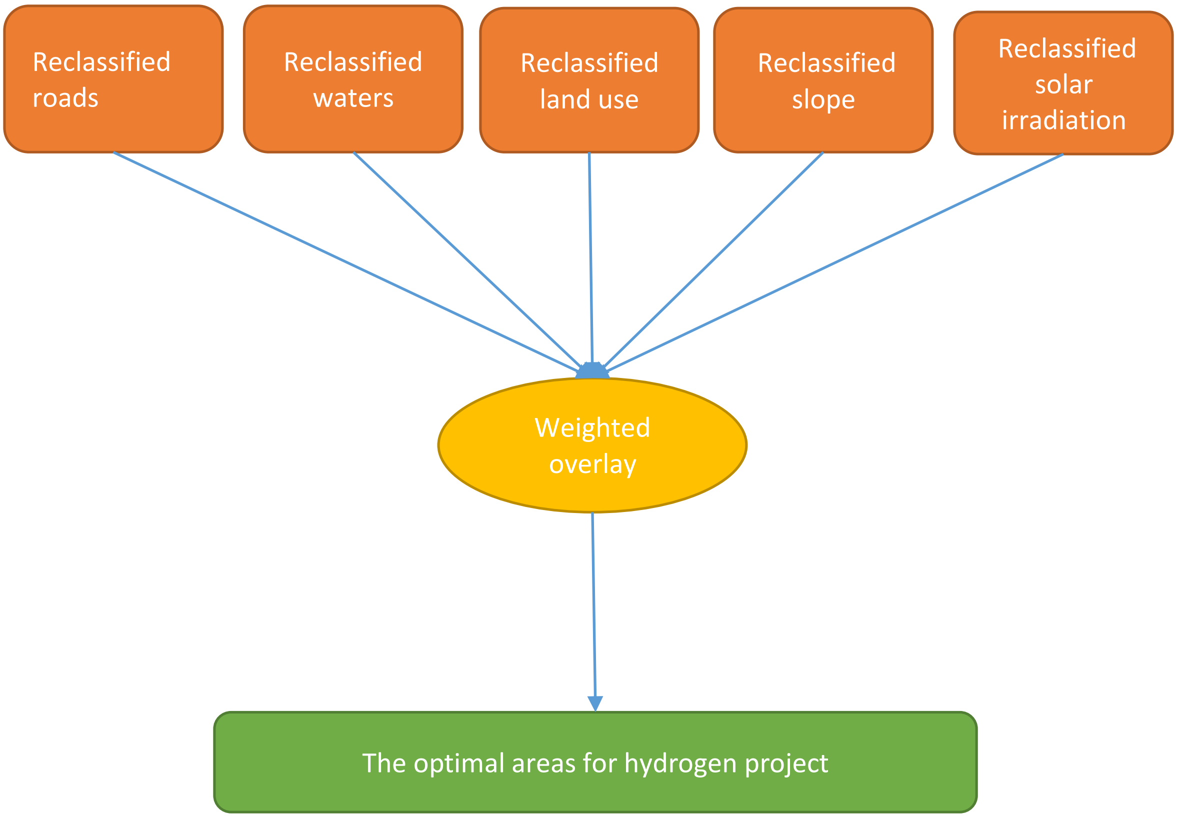


Figure3.8: step of integrating criteria

After clipping the not suitable area for the project, we got the following result:

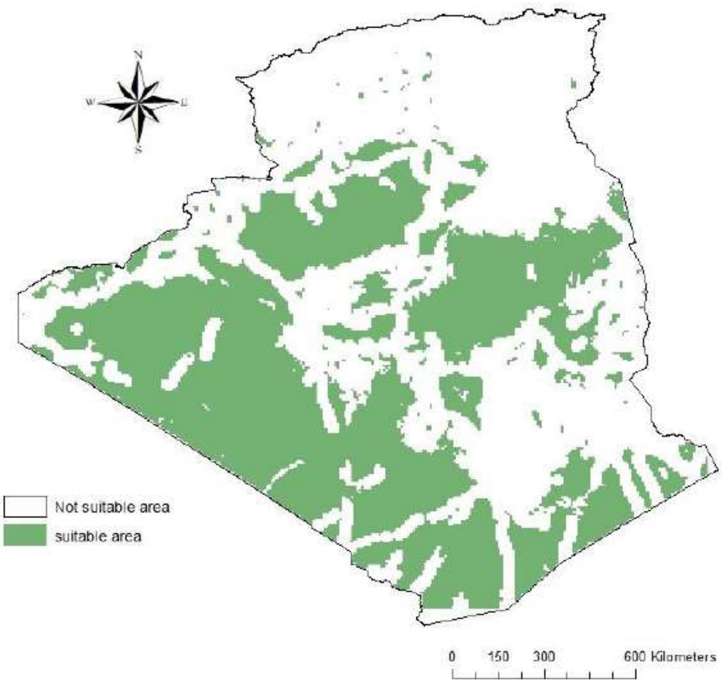


Figure3.9: the suitable areas for hydrogen solar in Algeria

The map shows the suitable and not suitable areas for hydrogen solar in Algeria, an area of 1054033 kilometers square representing 45% of Algeria total area is suitable area for hydrogen solar, and area of 1266938 kilometers square representing 45% of total area its not suitable for hydrogen project.

Most of the suitable area in the southern part of the country are based in the area used, road networks, water cluster areas, and few area with sever slopes.

3.11. Results and discussion

Algeria is one of countries with large spaces capable of establishing a solar hydrogen production project.

In this study, the GIS program was used to select suitable site for hydrogen solar in Algeria based on the method of integrating multi-criteria selected according to project requirements.

A map of the average daily solar radiation values of the project's achievable places and shows the most polarizing places of solar radiation.

The following figure sets out the solar radiation values of the project suitable areas ranging from 4,481 (kwh/m²/day) to 6,987 (kwh/m²/day).

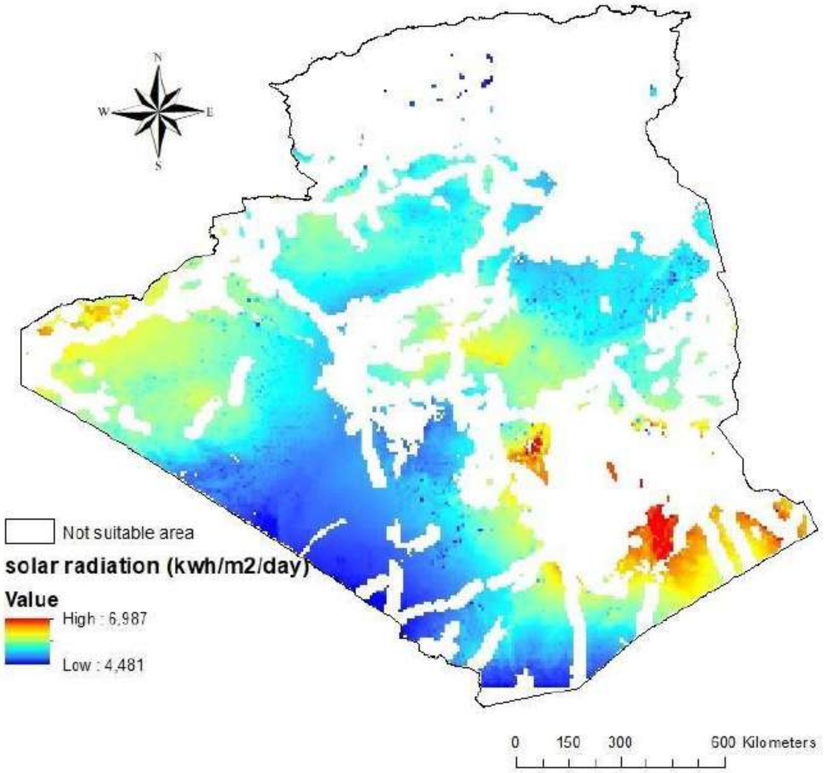


Figure 3.10: solar radiation of suitable area

The map sows the daily solar radiation values of the project's achievable places where the region of Ilizi recorded the largest polarization area for the largest daily solar radiation values of 6.98 (kwh/m²/day) falls over an area of 3877 (km²) followed by the region of temenghast with an area of 1596 (km²) with the same value as daily solar radiation, the region of adrar recorded an average of 6.23 (kwh/m²/day) solar radiation falls over an area of 8495 (km²), while other regions recorded solar radiation values ranging from 5.98 to 4.98 (kwh/m²/day).

3.12. Conclusion

Solar hydrogen, an essential source of clean energy worldwide. This chapter has focused on the use of a GIS approach to identify optimal sites for solar hydrogen production in Algeria. The establishment of green hydrogen production projects has become necessary to cover energy needs and dispense with fossil fuels that cause more serious damage to the environment. The most suitable site to complete a solar radiation hydrogen project was selected based on three technical, environmental and economic criteria using a multi-criteria GIS approach. The project achievable area was 1054033 (km²) with an average daily solar radiation of between 4 and 7 (kwh/m²/day) enough to produce abundant amount of solar hydrogen.

We also provided a sizing of the components of the facility through a set of equations that gave us the amount of hydrogen that is produced from(1GW). It was 27180204.8(Kg), This quantity can be produced mathematically after implementing the project in the cities of the south.

General conclusion

General conclusion

Renewable energies are the future. Green hydrogen is the promising future in the field of energy that countries are heading towards, as it is considered the cleanest energy with zero carbon. Because it is produced from water and renewable energies only, it is considered the fuel of the future for which countries compete.

The establishment of green hydrogen production projects has become necessary to cover energy needs and dispense with fossil fuels that cause more serious damage to the environment. In our work, we relied on the Geographic Information System, and this is after introducing a set of different maps. We got that most of Algeria's area is capable of achieving this project. This area is located in the south.

The green hydrogen project in Algeria is very promising, important and beneficial to Algeria in several aspects, including natural and economic ones.

In our work, we used solar energy. Wind energy can also be used, as it is an important source for green hydrogen production, and Algeria has a very huge amount of this energy.

The most suitable site to complete a solar radiation hydrogen project was selected based on three technical, environmental and economic criteria using a multi-criteria GIS approach. The project achievable area was 1054033 (km^2) with an average daily solar radiation of between 4 and 7 ($kwh/m^2/day$) enough to produce abundant amount of solar hydrogen.

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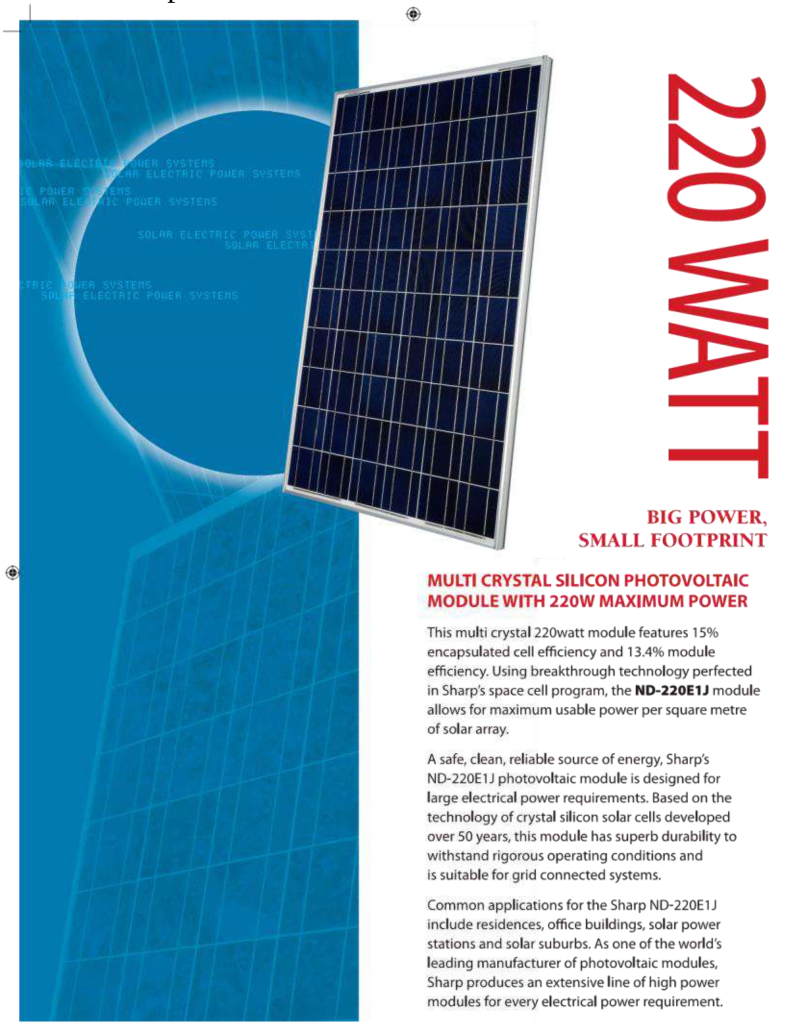
Bibliography

Annexe

PV module specifications:



ND-220E1J – MAXIMUM POWER

ELECTRICAL CHARACTERISTICS

Cell	156.5mm Square Polycrystalline silicon
No. of Cells and Connections	60 in series
Open Circuit Voltage (Voc)	36.5V
Maximum Power Voltage (Vpm)	29.2V
Short Circuit Current (Isc)	8.20A
Maximum Power Current (Ipm)	7.54A
Maximum Power (Pm)[1]	Typical 220W
Encapsulated Solar Cell Efficiency (ηc)	15%
Module Efficiency (ηm)	13.4%
Maximum System Voltage	DC 1000V
Series Fuse Rating	15A
Type of Output Terminal	Lead Wire with MC3 Connector

Specifications are subject to change without notice
[1] (STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5

MECHANICAL CHARACTERISTICS

Dimensions	994 x 1652 x 46mm
Weight	21.0kg

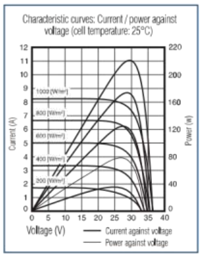
TEMPERATURE COEFFICIENT

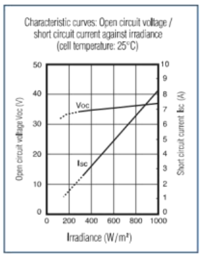
Temp. Coefficient of Pmax	-0.485	% / °C
Temp. Coefficient of Voc	-0.13	V / °C
Temp. Coefficient of Isc	0.053	% / °C

ABSOLUTE MAXIMUM RATINGS

Parameters	Rating	Unit
Operating Temperature	-40 to +90	°C
Storage Temperature	-40 to +90	°C
Dielectric Voltage Withstood	3000 max.	V-DC

IV CURVES





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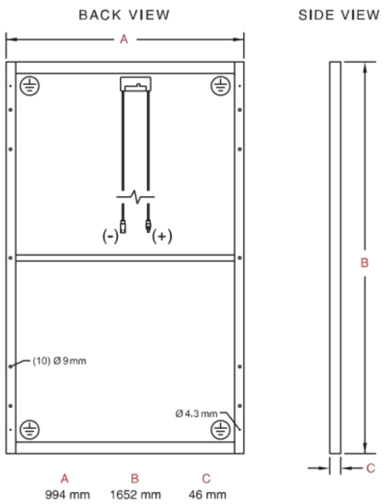

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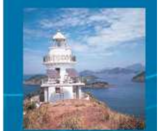

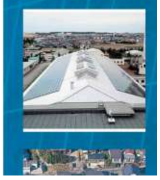

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