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THEME

Combining GIS and MCDA to select suitable areas for new solar energy projects in the south of Algeria

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Abstract

Solar is one of the most promised renewable energies in the South of Algeria. However, the share of this energy is still low, which is mainly due to the low cost of energy production by fossil fuel. The South of Algeria has appropriate irradiation (can reach 7.2 KWh/m^2/day) for solar energy deployment. Algeria has experienced a high population growth and a rise of living level, which increased energy demand that appears in many problems in electricity, especially in summer. These factors, combined with new renewable energy policies, could create an opportunity for solar to provide some of the energy that will be required to cover this increase. The aim of the study is to investigate the potential for solar power generation in the South regions by identifying suitable areas for a new solar power projects. Specific areas with good irradiation will be treated by Geographic Information Systems (GIS) and assessed by Multi-criteria decision analysis (MCDA).

Keywords: Solar energy, energy demand, GIS, MCDA

Résumé

L'énergie solaire est l'une des énergies renouvelables les plus promises dans le sud d'Algérie. Toutefois, le partage de cette énergie est encore faible, à cause de faible coût de production d'énergie par les combustibles fossiles. Le sud d'Algérie a une radiation appropriée (peut atteindre 7,2 kWh/m^2/jour) pour le déploiement d'énergie solaire. L'Algérie a connu une croissance démographique élevée et une augmentation du niveau de vie qui ont augmenté la demande d'énergie, il apparaît dans de nombreux problèmes d'électricité, surtout en été. Ces facteurs, combinés avec nouvelles politiques concernant l'énergie renouvelable, pourraient créer une occasion de l'énergie solaire pour couvrir une partie de cette augmentation. L'objectif de cette mémoire est d'étudier le potentiel de production d'énergie solaire dans les régions du Sud par l'identification de zones appropriées pour un nouveau projet d'énergie solaire.

Les zones spécifiques avec une bonne irradiation seront traitées par les systèmes d'information géographique (SIG) et évaluées par la méthode d'analyse de décision multicritères (MCDA).

Mots-clés : Energie solaire, demande d'énergie, SIG, MCDA

Abstract

الملخص

الطاقة الشمسية هي واحدة من الطاقات المتجددة الواعدة في جنوب الجزائر ومع ذلك فإن حصة هذه الطاقة لا تزال منخفضة، وذلك أساسا بسبب انخفاض تكلفة إنتاج الطاقة بواسطة الوقود الأحفوري. جنوب الجزائر يتمتع بالإشعاعية المناسبة (قد يصل إلى 7.2 كيلو واط /م^2/يوم) لنشر الطاقة الشمسية. وقد شهدت المنطقة ارتفاعا في معدل النمو السكاني وارتفاعا في مستويات المعيشة، مما أدى إلى زيادة الطلب على الطاقة، خاصة في فصل الصيف. هذه العوامل، جنبا إلى جنب مع سياسات جديدة في هذا المجال يمكن أن تخلق الفرصة للحصول على الطاقة الشمسية وتوفير جزء منها لتغطية هذه الزيادة. والهدف من هذه الدراسة هو تحقيق إمكانيات توفير الطاقة الشمسية في المناطق الجنوبية من خلال تحديد المناطق المناسبة لمشروع جديد لطاقة شمسية. المناطق المختارة سوف تتم معالجتها عن طريق، نظم المعلومات الجغرافية GIS و تقييمها بواسطة طرق تحليل القرار متعدد المعايير MCDA

الكلمات المفتاحية: الطاقة الشمسية، الطلب على الطاقة، نظم المعلومات الجغرافية، تحليل القرار متعدد المعايير

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NOMENCLATURE

Symbole	Definition	Unit
A	Alternatives	
AC	Alternative current	
C	Criteria	-
DC	Direct current	-
E	Energy	J
kg	Kilogram	
H	Planck's constant: 6.626 x 10 34	Js
m	Meters	
MW	Mega Watts	
W	Watts	
Wt	Weight	%

Abbreviations

AHP	Analytic Hierarchy process
MENA	Middle East and North Africa
CCGT	Combined Cycle Gas Turbine
CSP	Concentrating Solar Power
GDB	Global Data Base
GIS	Geographical Information System
LNG	Liquefied Natural Gas
MCDA	Multi-criteria decision analysis
NREL	National Renewable Energy Laboratory.
PV	Photovoltaic
RNS	Renewable Energy Sources
SMART	Simple Multi-Attribute Rating Technique
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
WSM	Weighted Sum Method
WPM	Weighted Product Method

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Introduction

Solar power is the flow of energy from the sun to Earth. The primary forms of solar energy are heat and light. Sunlight and heat are transformed and absorbed by the environment in a multitude of ways. Solar energy has an enormous potential, and the prediction about this type energy show that the use of it can be increased in a significant way.

Photovoltaic (PV) converts directly the sun light into electricity, which means that PV is more effective during daylight hours and less helpful during nights (until now storing electricity is not very attractive). Heat storage is a far easier and efficient method, which is what makes solar thermal so attractive for large-scale energy production. Heat can be stored during the day and then converted into electricity at night. Solar thermal plants that have storage capacities can drastically improve both the economics and the dispatch ability of solar electricity.

Accordingly, different techniques of active solar heating and solar thermal power generation projects are technically feasible and cost effective, and some commercially available plants can produce up to 350 MW [1]. Nevertheless, several PV projects have been realized producing to more than 20 MW [2]. These projects are highly dependent on the local climate and energy needs; and also, important factors because only in certain regions these systems can be efficient enough to be implemented.

For that, we gather data from different resources, such as Algerian maps, NREL (National Renewable Energy Laboratory), Google Earth, and many other sources, such as articles of technology and science. Then, we treat them by ArcGIS software in purpose of preparing the appropriate land information to select locations for new solar projects, such as road identification, urban areas, agricultural areas, mountains and sand dunes.

Choosing the best and the suitable alternative for the establishment of a new solar energy project is a very difficult stuff due to the diversity of the indicators (criteria) that are used to assess these alternatives, these complex interactions shows how decision making is extremely complicated. Just the methodic way can solve this complication by applying one of the multi criteria decision analysis (MCDA) theories.

To reach these objectives, this work has been effectuated and divided into 4 chapters:

-Initiation to solar energy: this chapter is a review of the main solar energy technologies and the actual situation of electricity production by solar in Algeria and the world.

- In the second chapter, we present some work of Google Earth and ArcGIS software's to determine the available locations (empty areas), roads, dunes, urban areas, etc.

- In the third chapter, we illustrate the different steps of Multi-criteria decision analysis (MCDA) methods, including select alternative, select criteria, weighting criteria, performance matrix.

- In chapter four, we collected the obtained results from ArcGIS and generate the performance matrix to make our decisions; finally, we apply MCDA method to choose the appropriate region for new solar energy in the south of Algeria.

Chapter 01: Solar Energy

Chapter 01: Solar Energy

As economies develop and become more complex, energy needs increase greatly. Historically, as supplies of firewood and other biomass energy proved insufficient to support growing economies, people turned to other types of energies like, hydropower, then to coal during the nineteenth century, and then to oil and natural gas during the twentieth century. In the 1950s-nuclear power was introduced into the energy production technologies.

Today, fossil fuels coal, oil and natural gas are almost the dominant energy source in industrial economies, and the main source of energy production growth in developing economies.

But the twenty-first century is already seeing the start of the next great transition in energy sources away from fossil fuels towards renewable energy sources. This transition is motivated by many factors, including concerns about environmental impacts (particularly climate change), limits on fossil fuel supplies, prices, and technological change.

1.1. Solar energy

Solar energy is the most abundant energy resource and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean etc.) forms. About 60% of the total energy emitted by the sun reaches the Earth's surface. Even if only 0.1% of this energy could be converted at an efficiency of 10%, it would be four times larger than the total world's electricity generating capacity of about 5 000GW (World Energy Council 2013) [3].

1.2. Solar Photovoltaic (PV)

Semiconductor materials such as silicon are used in photovoltaic solar cells. Photovoltaic are electronic devices that convert sunlight directly into electricity, when photons drop on solar cells, they separate positive and negative charge carriers. This produces an electrical voltage and the electrical current can drive loads (see figure 1.1). Since solar cells are modular, they can be assembled in units of any size. An inverter converts DC voltage to AC and feeds the solar power into the grid [4].
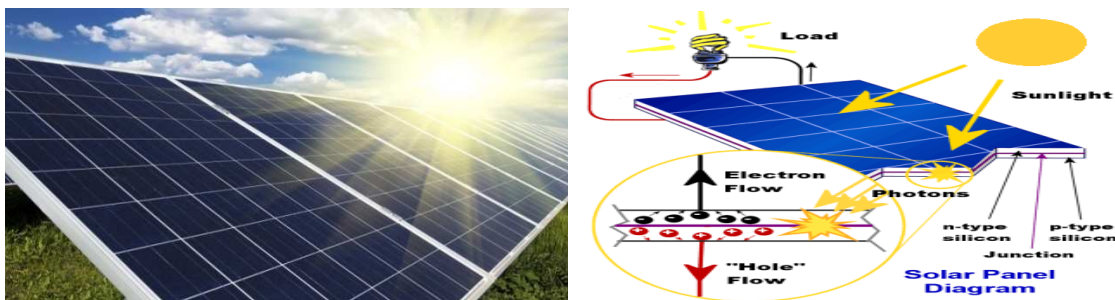
Figure 1.1: Photovoltaic panel and functioning principal. (Engineers journal, 2017)

The modern form of the solar cell was invented in 1954 at Bell Telephone Laboratories. Today, PV is one of the fastest growing renewable energy technologies and it will play a major role in the future global electricity generation. PV technology offers a number of significant benefits, including: the availability everywhere. Unlike many other electricity generation technologies, PV can therefore offer a price hedge against volatile fossil fuel prices. Many PV cells are encapsulated together to form a PV panel or module. A PV array, which is the complete power generating unit, consists of any number of PV modules/panels. Depending on their application, the system will also require major components such as a battery bank and battery controller, DC-AC power inverter, auxiliary energy source etc. Individual PV cells typically have a capacity between 5 and 300 W but systems may have a total installed capacity ranging from 10 W to 100 MW. The very modular nature of PV panels as building blocks to a PV system gives the sizing of systems an important flexibility [1].

Strengths

- Technology is mature. It has high reliability and long lifetimes (power output warranties from PV panels now commonly for 25 years).
- Automatic operation with very low maintenance requirements.
- No fuel required (no additional costs for fuel nor delivery logistics).
- Modular nature of PV allows for a complete range of system sizes as application dictates.
- Environmental impact low compared with production for PV solar conventional energy sources.
- The solar system is an easily visible sign of a high level of responsibility, environmental awareness and commitment.
- The user is less affected by rising prices for other energy sources PV.

Weaknesses

- Performance is dependent on sunshine levels and local weather conditions.
- Storage/back-up usually required due to fluctuating nature of sunshine levels/no power production at night.
- High capital/initial investment costs.
- Specific training and infrastructure needs.
- Energy intensity of silicon cells.
  - Provision for collection of batteries and facilities to recycle batteries are necessary
  Use of toxic materials in some PV panels.

1.2.1. Type solar energy PV

There are a wide range of PV cell technologies on the market today, using different types of materials, and an even larger number will be available in the future. The base material used to make most types of solar cell is silicon (approx. 87 %). The main technologies in use today are:

a)- Mono-crystalline silicon cells: are made of silicon wavers cut from one homogenous crystal in which all silicon atoms are arranged in the same direction, with a conversion efficiency of 12-15 %).

b)-Poly-crystalline silicon cells: are poured and are cheaper and simpler to make than mono-crystalline silicon and the efficiency is lower (conversion efficiency 11-14 %).

c)-Thin film solar cells: are constructed by depositing extremely thin layer of photovoltaic materials on a low-cost backing such as glass, stainless steel or plastic (conversion efficiency 5-12 %).

d) -Multiple junction cells: use two or three layers of different materials in order to improve the efficiency of the module by using wider spectrum of radiation (conversion efficiency 20-30%) [1].

1.2.2. Main PV projects around the world

The following list is of the photovoltaic power stations that are larger than 150 megawatts (MW) in current net capacity. Most of them are individual, but some, are groups; owned by different independent power producers with separate transformer connections.

The size of photovoltaic power stations has increased progressively over the last decade with frequent new capacity records. As of April 2017, India has the largest solar plant with 900 MW of the 1,000 MW. Topaz Solar Farm is a PV solar plant at 550 MWAC in central coast area and a second 550 MW plant, the Desert Sunlight Solar Farm which is located in the eastern desert region of Riverside County, California. These two plants were superseded by a new "world's largest" facility in June 2015. A 579 MWAC Solar Star project went online in the Antelope Valley region of Los Angeles County, California. The current largest photovoltaic power station in the world is Longyangxia Dam Solar Park, in Gonghe County, Qinghai, China.

Table 1.1: The largest PV power station in the whole world (PV Guangzhou, 2017)

Year	PV power station	Country	Capacity MW

2016	yanchi solar pv station	-China , *Yanchi ,* Qinghai Province	1000
2015	solar star projects	USA, *Rosamond, CA*	575
2015	Desert Sunlight Solar Farm	USA, *Riverside County, CA*	550
2011-2014	Topaz Solar Farm	USA, *San Luis Obispo County, CA*	550
2013-2015	Longyangxia Hydro-Solar PV Station	China, *Longyangxia Dam,*Qinghai Province	480
2015	Copper Mountain III Solar Facility	USA,Boulder ctiy,NV	350
2012-2015	Charanka Park PV power plant	India,*Charanka,* Patan District	245
2015	Centrale solaire de Cestas	France, Cestas, *Bordeaux* Gironde	300
2012	Agua Caliente Solar Project	USA *Yuma County, AZ*	290
2016	Silver State South Solar	USA, *Primm, NV*	250

1.3. Solar Thermal

Solar thermal systems use the sun's power in terms of its thermal or heat energy for heating, drying, evaporating and cooling. Many developing countries have indigenous products such as solar water heaters, solar grain dryers, etc. These are usually local rather than international products, specific to a country or even to a region. The main solar thermal systems employed in developing countries are discussed briefly below [1].

Nowadays, the solar thermal has two types of use such as providing power and for human daily activities.

1.3.1. Solar thermal power plants

a) - Parabolic Trough

Parabolic Trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough focal line. In these tubes, a thermal transfer fluid is circulated, such as synthetic thermal oil. Heated to approximately 400°C by the concentrated sun's rays, this oil is then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator, which can either be part of a conventional steam cycle or integrated into a combined steam and gas turbine cycle [5].
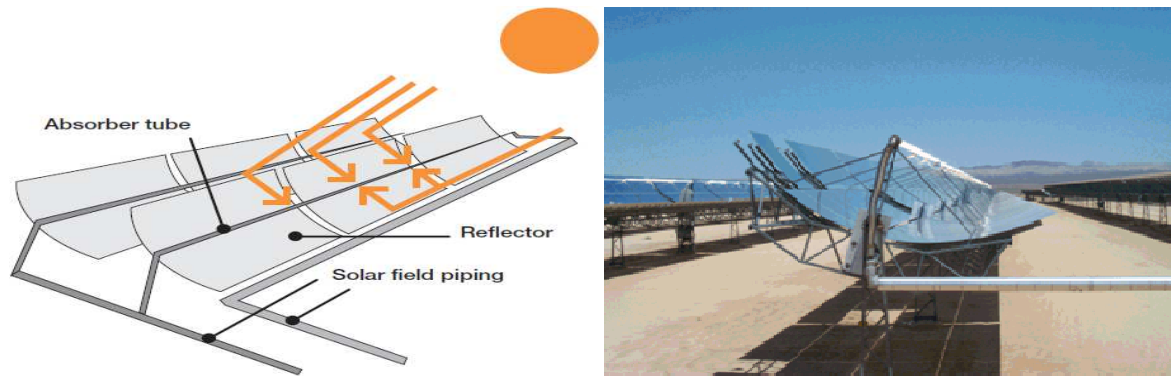
Figure 1.2: Parabolic Trough (Michael Geyer, 2016)

b) - Central Receiver/Solar Tower

A circular array of large individually-tracking mirrors (heliostats) is used to concentrate sunlight on to a central receiver mounted at the top of a tower. A heat transfer medium in this central receiver absorbs the highly-concentrated radiation reflected by the heliostats and converts it into thermal energy to be used for the subsequent generation of superheated steam for turbine operation. Heat transfer media so far demonstrated include water/steam, molten salts, liquid sodium and air. If a gas or even air is pressurized in the receiver, it can be used alternatively to drive a gas turbine (instead of producing steam for a steam turbine) [5].
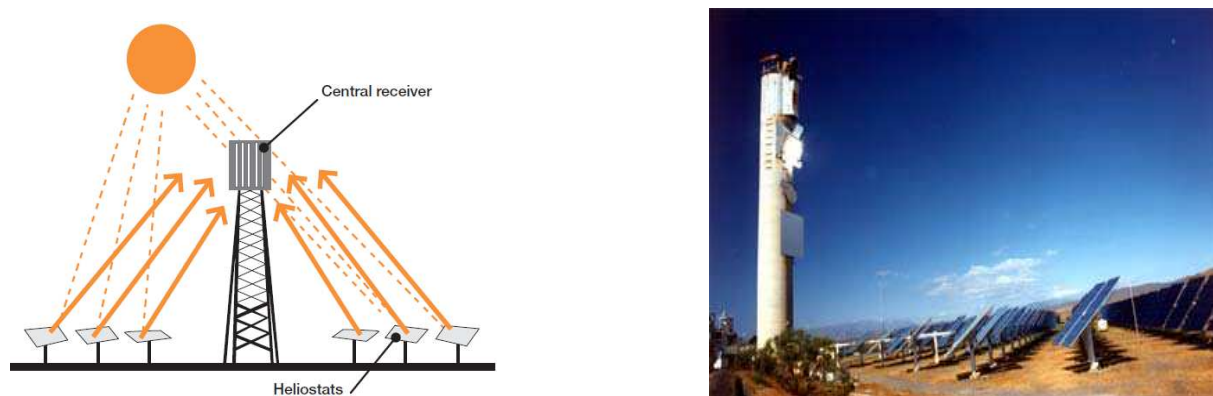
Figure 1.3: Central Receiver/Solar Tower (Michael Geyer, 2016)

c) - Parabolic Dish

A parabolic dish-shaped reflector is used to concentrate sunlight to a receiver located at the focal point of the dish. This absorbs energy reflected by the concentrators, enabling fluid in the receiver to be heated to approximately 750°C. This is then used to generate electricity in a small engine, for instance sterling engine or a micro turbine, attached to the receiver. Each technology has its own characteristics, advantages and disadvantages, some of which are shown in (Table 1.2) [5].
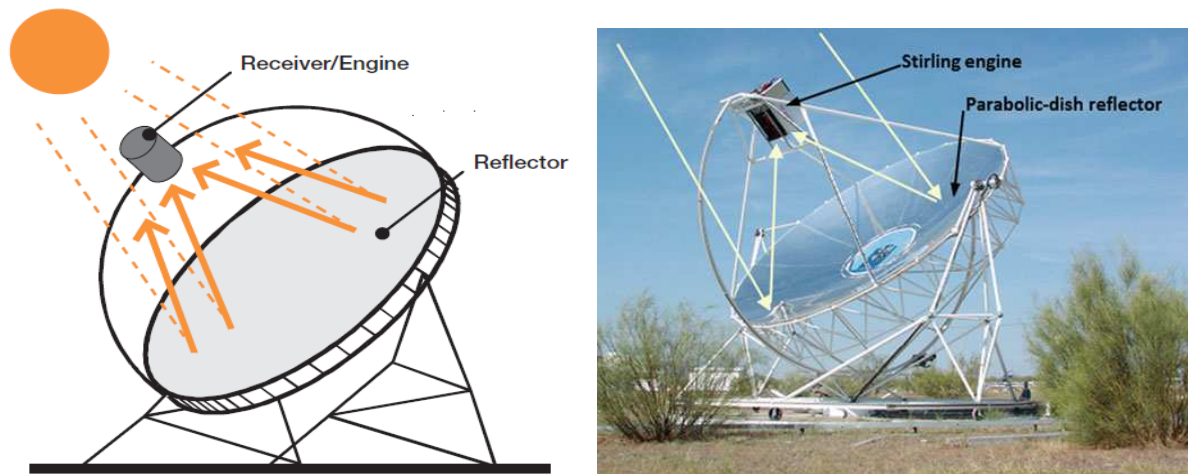
Figure 1.4: Parabolic Dish (Roldàn, 2015)

d) - Linear Fresnel Reflector (LFR)

An array of nearly flat reflectors concentrates solar radiation onto elevated inverted linear receivers. Water flows through the receivers and is converted into steam. This system is linear-concentrating, similar to a parabolic trough, with the advantages of low costs for structural support and reflectors, fixed fluid joints, a receiver separated from the reflector system, and long focal lengths which allows the use of flat mirrors. The technology is seen as a potentially lower cost alternative to trough technology for the production of solar process heat and steam.
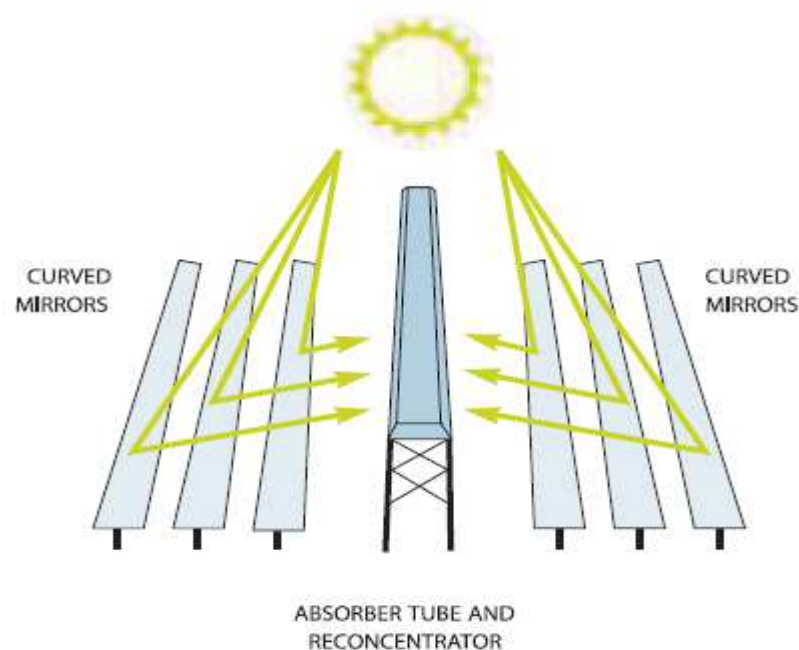
Figure 1.5 Linear Fresnel Reflectors (ESTELA, Greenpeace et Solar PACES, 2016)

Table 1.2: Comparison of Main Technology Types for Solar Thermal Electricity
(ESTELA, Greenpeace, Solar PACES, 2016)

	Parabolic Trough	**Central Receiver**	**Parabolic Dish**	**Fresnel Linear Reflector**
Applications	Grid-connected plants, process heat (Highest solar unit size built to date:280 MW)	Grid-connected plants, high temperature process heat (Highest solar unit size built to date: (392 MW)	Stand-alone applications or small off-grid power systems (Highest solar unit size built to date: 225 MW)	Grid connected plants, or steam generation for use in Conventional thermal power plants. (Largest single unit solar capacity to date:125MW)
Advantages	• Commercially available– over 16 billion kWh of operational experience; operating temperature potential up to 500°C (400°C commercially proven) • Commercially proven annual net plant efficiency of 14% (solar radiation to net electric output) • Commercially proven investment and operating costs • Modularity • Good land-use factor • Lowest materials demand • Hybrid concept proven • Storage capability	• Good mid-term prospects for high conversion efficiencies, operating température potential beyond 1,000°C (565°C proven at 10 MW scale) • Storage at High températures • Hybrid operation possible • Better suited for dry cooling concepts than troughs and Fresnel • Better options to use non-flat sites	• Very high conversion efficiencies – peak solar to electric conversion of about 30% • Modularity • Hybrid operation possible • Operational experience of first prototypes	• Readily available • Flat mirrors can be purchased and bent on site, lower manufacturing costs • Hybrid operation possible • The most land-efficient solar technology, generating 1.5-to-3 times more power per acre of land than competing solar technologies (according to Ausra)
Disadvantages	• The use of oil-based heat transfer media restricts operating temperatures today to 400°C, resulting in only moderate steam qualities.	• Projected annual performance values, investment and operating costs need wider scale proof in commercial operation	• Reliability needs to be improved • Projected cost goals of mass production still need to be achieved	• Récent Maret entrant, only Small projets operating

1.3.2. Domestic solar thermal applications

a) - Solar water heating

The Principe of the system is to heat water, usually in a special collector and store it in a tank until required. Collectors are designed to collect the heat efficiently, usually into a heat transfer fluid, which then transfers its heat to the water in the storage tank. The two main types of collector are: flat plate and evacuated tube.

For example, to heat 100 liters of water through a temperature rise of 40o C with a simple flat plate solar collector requires only approximately 2.5 m2 of collector area but saves approx. 10 kg of wood fuel that would normally be required to heat this quantity of water [1].
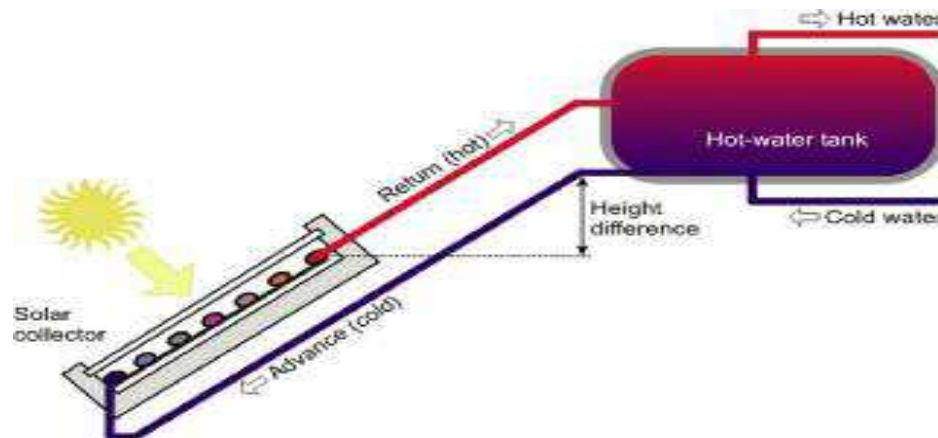
Figure 1.6: Solar water heating system (Technology Fundamentals published in Renewable Energy World 02/2004 pp. 95-99)

b) - Solar drying

Solar drying, timber drying systems are those that use the sun's energy more efficiently than simple open-air drying.

Solar drying, in the open air, has been used for centuries. Drying may be required to preserve agricultural/food products or as a part of the production process.
In general, solar drying is more appropriate when:

- The higher the value per ton of products dried;

- The higher the proportion of the product currently spoiled in the open air;

- The more often the drier will be used.

c) - Solar distillation

Solar distillation is an enhanced distillation process to produce potable water from a saline source. It can be used in areas where, for instance, drinking water is in short supply but brackish water, containing dissolved salts, is available.

In general, solar distillation equipment, or stills, is more economically attractive for smaller outputs. Costs increase significantly with increased output, in comparison to other technologies which have considerable economics of scale.

d) - Solar cooling

Several forms of mature technologies are available today for solar-thermally assisted air-conditioning and cooling applications. In particular, for centralized systems providing

conditioned air and/or chilled water to buildings, all necessary components are commercially available.

The great advantage of this solar application, especially in tropical and equatorial countries, is that the daily cooling load profile follows the solar radiation profile [1].

1.4. Solar projects in Algeria

Algeria has the highest technical and economical potential for solar power exploitation in the MENA region, with about 170 TWh per year. First industrial scale solar thermal power project has been initiated by inauguration of Hassi R'Mel power station in 2011. This new hybrid power plant combines a 25-megawatt (MW) concentrating solar power array in conjunction with a 130 MW combined cycle gas turbine plant.

In addition, Algeria has launched in 2011 a national program to develop renewable energy based on photovoltaic (PV), concentrated solar power (CSP), and to promote energy efficiency.

The program consists of installing up to 12 GW of power generating capacity from renewable sources to meet the domestic electricity demand by 2030[6].

Conclusion

Solar thermal and photovoltaic electricity generation are two promising technologies for climate-compatible power with such enormous potential that, theoretically, could cover much more than just the present worldwide demand for electricity consumption.

Together both thermal and photovoltaic technologies can provide an important contribution to climate protection. Photovoltaic systems have advantages for low-power demand, stand-alone systems and building-integrated grid-connected systems. Solar thermal power plants are best operated in large grid-connected systems. Due to the higher direct solar irradiation in the South. Even if only a small percentage of its potential put to work, solar electricity generation will be an important pillar in the struggle against global warming [5].

South Algeria, technically and economically is a great potential for solar power exploration, with about 170 Twh per year. In the industrial scale is so promising, and by keeping this frequency, it can feed the domestic electricity demand in 2030 [6].

Chapter 02: Information Systems (GIS)

Chapter 02: Geographic Information Systems (GIS)

In order to collect information, we utilize different resources, such as Algerian and world maps, NREL (National Renewable Energy Laboratory), Google Earth, and many other sources, for examples; articles of technology and science. Then, we treat them by ArcGIS software in purpose of preparing the appropriate land information to select locations for new solar projects, such as road identification, urban areas, agricultural areas, mountains and sand dunes.

Google Earth combines the power of Google search and satellite images, maps، terrain and 3D buildings to place geographic information about the studied areas [7].

ArcGIS software allows compiling all the parameters and identifying which areas are available, the different criteria, and alternative values which will be used by MCDA method to reach the final decision.

2.1. The use of Google Earth in this study

Google earth has an important role in our study, represented in these steps:
- ✓ Drawing road and grid lines
- ✓ Identification of urban and agricultural areas, mountains, and sand dunes
- ✓ Caliper and extract underground water map

2.1.1. Determine roads

Google Earth gives the opportunity to find the main roads in the map and by this option; we can define the roads using the "Add Path" option (line or lines),(figure 2.1 and 2.2). Then, we click on the path button at the top of the screen, and use the target box to create the line.

In the properties box, give the line name and description. Adjust the color and thickness of the line in the style and color tab. In the Altitude tab, you can choose how you can lift your line from the ground by adjusting the distance from the ground. In the Measurements tab, Google Earth measures the distance of the line you created in various distance measurements.

Figure 2.1: Adding a path
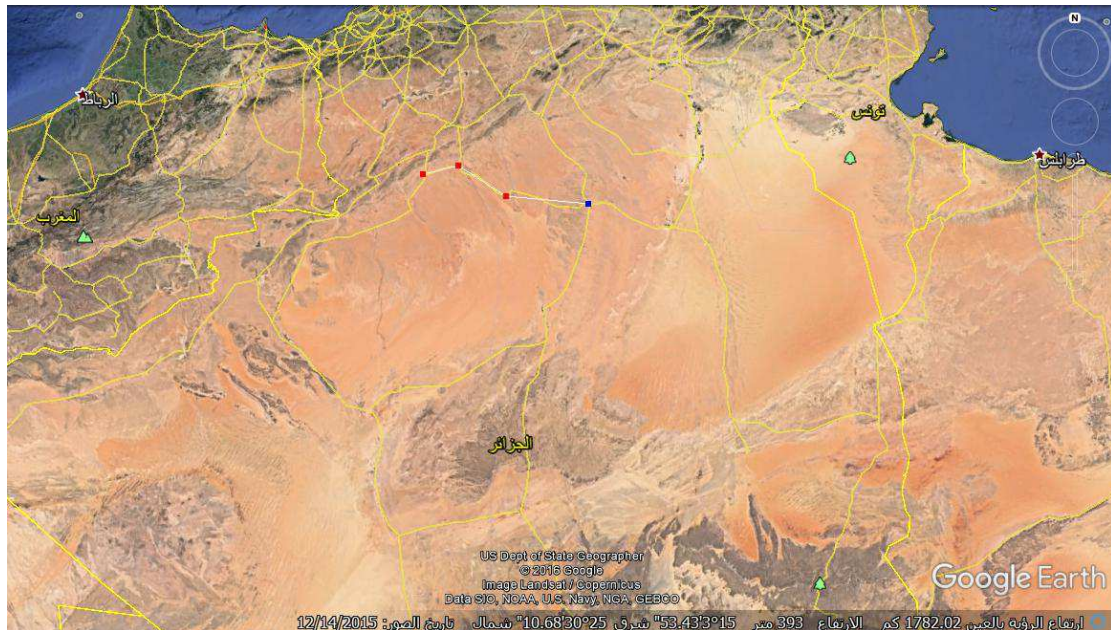
Figure 2.2: Drowning the principal roads of the south of Algeria

2.1.2. Identification of urban and agricultural areas, mountains, and sand dunes

Google Earth has a sufficient accuracy to see all urban, agricultural, sand dune areas, and mountainous. Polygon option allows to identify these areas. With Google Earth, we can also determine the height of dunes and mountains that appears on bottom of Google Earth screen.

To create a polygon, click on the polygon icon above, the properties box will also appear, then click and hold the mouse over the area where you would like to create the polygon and draw your shape. Once you complete the shape, the area fills with a color, and you can adjust the properties of the polygon in the Properties Box (figure 2.4, 2.5 and 2.6).
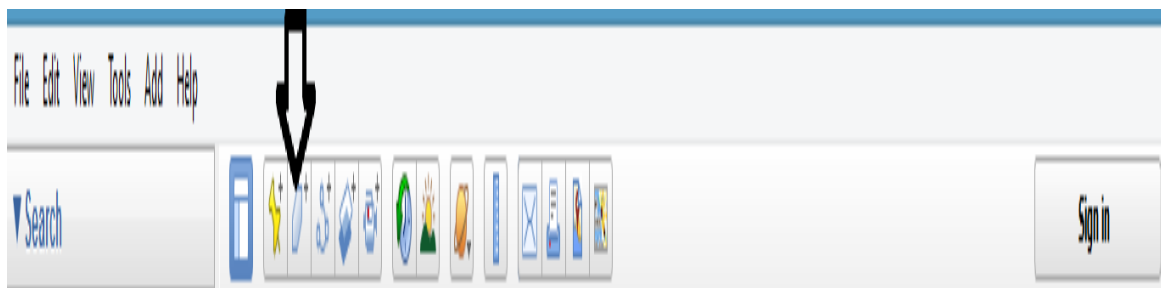
Figure 2.3: Adding a polygon
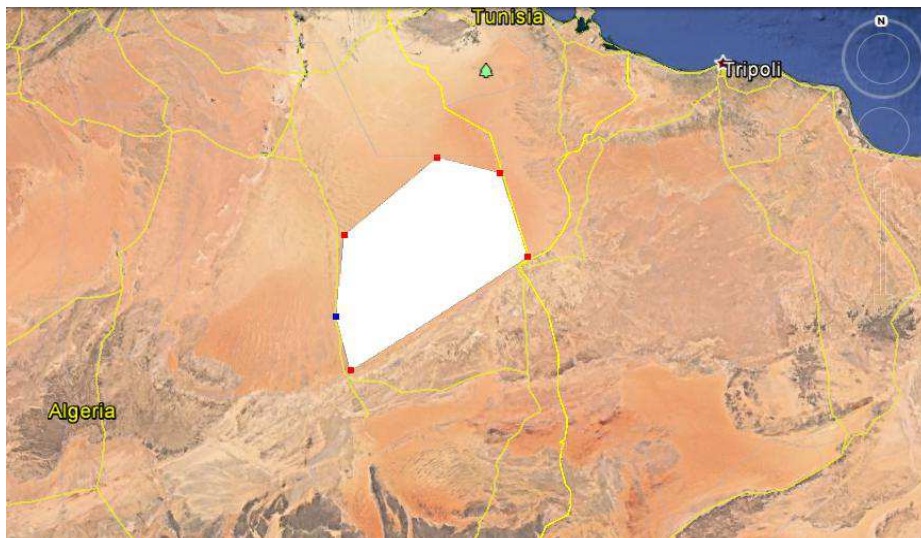
Figure 2.4: Selecting area in Google earth
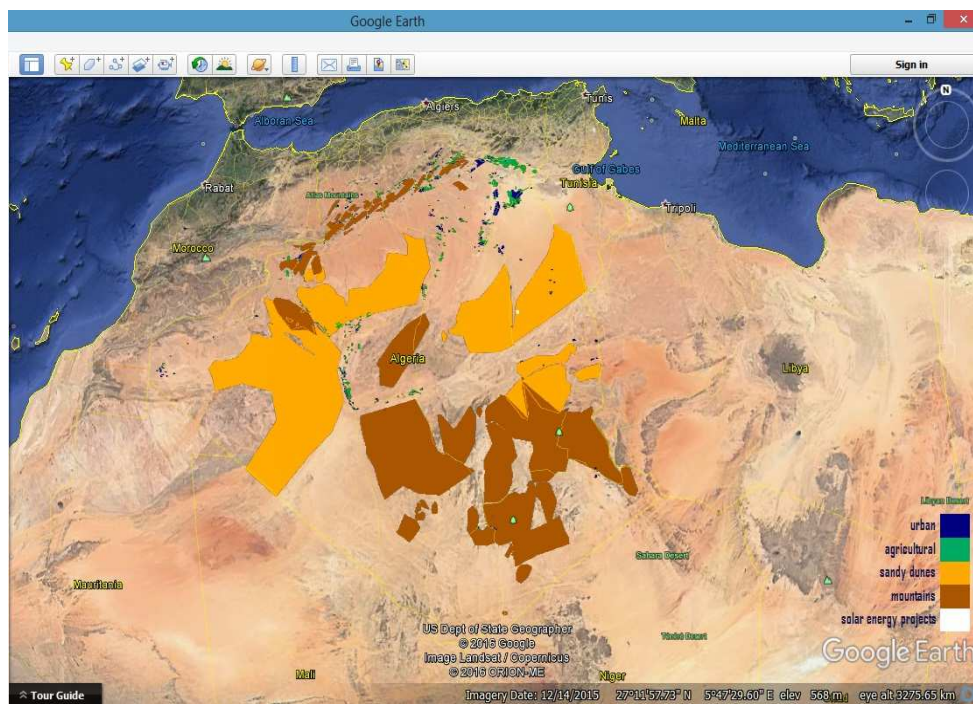
Figure 2.5: Urban, Agricultural, mountain and Sandy area

2.1.3. Identifying underground water

Water is a required substance most solar energy projects, for cooling, steam generation or/and daily use. Due to that, we attempt to identify the reachable aquifer system in Algeria. Figure (2.6, 2.7)
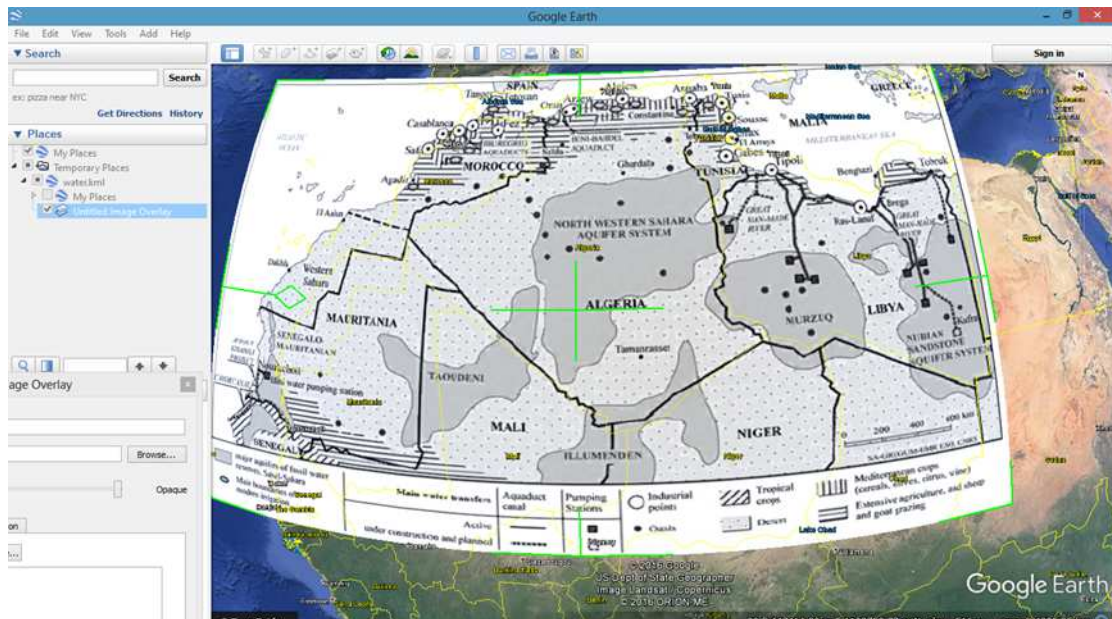
Figure 2.6: Adding image by overlay option
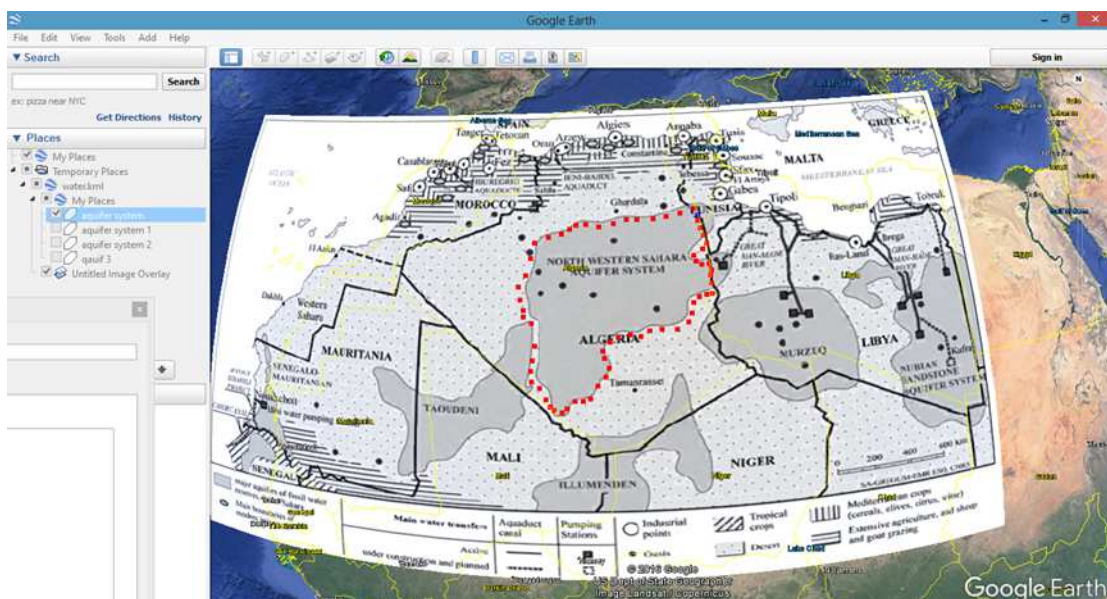
Figure 2.7: Selecting of aquifer system

2.1.4. How to save/share your map or image

You can save your map as an image or as a special Google Earth format (kml or kmz), so anyone can use and edit your work by Google Earth or other software.

a. Saving map image in ".jpeg" format

File > Save > Save Image

You can only save Google Earth images in ".jpeg" format

b. Saving a single place mark (polygon, or line)

File > Save > Save Place As…

Or, you can right-click the placemark (located on the left of the screen) and select Save Place As.

You can save your place mark as a. kmz or. kml (these are special file formats by Google Earth. kmz is recommended for saving single place marks). When you open a. kmz file, the file will instantly open in Google Earth in the exact angle that you saved your place mark location. You can also edit your kmz file and re-save it.

c. Save an entire layer

Right-click the name of the layer folder and select Save Place As.

You can save it as either a. kmz or. kml (.kml is recommended). When you open a. kml file, the file will instantly open in Google Earth. You will see all of your saved place marks. To expand the folder, click on the little "+" next to your file name under "Places" and you will see each individual place mark for your layer. You can also edit your layers and re-save them [7].

2.2. The use of ArcGIS in this study

Those are the principal steps to be followed using ArcGIS in this work:

- ✓ Import a data file and convert it to the format supported by ArcGIS
- ✓ Final dividing and selection of the available areas
- ✓ Evaluate the distance between the roads and the available areas
- ✓ Determination of solar radiation in all regions
- ✓ Determine the wind speed fields
- ✓ Determine electric grid

2.2.1. Import data file and convert it to the format supported in ArcGIS

a. Urban and agricultural areas, mountains, and sand dunes as polygons

Converting data to ArcGIS format is the key step for any new projects. Firstly, we import ".kml" files to ArcGIS using the "Quick import" option. Then, ArcGIS will be executed and translate the file to ". gdb" format.

After that, we add this processed file using "add data" option to be modelled as placemark Polygon in. Lyr format.

These instructions are applicable for agricultural, mountainous, sand dunes, etc. figure (2.8, 2.9, 2.10)
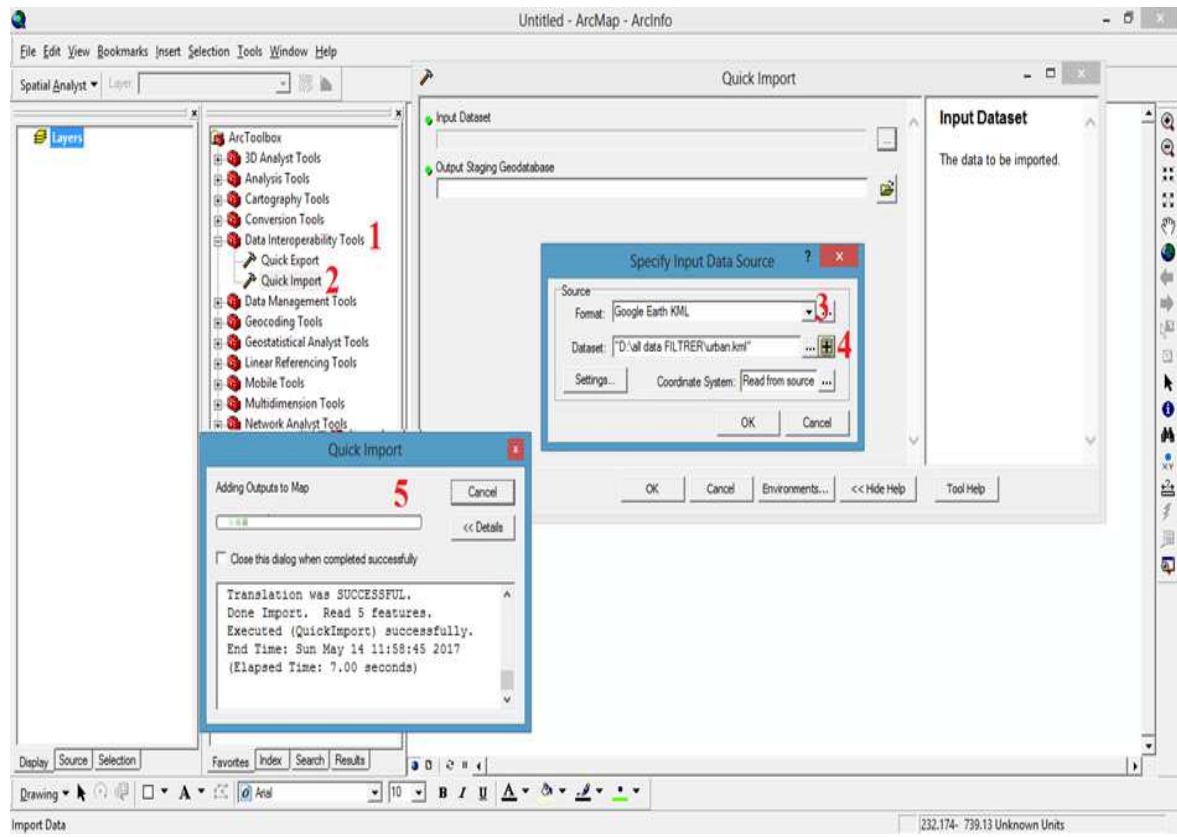
Figure 2.8: Quick import option
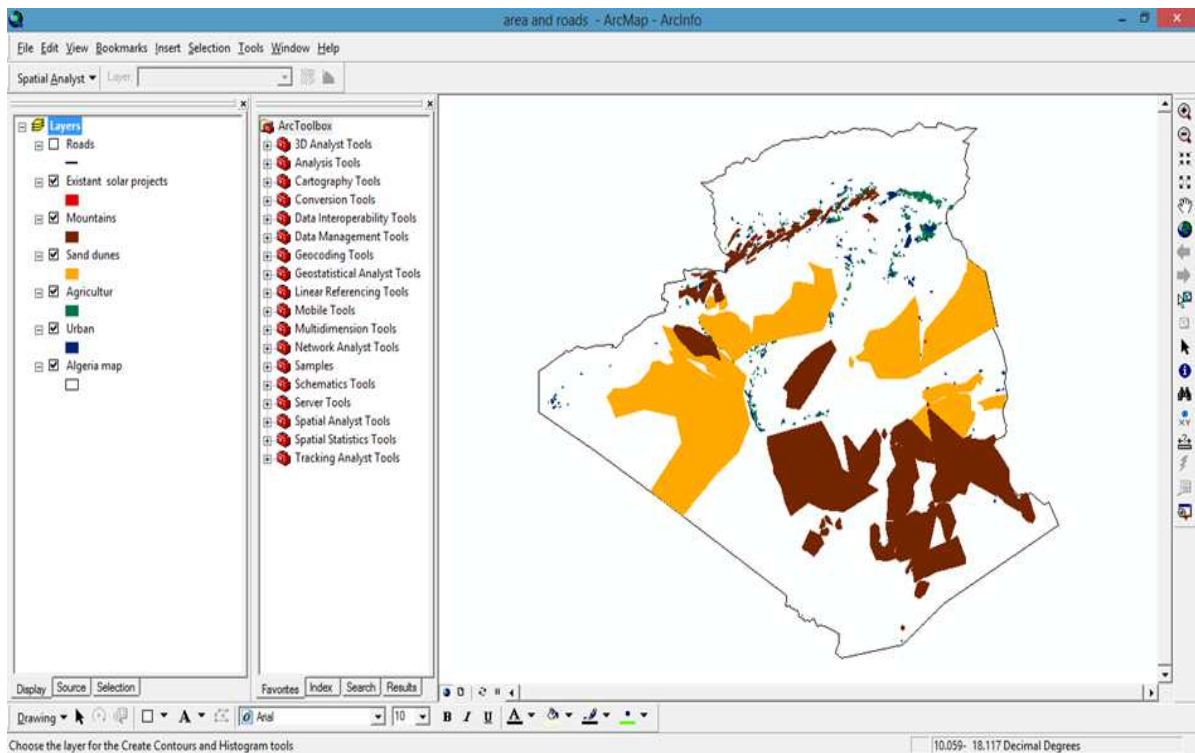
Figure 2.9: Adding different areas (polygons)
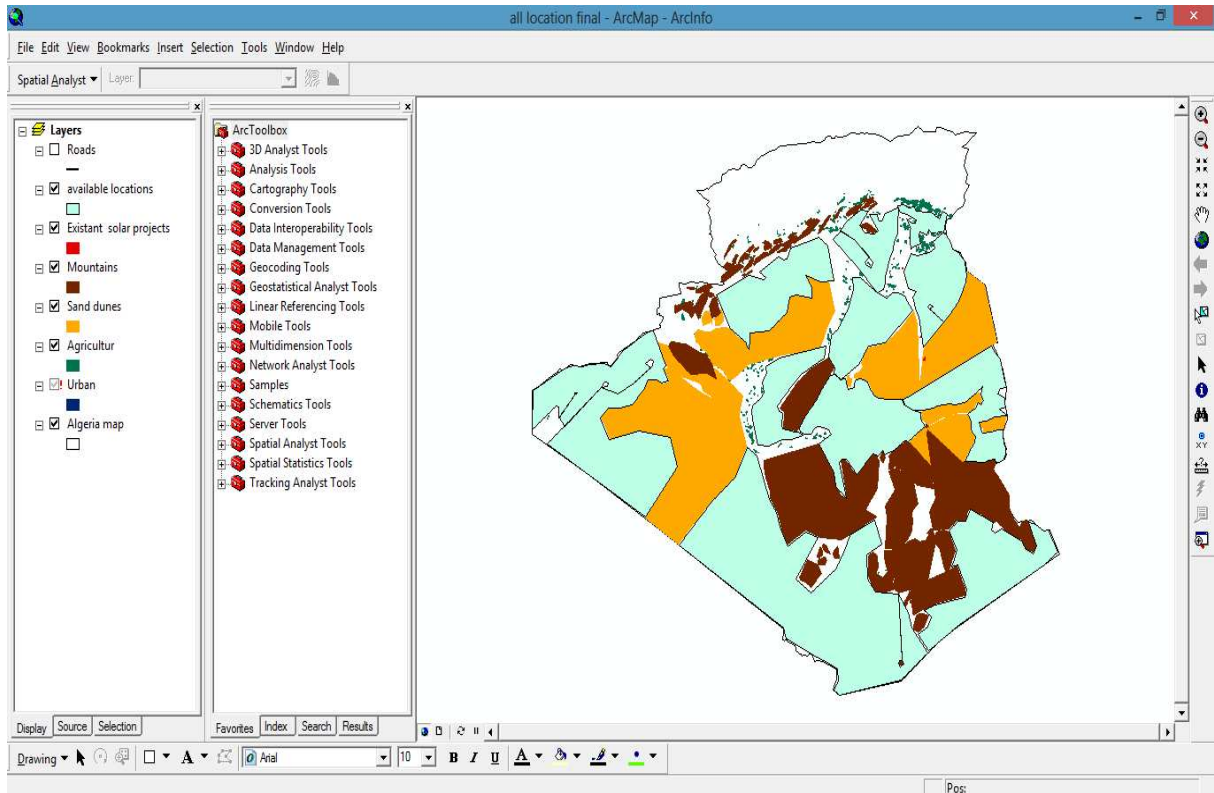
Figure 2.10: Available area
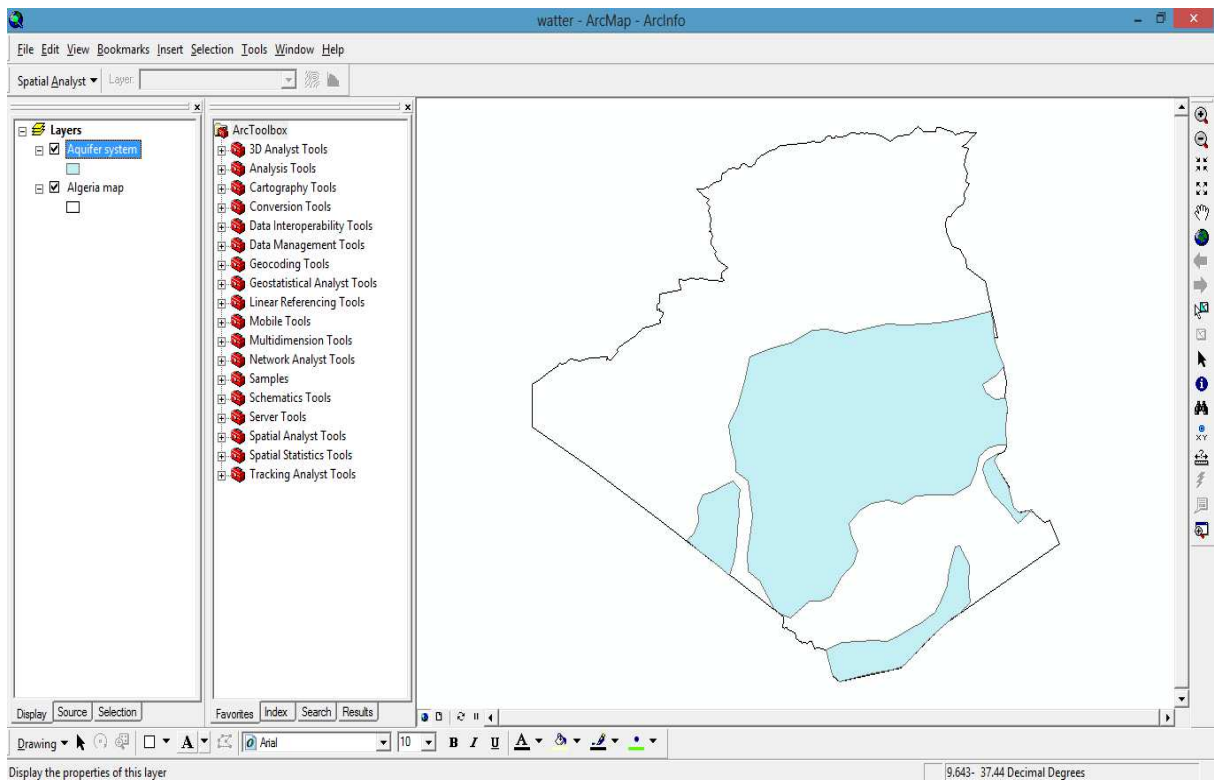
Figure 2.11: Aquifer system

b. Road as a polyline

All "KML" data have the same method of importing and converting, but Road data will be modeled as placemark line in "lyr" format.

After that, we add this processed file using "**add data**" option to be modelled as placemark line in. **Lyr** format. Figure (2.13)
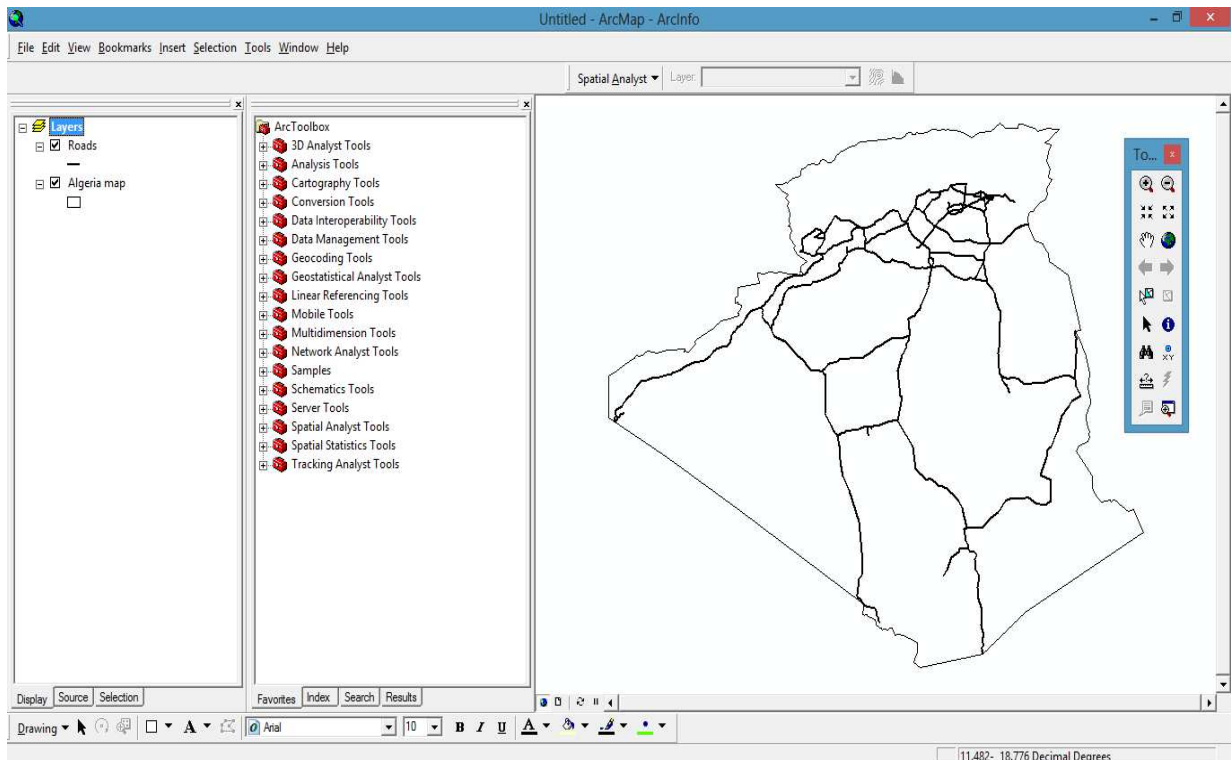
Figure 2.12: Roads map in ArcGIS

2.2.2. Study of distance between roads and other regions

In this step, we add the polygon from **".gdb"** file of Algeria map, and we make a projection of the roads on it. The spatial analyst option allows to model and evaluate the distance between the roads and other areas. figure (2.14)
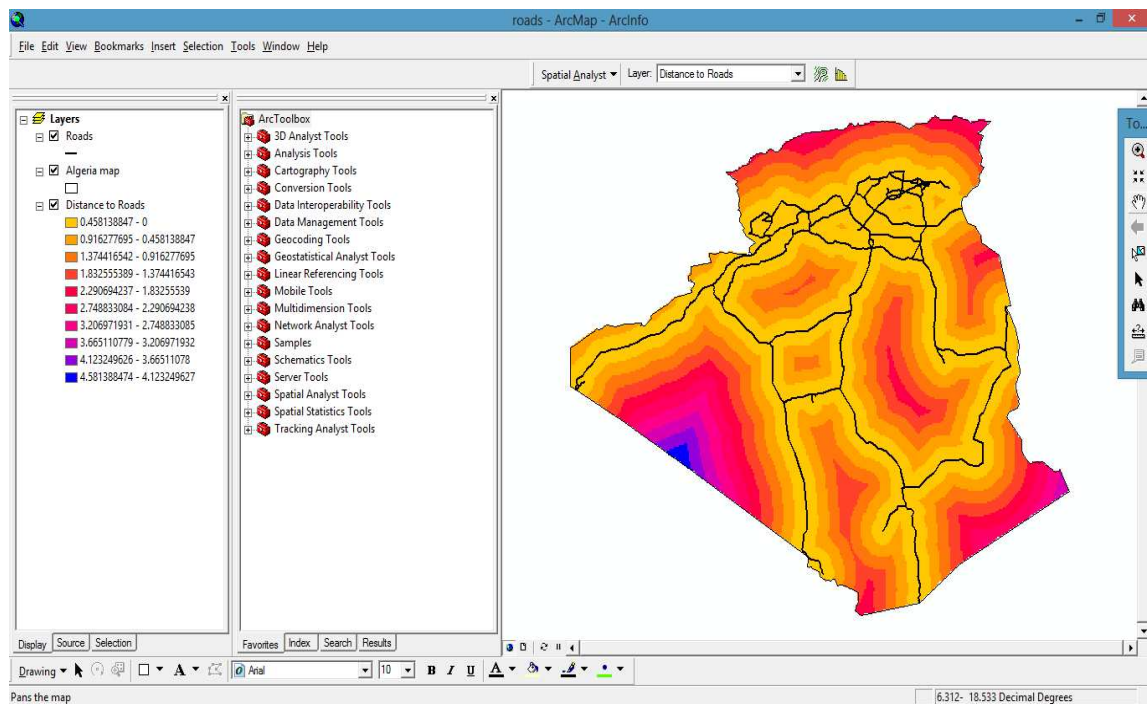
Figure 2.13: Straight distance analyst for roads

2.2.3. Grid (electric network)

SONELGAZ's electrical system consists of a north network extending from east to west for 1300 km and a South network which is partially connected to the North network. Using google earth and electrical grid map, we retraced the 220 kV electric lines by "path" option. Figure (2.15)
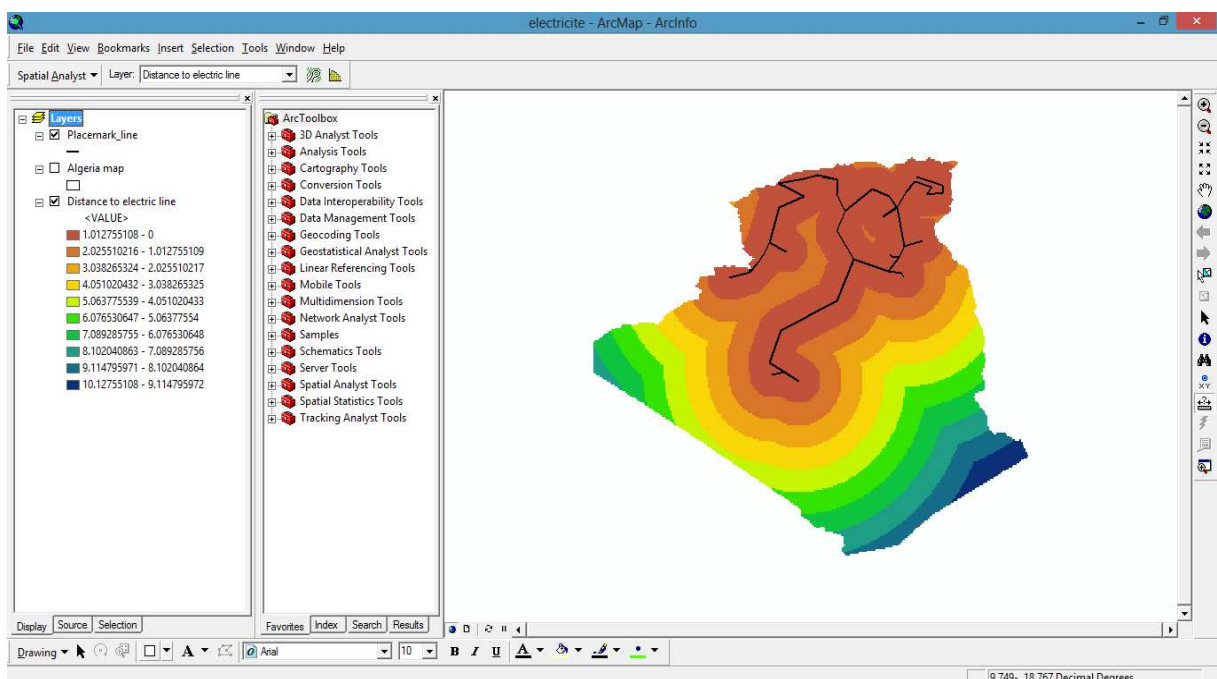
Figure 2.14: Straight distance analyst for grid

2.2.4. Determination of solar irradiation

We have Used NREL solar map to collected the solar irradiation data of the world, after that we added them to ArcGIS.

By the conversion tools option, we convert these data to be modeled as map. The extraction by mask option help us to extract just the needed data for our selection (the map of Algeria). Figure (2.16, 2.17, 2.18)
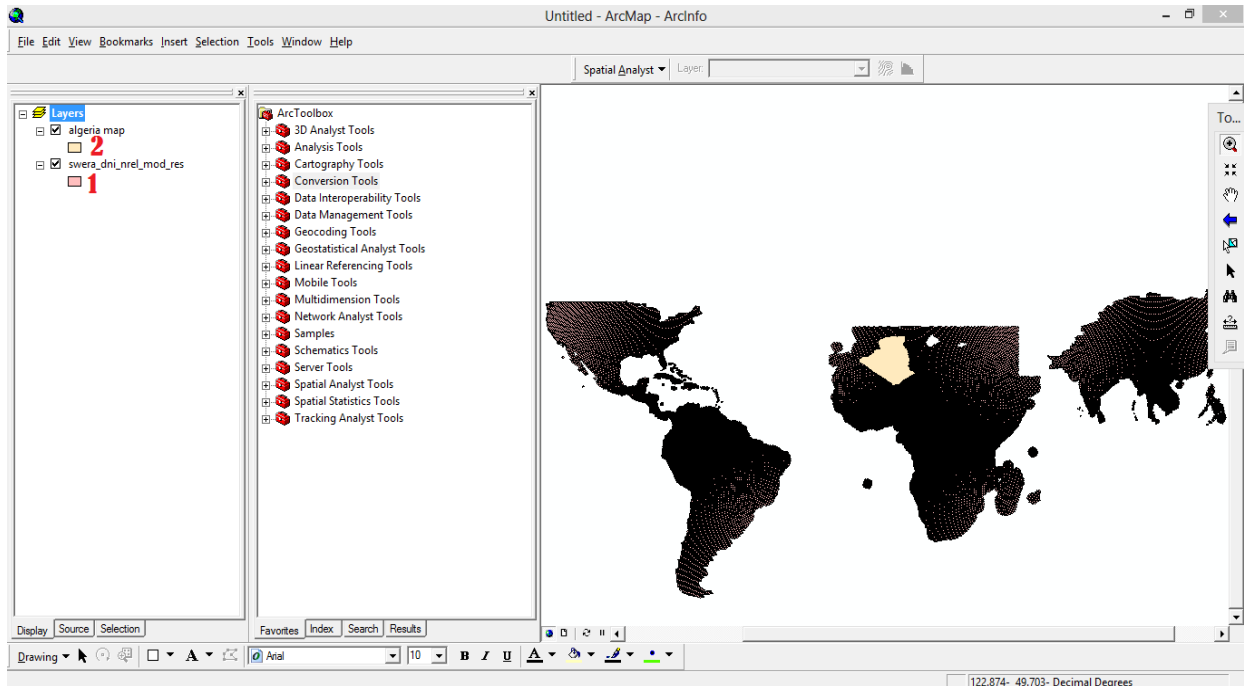
Figure 2.15: Adding data of solar irradiation
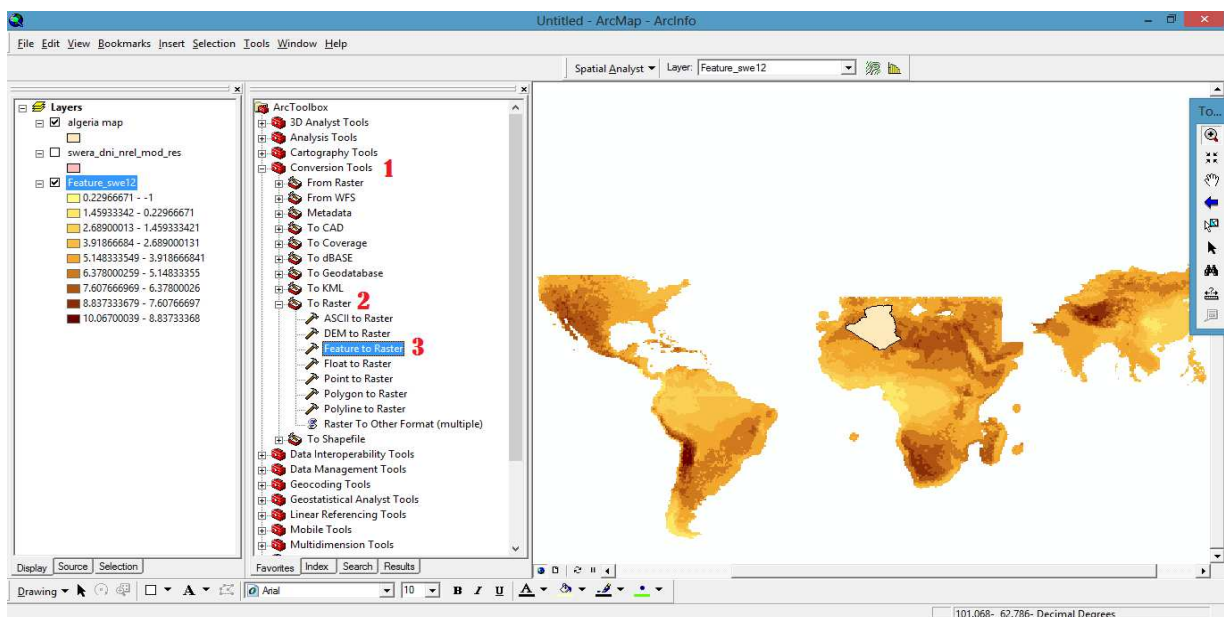
Figure 2.16: Conversion from feature to raster
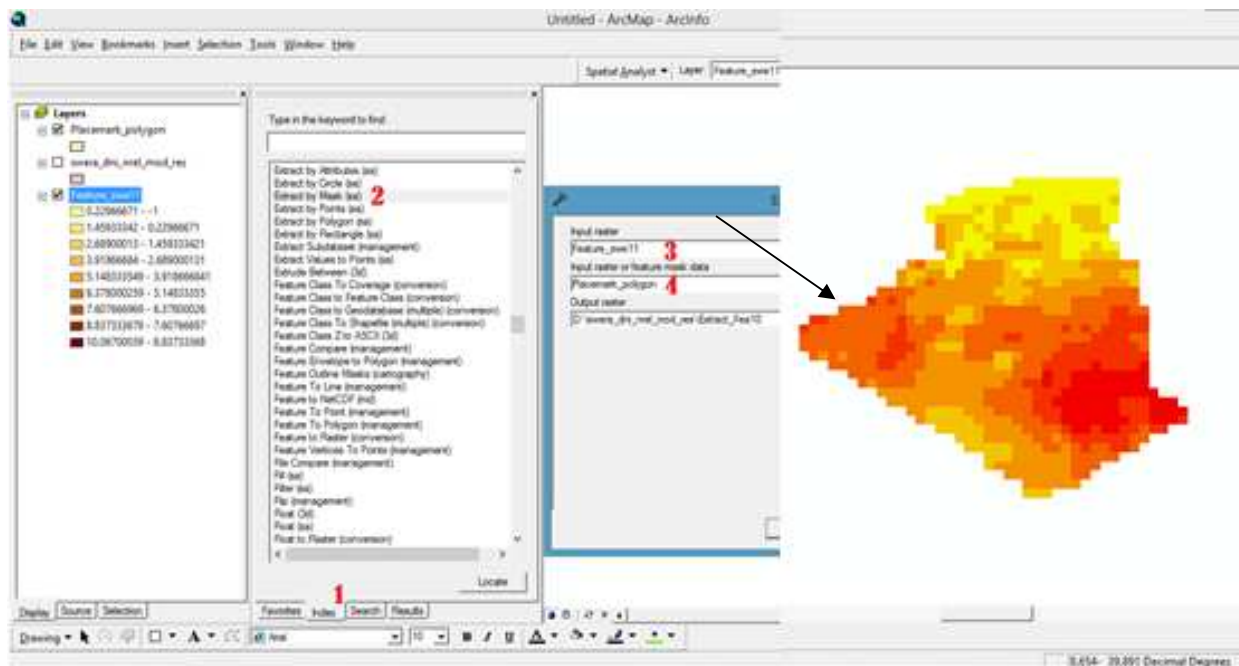
Figure 2.17: Extracting mask (defined area)

2.2.5. Determine the wind data

To create the wind map, we utilize a file with **XY** position of several weather stations and airports, and average wind speed.

We import the excel file to ArcGIS, then it will interpolate the surface from the imported points (**XY**). Table (2.1), figure (2.19, 2.20, 2.21)

Table 2.1: Annual wind speed for different stations

Station	Longitude	Latitude	Annual Speed m/s
Adrar	-0.2	27.8	6.3
Ain Sefra	-0.6	32.8	4.7
Algiers	3.1	36.8	1.9
Annaba	7.8	36.8	2.3
Batna	6.3	35.2	3
Bechar	-2.3	31.7	3.7
Bejaia	5.1	36.7	3
Biskra	5.7	34.8	4.2
Bou-saada	4.2	35.3	4.2
Chlef	1.3	36.2	2.9
Constantine	6.6	36.3	2.7
Djanet	9.5	24.3	3.5
Djelfa	3.2	34.7	4.3
El-Golea	2.9	30.6	3.6
Eloued	6.8	33.5	3.2
Chardaia	3.8	32.4	3.4
Chelma	7.7	36.5	2.3
Griss	0.2	35.2	2.1

H Messaoud	6.2	31.7	3.7
H R'mel	3.3	32.9	6.1
Illizi	8.4	26.5	4.1
Inamenass	9.864	28.023	4.7
InSalah	2.5	27.2	5.1
Jijel	5.9	36.8	2.5
Laghouat	2.9	33.8	3.3
Oran	-0.6	35.6	2.7
Ouragla	5.4	31.9	3.8
Setif	5.3	36.2	3.4
Tamanrasset	5.4	22.8	3
Tebessa	8.1	35.4	2.8
Tiaret	1.5	35.3	3.3
Timimoun	0.3	29.2	5
Tindouf	-8.64	27.92	5.7
Tlemcen	-1.5	35	2.5
Touggourt	6.1	33.1	3.4
Teoric point	3.69	19.08	3.8
Teoric point	0.73	21.72	3.8
Teoric point	-1.48	25.2	5
Teoric point	-6.75	27.3	3.7
Teoric point	11.831	23.695	3.6
Teoric point	10.205	22.94	3.5
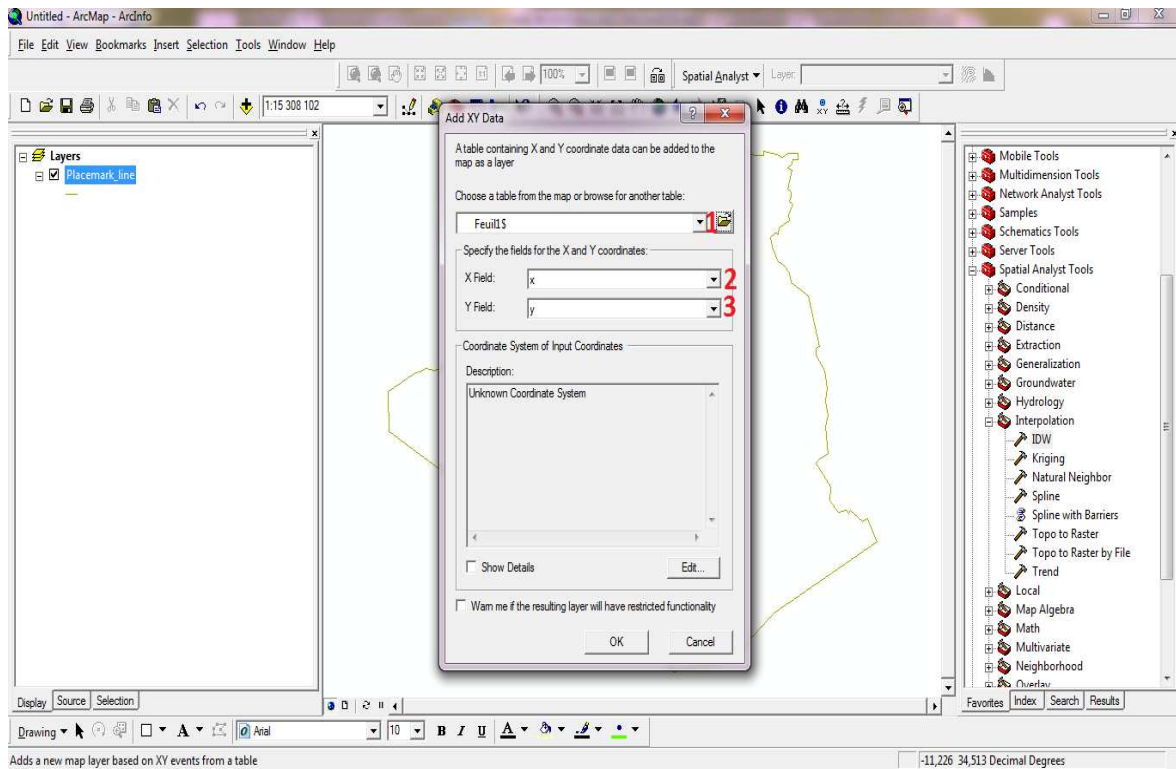
Figure 2.18: Adding XY data file
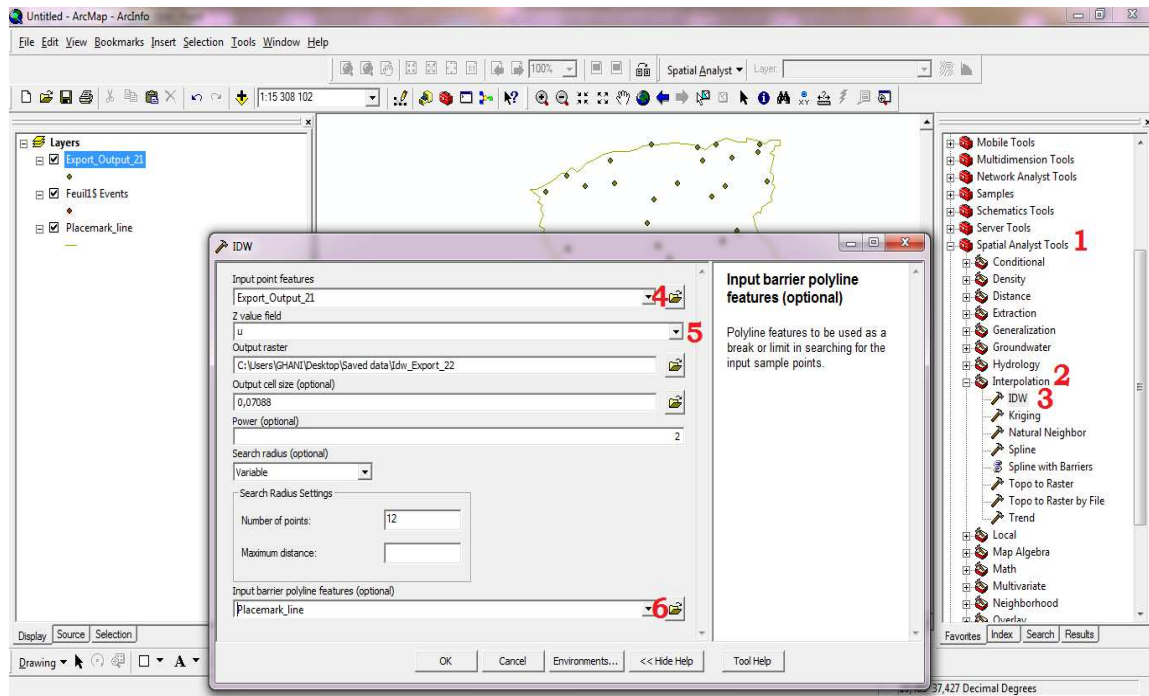
Figure 2.19: Interpolation by IDW (Inverse Distance Weight)
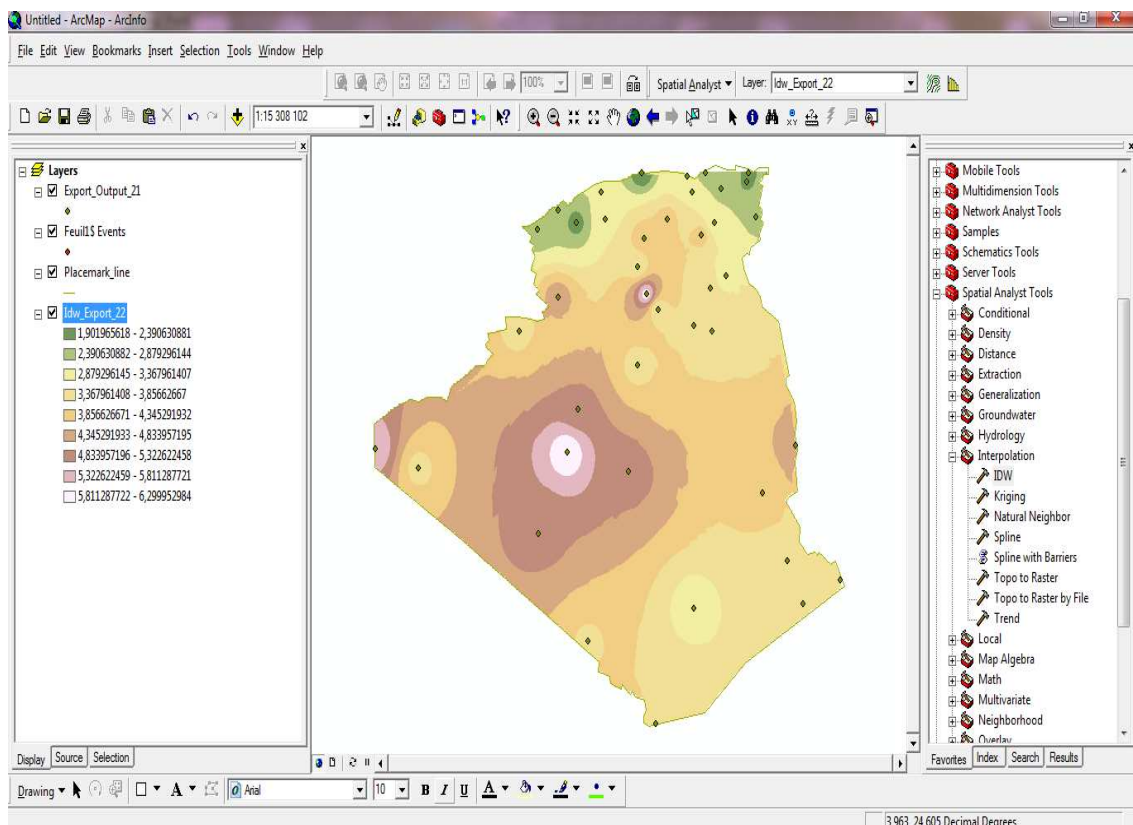
Figure 2.20: Annual wind speed map

Conclusion

ArcGIS and Google Earth are flexible and powerful softwares to manipulate and create maps, import and export data in different formats, also, they have many different options to work in collaboration in purpose of making the user's work easier.

After gathering the desired ArcGIS and google Earth data, we finished by selecting 11 appropriate areas that have the most needed factors.

These areas considered as candidates to select and rank by applying MCDA method in the next chapters.
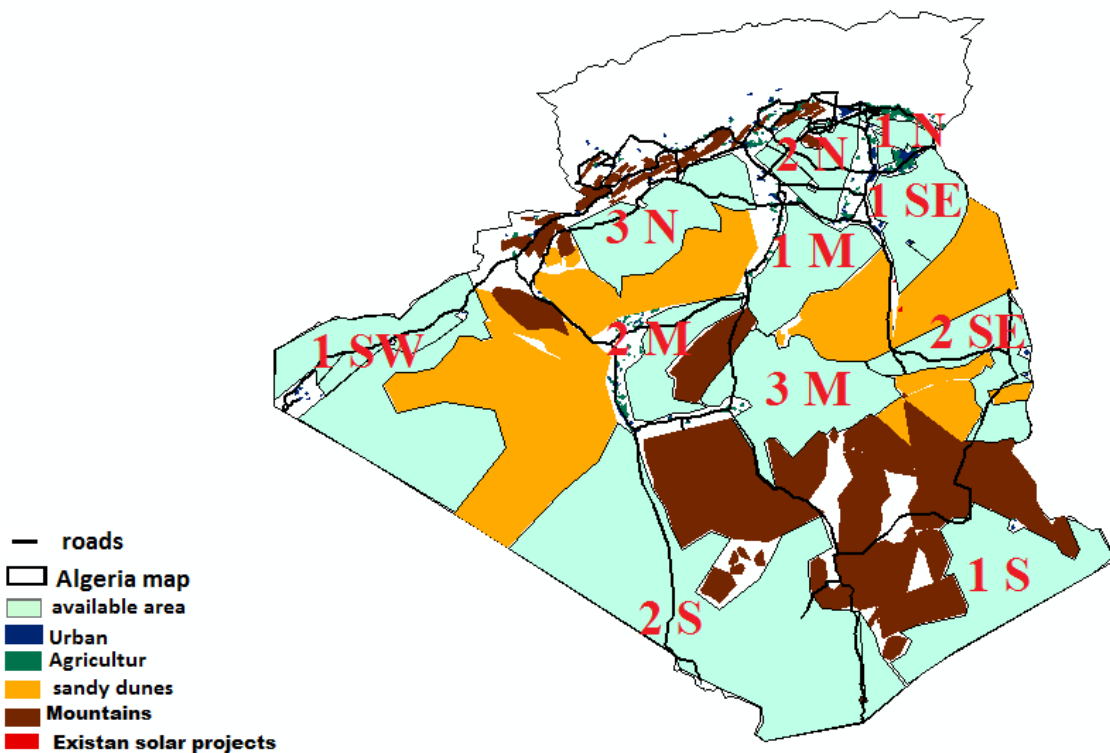
Figure 2.21: Available areas

Chapter 03: Multi-Criteria Decision Analysis (MCDA)Methods

Chapter 3: Multi-Criteria Decision Analysis (MCDA) Methods

In the previous chapter, we identified the available areas, which represent the different alternatives, to which we can apply one of the theories of multi criteria decision analysis. In this chapter, we will determine the suitable location or region for the establishment of new solar energy project by the application of MCDA method.

A number of approaches for defining decision problems have been suggested in the MCDA literature (e.g., Keeney 1992; Chankong and Haimes 1983, Wong 2009, WCED.2009, Hofman K, 2009). At the most rudimentary level, a multicriteria decision problem involves a set of alternatives that are evaluated on the basis of conflicting and incommensurate criteria according to the decision maker's preferences. There are three key terms in this definition that are the main elements of any multicriteria decision problem: decision maker(s), alternatives, and criteria (Zarghami and Szidarovszky 2011). The procedures for tackling spatial multicriteria problems involve three main concepts: value scaling (or standardization), criterion weighting, and combination (decision) rule (Eastman et al. 1993; Thill 1999; Malczewski 1999, 2006; Greene et al. 2011). These are fundamental concepts for MCDA in general and GIS-MCDA in particular. They can be considered as the building blocks of spatial decision support procedures [8].
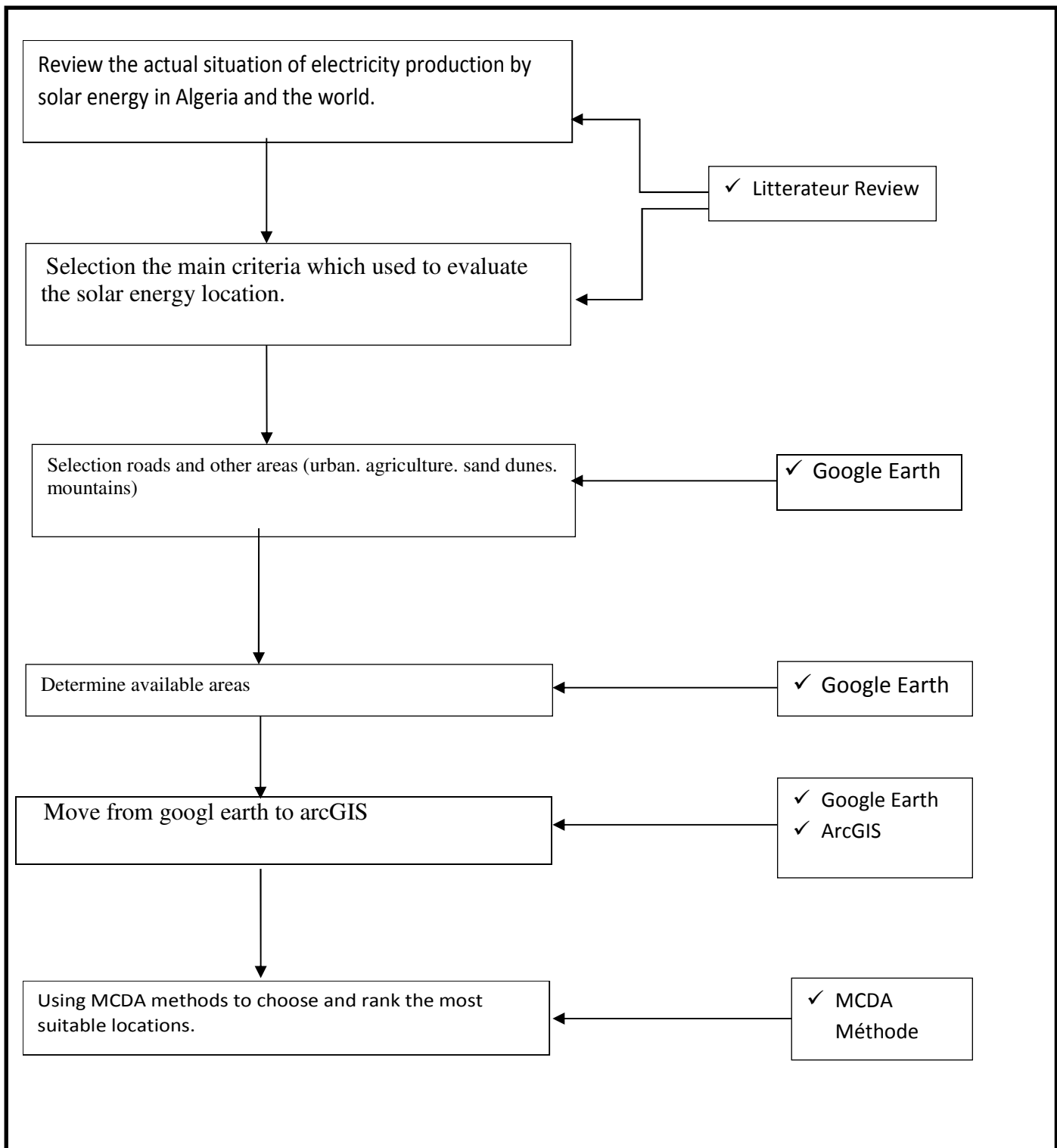
Figure 3.1: Summary of research steps and methodology

3.1 Criteria selection

Evaluation criteria and methods that could measure sustainability is a prerequisite for selecting the best alternative (or solution). The development and selection of criteria require parameters related to the reliability, appropriateness, practicality and limitations of measurement. The used criteria to evaluate the energy supply systems in the literatures mainly divide to four aspects: technical, economic, environmental and social criteria [9].

3.1.1 Technical criteria

a) - Efficiency

Efficiency refers to how much useful energy we can get from an energy source. The efficiency coefficient is the ratio of the output energy to the input energy, which is used to evaluate energy systems.

b) – Safety

Continuous changes in technology, environmental regulation and public safety concerns make the analysis of complex safety-critical of energy systems more and more demanding.

The basic safety is of workers on the site of energy project and it must be guaranteed first. (wang et al 2009) [10].

3.1.2 Economic criteria

a) - Investment cost

Investment cost comprises of all costs relating to: the purchase of mechanical equipment, technological installations, construction of roads and connections to the national grid, engineering services, drilling and other incidental construction work.

b) - Operation and maintenance cost

Operation and maintenance costs consist of two parts. One is the operation cost that includes employees' wages, and the funds spent for the energy, the products and services for the energy system operation. Another is the maintenance cost that aims to prolong energy system life and avoid failures that may lead to its operation suspension [10].

3.1.3 Environmental criteria

a) - CO2 emission

CO2 is mainly released through the combustion of coal/lignite, oil and natural gas in energy systems. Different energy systems have different CO2 emissions; it leads to the global warming, which is focused by many governments, academies, and researchers. Naturally, CO2 emission of energy system is certainly a criterion to evaluate its sustainability (Wang et al, 2009).

b) -Land use

It represents one of the most critical factors for the intervention site, especially where the human activities are relevant factors of environmental pressure (Beccali M, 2003). Land use can be a social criterion to evaluate the energy system cause the environment and landscape are directly affected by the land occupied with energy systems [10].

3.1.4 Social criteria

Social aspects were definitely the most important criteria for people's acceptance of energy systems during the past decades.

a) - Social acceptability

Social acceptability expresses the overview of opinions related to the energy systems by the local population regarding the hypothesized realization of the projects under review from the consumer point of view.

b) - Job creation

Energy supply systems employ many people during their life cycle, from construction and operation till decommissioning. The energy systems are closely related to the society Local societies where energy systems were established based their development and prosperity on them for many decades [10].

3.1.5 The selected criteria in this study

After listing the most energy evaluation criteria that were utilised by previous studies, we selected the following criteria that:

    a. **Roads:** The proximity or distance of the road is an important criterion in the process of reporting or determining the appropriate place to set up the solar energy project,

which facilitates the transport factor that allows the easiest access to the plant during installation and operating phases.

b. **Solar irradiation:** The rise in solar radiation values and the reduction in other sub-regions is a key criterion in determining the suitable area for the establishment of solar energy project because it is the only source of energy in such projects.

c. **Grid (electricity network):** The construction of a solar project somewhere is better to be close to the electrical grid and therefore the proximity distance from the electrical grid is an important criterion for determining the appropriate place for the project.

d. **Wind speed:** Wind criterion is a negative factor (mainly when combined with sand) in such cases of decisions; the wind reduces the percentage of likelihood in determining such place suitability for the solar energy project.

e. **Area surface:** Solar projects vary in size depending on the energy produced. Therefore, the space factor has a role important role in sizing solar energy project and perhaps extending these projects in the future.

f. **Underground water:** Water is a required substance most solar energy projects, for cooling, steam generation or / and daily use. This is why we can consider water as one of the criteria in this study.

3.2. Weighting methods

All factors have their internal impact reclassified to a common scale so that it is necessary to determine each criterion's relative impact in the sustainable energy DM problem. Weight is assigned to the criteria to indicate its relative importance. Different weights influence directly the DM results of energy systems' alternatives. Consequently, it is necessary to obtain the rationality and veracity of criteria weights. Three factors are usually considered to obtain the weights: the variance degree of criteria, the independency of criteria, and the subjective preference of the decision-makers. Generally, there are two methods: the equal weights and the rank-order weights [11].

A. Equal weights method

The criteria weight in equal weights method is defined as

$$w_i = 1/n; \quad i = 1; 2; \ldots ; n \tag{3.1}$$

The method requires minimal knowledge of the decision maker's priorities and minimal input from decision maker. The equal weights method was popularized and applied in many decision-making problems since Dawes and Corrigan argued that this method often produced

the results nearly as good as those optimal weighting methods in 1974. Equal weights method is the most popular in sustainable energy DM (Wang et al, 2009) [11].

3.2.1. Subjective weighting methods

Subjective weighting methods such as pair-wise comparison (Mamlook R, Wang J-J, 2008). AHP and Simos, were the most used methods in sustainable energy DM. Especially, priority given to one indicator with others being the same was employed to protrude the performances in one aspect in literatures (Pilavachi PA, 2009). The following part introduces briefly several representative subjective weighting methods.

a) Simple multi-attribut rating technique (SMART)

SMART was originally described as the whole process of rating alternatives and weighting criteria by Edwards in 1977. The participants are asked to rank the importance of the changes in the criteria from the worst criteria levels to the best levels. Then they assign 10 points to the least important criteria, and increasing number of points (without explicit upper limit) are assigned to the other criteria to address their importance relative to the least important criteria. The weights are calculated by normalizing the sum of the points to one. Edwards and Barron listed the shortcomings, stressed that weights should clearly be related to the criteria ranges in 1994 (Edwards W, 1994) and presented an improved version, SMARTER. The idea of SMARTER is to use the centroid method so that the weight of a criteria ranked to be it his

$$W_i = \frac{1}{n} \sum_{k=i}^{n} \frac{1}{k}$$
(3.2)

b) SWING

With the SWING weighting method (Jia JM, 1998), the decision maker begins by rank ordering criteria in terms of their associated value ranges. First the respondent is asked to select the criteria that he would most prefer to change from its worst to its best level and to assign 100 points to these most important criteria. Then the respondent is continued to choose the criteria change from the worst to the best level which he considers to be the second most desirable improvement and to assign points less than 100 to that criteria change. Proceeding in this fashion, the decision maker ranks all criteria and assigns relative importance points to their value ranges. Finally, the given points are normalized to sum up to one to get the criteria weights. The SWING method is an algebraic, decomposed, direct procedure.

c) Pair-wise comparison

In the pair-wise comparison method, participants are presented a worksheet and are asked to compare the importance of two criteria at a time: ''which one of these two criteria is more important, and how much more important?'' Then the relative importance is scored.

The scales can be various, for example, a scale of 0 (equal importance) to 3 (absolutely more important) is commonly adopted. The results are consolidated by adding up the scores obtained by each criterion when preferred to the criteria it is compared with. The results are then normalized to a total of 1.0. This weighting method provides a framework for comparing each criterion against all others, and helps to show the difference in importance between criteria. However, it does not allow you to check the consistency of participants' preferences, especially, their transitivity. You should therefore examine the results' matrices for each participant to check for major problems [11].

3.2.2. Objective weighting methods

The objective weighting method elicits the criteria weights using the measurement data and information and reflects the difference degree. The literatures about objective weighting methods applied in sustainable energy DM are seldom in the reviewed published papers while the objective weighting methods were widely applied to other evaluation systems, such as social and ecological systems. Only entropy method was employed to elicit the weights (Wang J-J, 2008) in energy projects. The typical objective weighting methods are presented as follows.

a. Entropy method

The entropy shows that how much the criteria reflects the information of system and how great the uncertainty of criteria is. A vector of $x_j = (x_{1j}; x_{2j}; \dots \dots; x_{mj})$ characterizes the set X in terms of the i-th criteria, defined as follows:

$$X_j = \sum_{i=1}^{m} x_{ij}, \quad j = 1,2,\dots\dots, \tag{3.3}$$

Then the entropy measure of j-th criteria contrast intensity is:

$$e_j = \frac{1}{\ln m} \sum_{i=1}^{m} \frac{d_{ij}}{D_j} \, \ln \frac{d_{ij}}{D_j} \tag{3.4}$$

Finally, the normalized weights can be calculated as:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{m}(1-e_j)} \tag{3.5}$$

b. Technique for order preference by similarity to ideal solution (TOPSIS) method

The principle of TOPSIS (Hwang CL, 1981) is that the selected best alternative should have the shortest distance from the positive ideal solution in geometrical sense. The weighted distance between alternative Ai and the ideal solution A* is defined as follows:

$$(3.6) \quad h_i = \sum_{j=1}^{n} w_j^2 \left(x_{ij} - x_j^*\right)^2$$

Then the following optimal model is solved and the weights can be elicited [11].

$$\left. \begin{array}{l} \text{Min } \sum_{i=1}^{m} h_i = \sum_{i=1}^{m} \sum_{j=1}^{n} w_j^2 \left(x_{ij} - x_j^*\right)^2 \\ \\ \text{s.t. } \sum_{j=1}^{n} w_j = 1, w_j \geq 0 \end{array} \right\} \qquad (3.7)$$

3.2.3. Combination weighting methods

Combination weighting methods were gradually applied to the evaluation and comparison of complex systems, including energy projects. The methods have two basic combinations: multiplication synthesis and additive synthesis. The principle of multiplication synthesis is expressed as

$$w_j = \frac{w_{1j} \, w_{2j}}{\sum_{j=1}^{m} w_{1j} \, w_{2j}} \qquad (3.8)$$

Where w_{1j}, w_{2j} and w_j are subjective weight, objective weight and combination weight of the jth criteria respectively. While the additive synthesis is written as

$$w_j = k \, w_{1j} + (1 - k) \, w_{2j} \qquad (3.9)$$

Where; k is the linear combination coefficient and k ≥0. The combination coefficient can be determined by various methods, such as optimization based on sum of squares, minimum bias and relational coefficient of gradation. For example, the linear combination coefficient was solved in Jaynes maximal entropy theory and the optimization method and the criteria weights were obtained to be used to select the best CCHP scheme from alternatives (Wang J-J, 2008) [9].

3.3.   Multi-criteria decision analysis methods

It is the turn to determine the preference orders of alternative after determining the criteria weights so that MCAD methods are employed to get the ranking order. In the referred literatures, the comparisons of renewable energy plants and the DM of energy policy. Also, summaries all related MCDA methods that are divided into three categories: elementary

methods, methods in unique synthesizing criteria and outranking methods. An overview of several typical MCDA methods in energy systems is provided here.

3.3.1. Elementary methods

The former three methods are defined as non-preference information methods without decision maker, and other methods are multi attribute information methods with decision maker. Conjunctive and disjunctive methods belong to screening methods that the acceptable alternative must exceed given performance thresholds for all criteria. Lexicographic, elimination by aspects and linear assignment method are ordinal partiality methods. The latter two methods need the criteria preference of decision maker.

A. Weighted sum method (WSM)

WSM is the most commonly used approach in sustainable energy systems (Renn O.2003) the score of an alternative is calculated as:

$$\text{Si} \sum_{j=1}^{n} w_j x_{ij}, \quad i = 1,2,\ldots\ldots, m \tag{3.10}$$

Then the resulting cardinal scores for each alternative can be used to rank, screen, or choose an alternative. The best alternative is the one whose score is the maximum.

B. Weighted product method (WPM)

The WPM is similar to WSM. The main difference is that instead of addition in the calculation there is multiplication. The score of alternative i can be calculated as:

$$si = \prod_{j=1}^{n} x_{ij}{}^{w_j}, \quad i = 1,2,\ldots\ldots, m \tag{3.11}$$

Naturally, the alternative having the maximum score is the best scheme. Because of the exponent property, this method requires all ratings be greater than 1. For example, when a criteria has fractional ratings, all ratings in that criteria are multiplied by 10m to meet this requirement. Alternative scores obtained by the weighted product method do not have a numerical upper bound. The decision maker may also not find any true meaning in those scores. Hence, it may be convenient to compare each alternative score with the standard score. If an alternative is compared to the ideal alternative for the only comparison purpose, the ratio is given by:

$$Ri = \frac{s_i}{s_*} = \frac{\prod_{j=1}^{n} x_{ij}{}^{w_j}}{\prod_{j=1}^{n} (x_j^*)^{w_j}}, \quad i = 1,2,\ldots\ldots, m \tag{3.12}$$

Where x_j^* is the most favourable performance for criteria j. It is found clearly that the preference of alternative i increase when Reproaches to 1[10].

3.3.2. Unique synthesizing criteria methods

o **The Analytic Hierarchy Process Method (AHP)**

The Analytic Hierarchy Process (AHP) is an effective tool for dealing with complex decision-making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision-making process [12]. The AHP – Step by Step the AHP provides a means of decomposing the problem into a hierarchy of sub problems which can more easily be comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values and processed to rank each alternative on a numerical scale. The methodology of the AHP can be explained in following steps: Step 1: The problem is decomposed into a hierarchy of goal, criteria, sub-criteria and alternatives. This is the most creative and important part of decision-making. Structuring the decision problem as a hierarchy is fundamental to the process of [13].
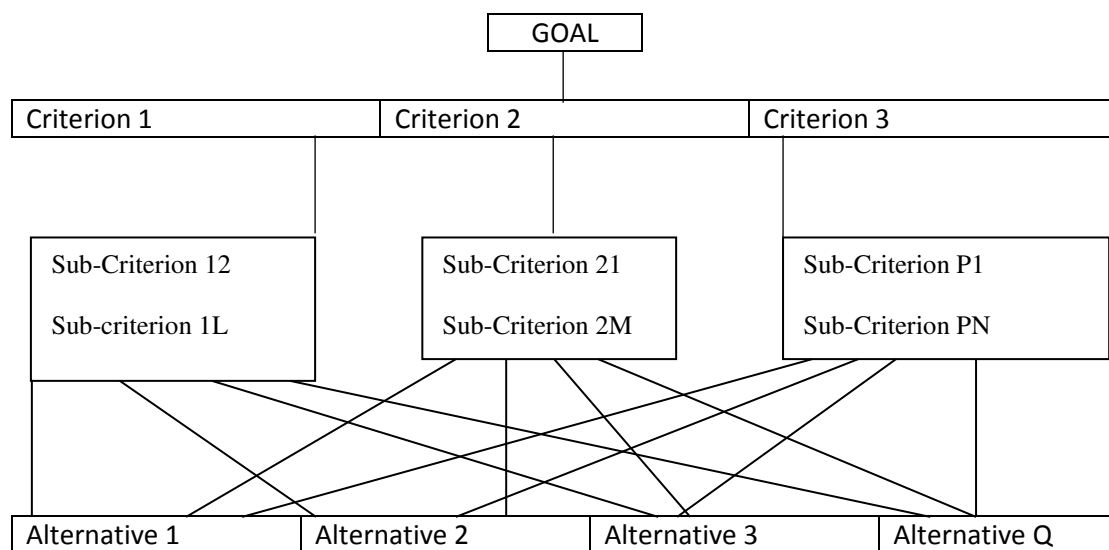
Figure3.1: Generic hierarchic structure

							X	
Extremely very strong	Very strong	Strong	Marginally Strong	Equal	Marginally Strong	Strong	Very Strong	Extremely Strong

Figure 3.2: Format for pairwise comparisons

the AHP. Hierarchy indicates a relationship between elements of one level with those of the level immediately below. This relationship percolates down to the lowest levels of the

hierarchy and in this manner every element is connected to every other one, at least in an indirect manner. A hierarchy is a more orderly form of a network. An inverted tree structure is similar to a hierarchy. Saaty suggests that a useful way to structure the hierarchy is to work down from the goal as far as one can and then work up from the alternatives until the levels of the two processes are linked in such a way as to make comparisons possible. Figure 3.1 shows a generic hierarchic structure. At the root of the hierarchy is the goal or objective of the problem being studied and analysed. The leaf nodes are the alternatives to be compared. In between these two levels are various criteria and sub-criteria. It is important to note that when comparing elements at each level a decision-maker has just to compare with respect to the contribution of the lower-level elements to the upper-level one. This local concentration of the decision-maker on only part of the whole problem is a powerful feature of the AHP. Step 2: Data are collected from experts or decision-makers corresponding to the hierarchic structure, in the pairwise comparison of alternatives on a qualitative scale as described below. Experts can rate the comparison as equal, marginally strong, strong, very strong, and extremely strong. The opinion can be collected in a specially designed format as shown in Figure 3.2. "X" in the column marked "Very strong" indicates that B is very strong compared with A in terms of the criterion on which the comparison is being made. The comparisons are made for each criterion and converted into quantitative numbers as per Table 3.1. Step 3: The pair wise comparisons of various criteria generated at step 2 are organised into a square matrix. The diagonal elements of the matrix are 1. The criterion in the ith row is better than criterion in the jth column if the value of element (i, j) is more than 1; otherwise the criterion in the jth column is better than that in the ith row. The (j, i) element of the matrix is the reciprocal of the (i, j) element [13].

Table 3.1: Gradation scale for quantitative comparison of alternatives

Option	Numerical value
Equal	1
Marginally strong	3
Strong	5
Very strong	7
Extremely strong	9
Intermediate values to reflect fuzzy inputs	2, 4, 6,8
Reflecting dominance of second alternative compared with the first	Reciprocals

Step 4: The principal eigenvalue and the corresponding normalised right eigenvector of the comparison matrix give the relative importance of the various criteria being compared [14]. The elements of the normalised eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives. Step 5: The consistency of the matrix of order n is evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index fails to reach a required level then answers to comparisons may be re-examined.

The consistency index, CI, is calculated as

CI = (λmax -n)/(n- 1)

Where λmax is the maximum eigenvalue of the judgement matrix. This CI can be compared with that of a random matrix, RI. The ratio derived, CI/RI, is termed the consistency ratio, CR. Saaty suggests the value of CR should be less than 0.1. Step 6: The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings. The AHP produces weight values for each alternative based on the judged importance of one alternative over another with respect to a common criterion [15].

o **EX: Choosing the Best Automobile**

This basic example illustrates the key aspects of the AHP and its implementation by the Expert Choice software. The hierarchy is easy to build and the instructor can demonstrate the replication command that simplifies the building of the hierarchy. The over-all goal of the example is to choose the best automat-bile with respect to the four criteria. Table 3.3 gives the data for the problem. The student can readily see that there is no one best alternative, as none of the automobiles is best across all criteria (as indicated by the asterisks).

The problem has both quantitative and qualitative data. The price data can be used directly in the EC comparison matrix by the data entry mode, but the data entry has to be inverted (invert button) in that a low price is better than a higher price (EC considers a higher number as being better than a lower number unless told otherwise) [14]. Note that the prices are of the same order of magnitude—we are not comparing a

Table 3.2: Data for Automobile Purchase Example

Alternatives	Price ($)	Miles/Gallon(MPG)	Prestige	Comfort
Avalon	15,000∗	26	Low	Good

| Babylon | 18,000 | 28* | Fair | Fair |
| Carryon | 24,000 | 20 | High* | High* |

cheap Ford Falcon to a Jaguar. Comparing items of the same "Order of Magnitude" is an axiom of the AHP. The price data can also be used indirectly by ask-ing the usual pairwise comparison question, e.g., "Is Avalon preferred to Babylon with respect to price and how more is it preferred?" Here the preference needs to be established using the 1–9 scale (or equivalent verbal scale) and the student has to decide how the $15,000 compares to the $18,000. Using the 1–9 scale for the dollar figures tends to build a utility evalua-tion on the dollars—the dollar spent for the cheaper auto has a greater utility than a dollar spent on a more expensive auto. The data entry mode treats all dollars as having the same utility. We suggest that the fac-ulty member first illustrate the data entry mode and then illustrating the 1–9 pairwise comparison mode [14]. The final rankings will probably stay the same but the weights assigned to the different elements will prob-ably be different.

The MPG numbers are direct data entry; the weights obtained are just the individual auto's MPG number divided by the sum of all the MPG numbers. For pres-tige and comfort, the student must make pairwise comparisons that respect the individual criterion tran-sitivity relationship (High>Good>Fair>Low). The 1–9 scale does a very good job in capturing the preferences (e.g., High/Low = 7, High/Good = 5, High/Fair = 3, and so on) [14].

3.4. Outranking methods

The foundation of the outranking methods is the construction and the exploitation of an outranking relation that is introduced by Roy. An outranking relation is a binary relation S defined on the set of alternatives A such that for any pair of alternatives A: AiSAk if, given what is known about the preferences of the decision maker, the quality of the evaluations of the alternatives and the nature of the problem under consideration, there are sufficient arguments to state that the alternative Ai is at least as good as the alternative Ak, while at the same time no strong reason exists to refuse this statement. Compared to the other multi-criteria evaluation methods, the outranking methods have the characteristic of allowing incomparability between alternatives. This characteristic is important in situations where some alternatives cannot be compared for one or another reason [11]. The main outranking methods are**:**

a- Elimination et choice translating reality (ELECTRE) method

b- Preference ranking organization method for enrichment evaluation (PROMETHEE)

Conclusion

We conclude from the work executed in this chapter (Multi-Criteria Decision Analysis) that the result or the decision we get through this method, is related to several factors; the most important are:

- Determine the ideal method (MCDA) to make the right decision,
- The accuracy of data related to the criteria for this study.

Chapter 04: Results and discussions

Chapter 04: Results and discussions

After deleting the most uncomfortable areas such as, urban and agricultural areas, mountains, and sand dunes, we selected the available areas (alternatives), which are 11 regions in this study,

4.1. The available areas in the south of Algeria (different alternatives) selected by ArcGIS

The most regions which can be an alternative for new solar energy project are presented in figure 4.1
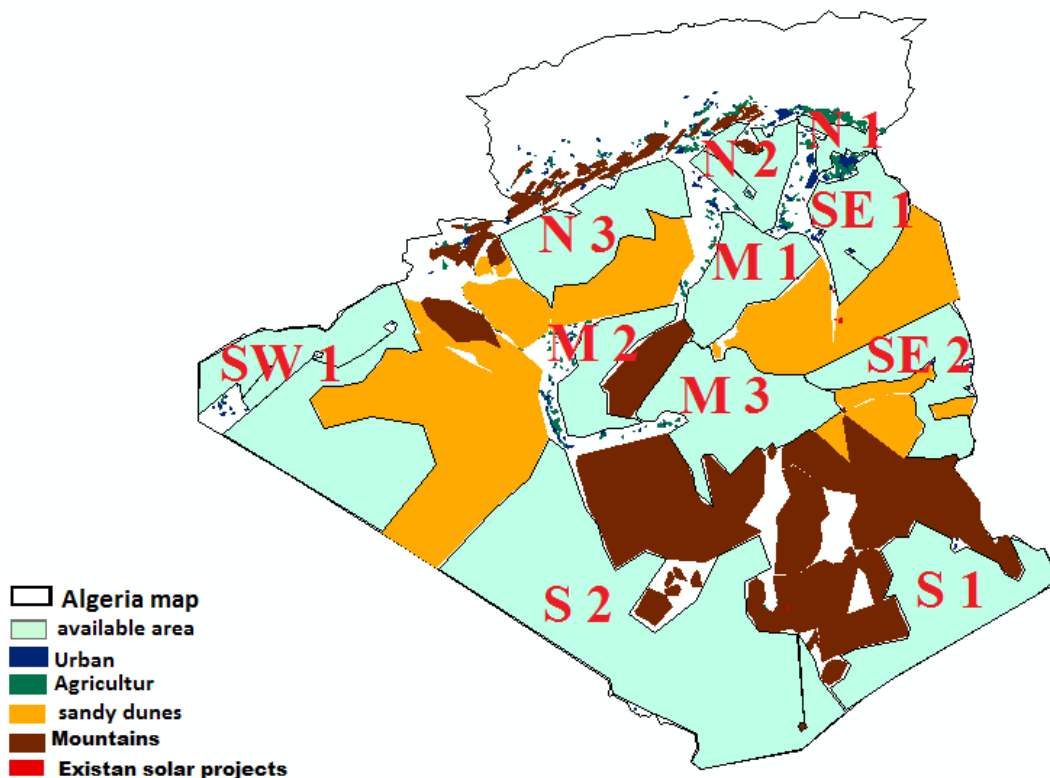
Figure 4.1: Available areas (alternatives)

4.2. Present of the sustainability criteria by ArcGIS

4.2.1. Roads: This criterion has an important role, because by roads we access to the facilities for implementation, operation and maintenance. Here we figure the roads extension for the entire South.
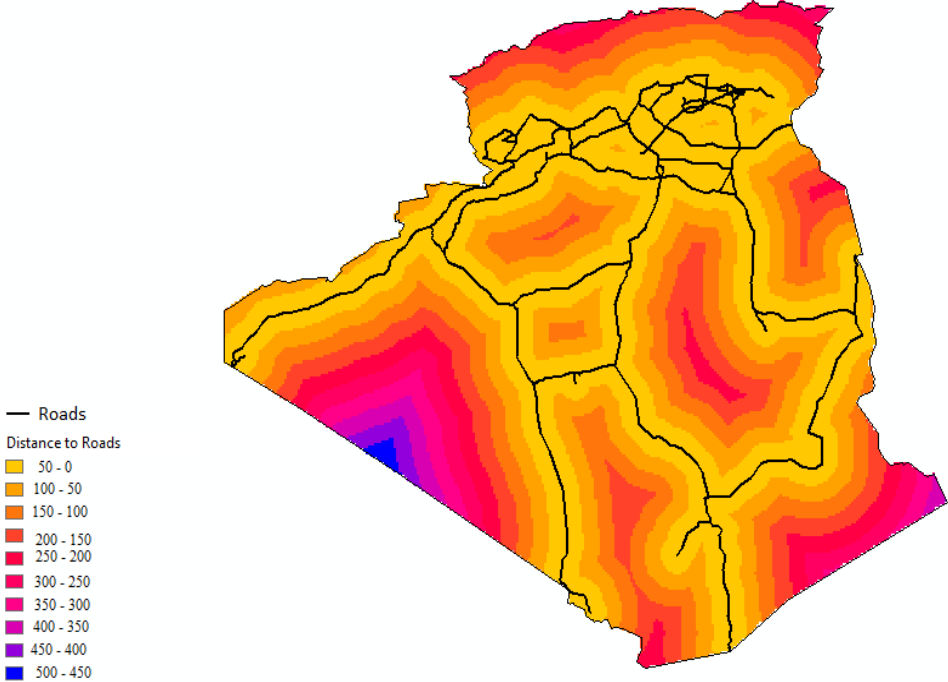
Figure 4.2: Distance of roads
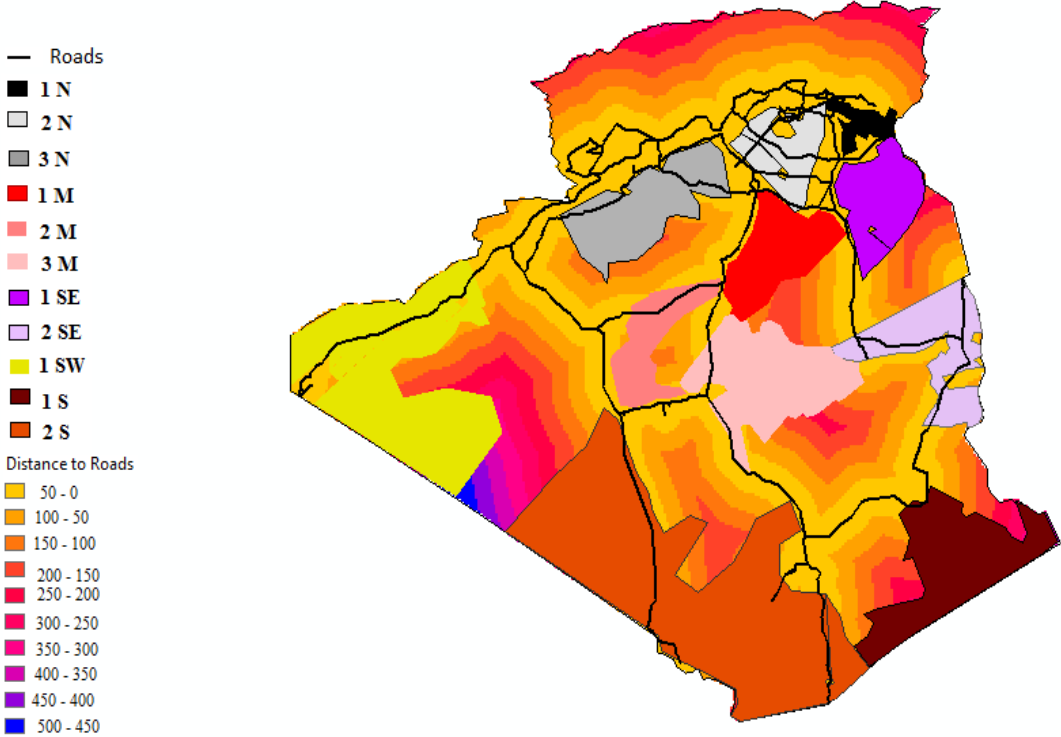
Figure 4.3: Distance between regions and roads

Table 4.1: Distance between regions and roads

Regions	N 1	N 2	N 3	M 1	M 2	M 3	1 SE	2 SE
Distance (km)	0-100	0-50	0-200	0-200	0-150	0-250	0-250	0-50

SW 1	S 1	S 2
0-500	0-300	0-400

We have observed that N2 is the nearest location to the road, followed by the locations SE2, N1, M2, N3, M1, M 3, SE1, S1, S2, and SW1.

4.2.2. Solar irradiation: This criterion decides the values of the project and its importance in side of the power interest. The map below introduces the solar irradiation for all the surface of Algeria.

Extract_Fea11
  <VALUE>
  4.688000202 - 3.335999966
  5.241000175 - 4.688000203
  5.677000046 - 5.241000176
  6.122000217 - 5.677000047
  6.616000175 - 6.122000218
  7.278999805 - 6.616000176
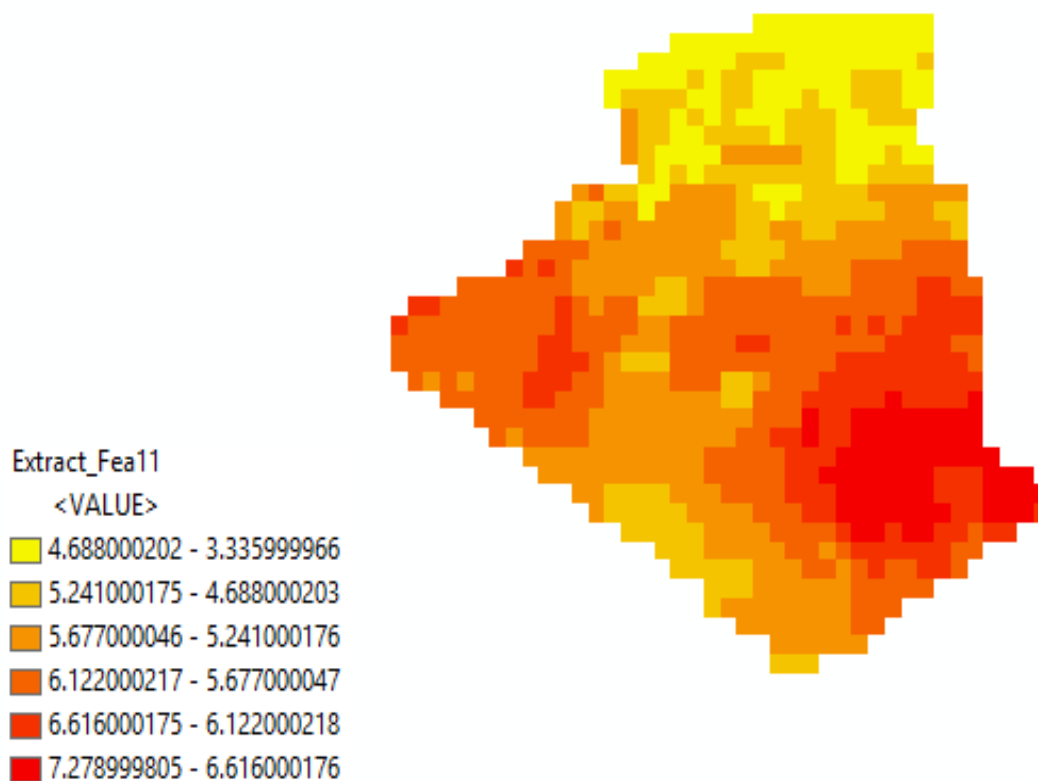
Figure 4.4: Irradiation solar
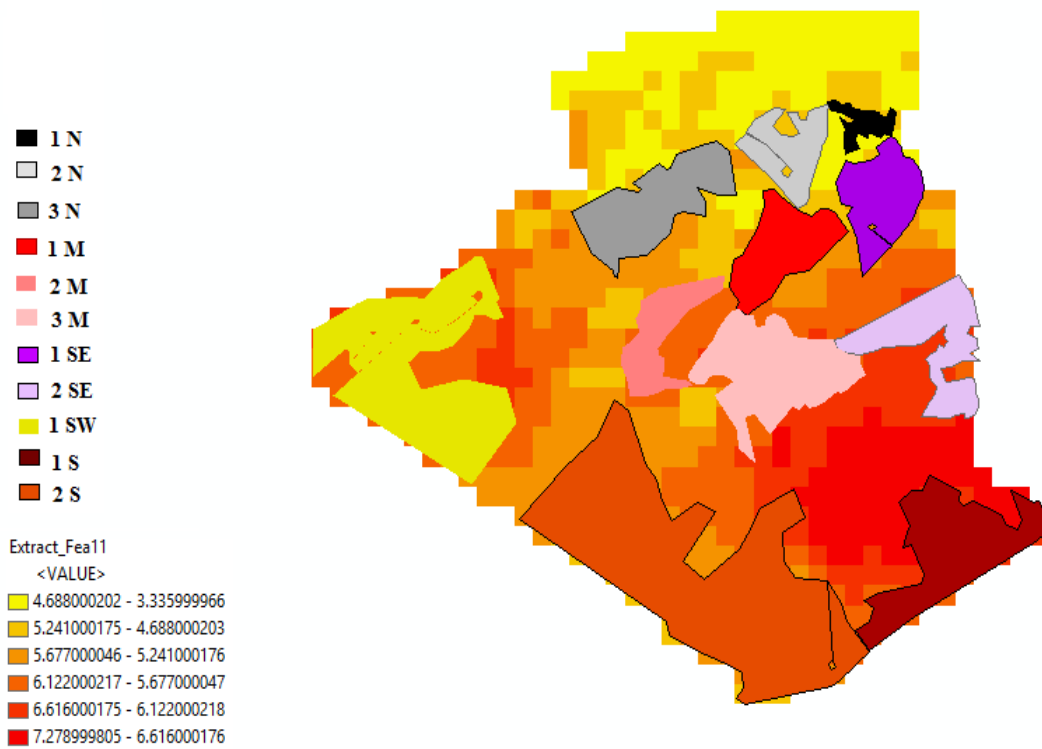
Figure 4.5: Irradiation solar and available area

Table 4.2: Irradiation solar of regions

Regions	N 1	N 2	N 3	M 1	M 2	M 3	1 SE	2 SE
Irradiation solar	5.24-4.68	5.24-4.68	5.67-4.68	6.12-4.68	6.12-5.67	6.61-5.67	5.67-4.68	6.61-5.67

SW 1	1 S	2 S
6.61-5.67	7.27-6.12	5.67-4.68

By competing the average solar irradiation, we find that location N3 is the best location.

4.2.3. Underground water: like the other criteria, water is very important for the project itself, and the human use in the project site. This map shows the extension of aquifer system in Algeria.
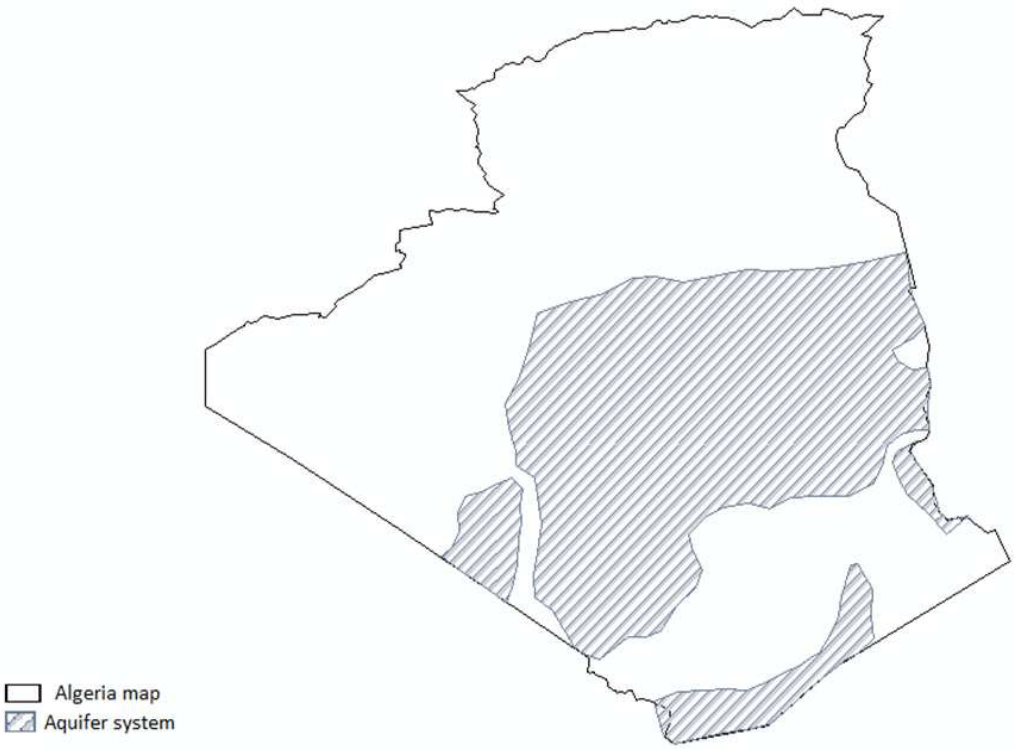
Figure 4.6: Aquifer system
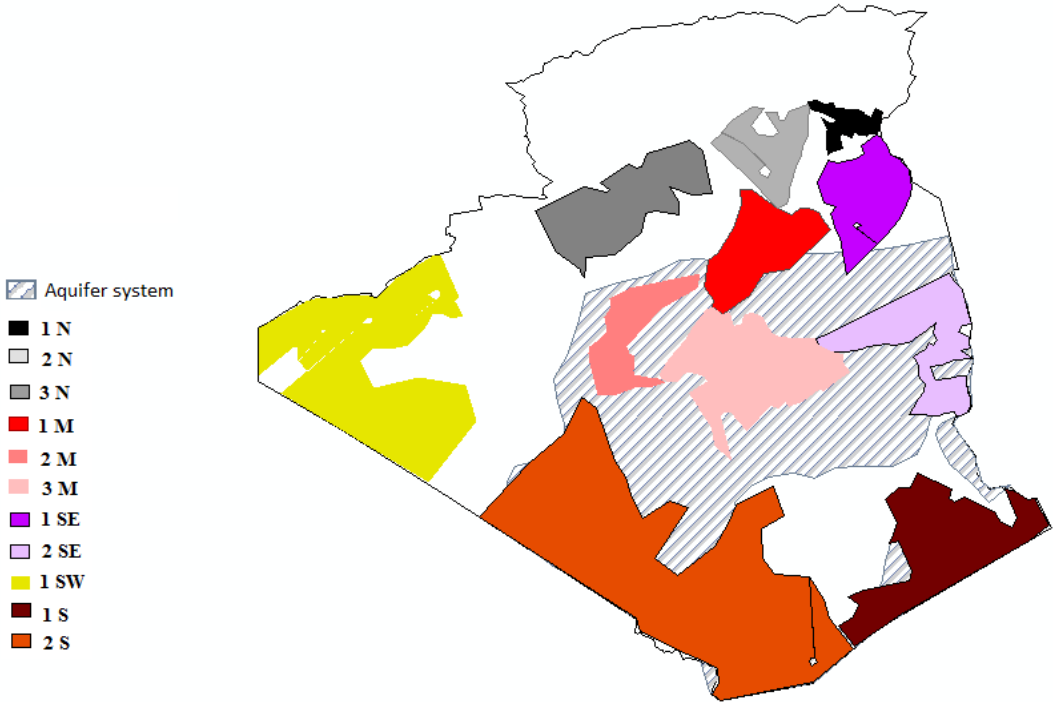
Figure 4.7: Aquifer system and available area

Table 4.3: Existence of water in regions

Regions	N 1	N 2	N 3	M 1	M 2	M 3	SE1	SE 2
Water	Middle	Middle	Middle	Near	Exist	Exist	Middle	Exist

SW 1	S 1	S 2
Far	Middle	Near

We note the presence of water in seven areas of the studied areas (alternatives) they are (M 1, M 2, M 3, SE 1, SE 2, S 1, S 2).

4.2.4. Wind speed: At some locations (like deserts), wind can have a high importance in deciding how far is possible to make a solar energy project or any other projects in the south (desert) due to its negative influence on the visibility, roads, panels, etc.

Figure 4.8, and 2.9 shos the map of the diversity of the wind speed in Algeria.

Idw_Export_O1
<VALUE>
1,901965618 - 2,341764355
2,341764356 - 2,781563091
2,781563092 - 3,221361828
3,221361829 - 3,661160564
3,661160565 - 4,100959301
4,100959302 - 4,540758038
4,540758039 - 4,980556774
4,980556775 - 5,420355511
5,420355512 - 5,860154247
5,860154248 - 6,299952984

Figure 4.8: Wind speed

1 N
2 N
3 N
1 M
2 M
3 M
1 SE
2 SE
1 SW
1 S
2 S

Idw_Export_O2
<VALUE>
1,901965618 - 2,341764355
2,341764356 - 2,781563091
2,781563092 - 3,221361828
3,221361829 - 3,661160564
3,661160565 - 4,100959301
4,100959302 - 4,540758038
4,540758039 - 4,980556774
4,980556775 - 5,420355511
5,420355512 - 5,860154247
5,860154248 - 6,299952984

Figure 4.9 : Wind speed and available areas

Table 4.4: Wind speed of regions

Regions	N 1	N 2	N 3	M 1	M 2	M 3	SE 1	SE 2
Wind speed	3.66-2.34	4.98-3.22	5.42-3.66	4.54-3.22	6.29-3.66	5.86-3.66	4.10-3.21	4.54-3.66

SW 1	S 1	S 2
6.29-4.10	4.10-3.21	5.86-2.78

We note that the highest avrage wind value (6.29) is founed in two regions (M2,SW 1)

4.2.5. Grid (electricity network): knowing the electricity network can help to better installation of the project, lifts its chances of success, and raises its value after it complets. The solar project is much better to be near the grid rther than at high distance.
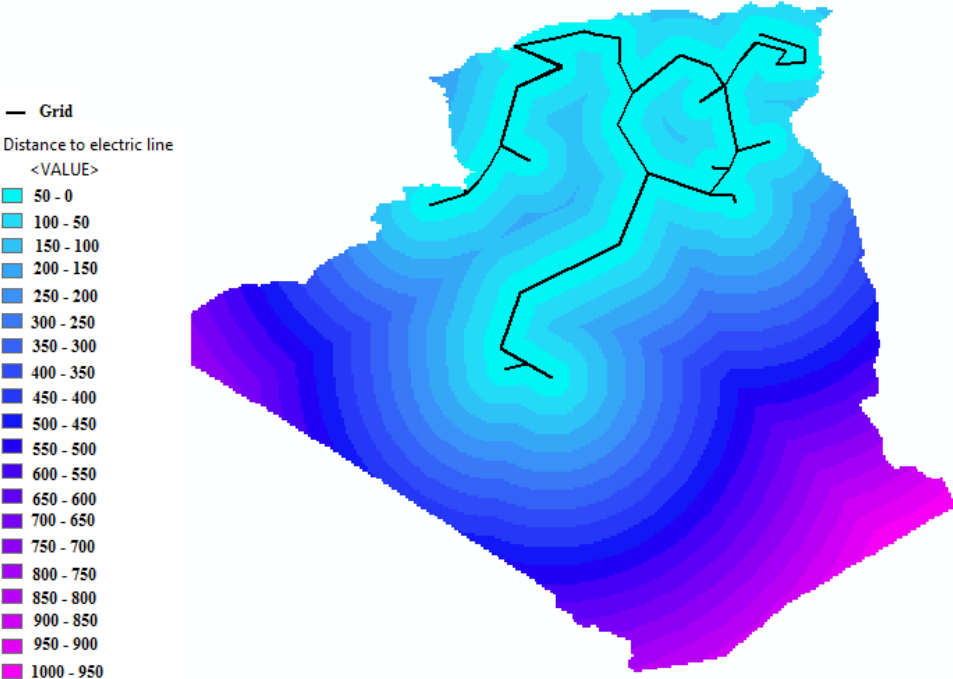
Figure 4.10: Distance to grid

Figure 4.11: Distance between grid and available areas

Table 4.5: Distance from regions to the nearest grid

Regions	N 1	N 2	N 3	M 1	M 2	M 3	SE 1	SE 2
Distance grid	150-0	150-0	200-50	200-0	150-0	450-100	200-50	700-300

SW 1	S 1	S 2
800-200	1000-700	900-50

Note that the values of the distance between the electric grid and the areas are large in the following areas, S 2, SW 1, SE2, and M 3
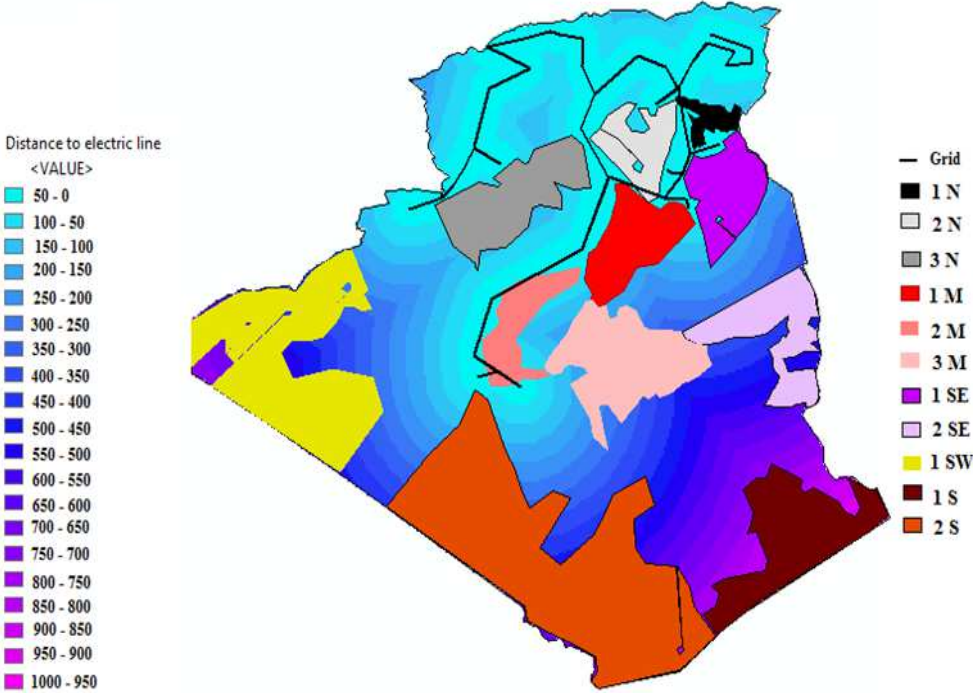
4.2.6. Area surface: Solar projects vary in size depending on the energy produced. Therefore, the space factor has an important role; therefore; it was nominated as a criterion in this study.

Table 4.6: Surface of regions

Regions	N 1	N 2	N 3	M 1	M 2	M 3	1 ES	2 ES
Surface km^2	11300	36000	70300	50200	37900	86700	49200	60700

WS 1	S 1	S 2
163100	90300	291300

From table 4.6, the largest areas are S 2 followed by WS 1.

4.3. Assessement and analysis by MCDA Methods

We applied MCDA scores for the 11 chosen regions (N 1, N 2, N 3, M 1, M 2,M 3, SE 1, SE 2, SW 1, S 1, S 2), using 7 sustainability criteria (Solar Irradiation, Roads, Surface Area, Wind Speed, and Grid, Effect of dunes, water), table 4.7, for 4 preference senarios; equal weights, capacity, stability, and maintenance and operation.

Table 4.7: Performance table

Criteria	N 1	N 2	N 3	M 1	M 2	M 3	SE 1	SE 2	SW	S 1	S 2
Irradiation	5.24-4.68	5.24-4.68	5.67-4.68	6.12-4.68	6.12-5.67	6.61-5.67	5.67-4.68	6.61-5.67	6.61-5.67	7.27-6.12	5.67-4.68
Surface	11300	36000	70300	50200	37900	86700	49200	60700	163100	90300	291300
Distance to Roads	0-100	0-50	0-200	0-200	0-150	0-250	0-250	0-50	0-500	0-300	0-400
Distance to Grid	150-0	150-0	200-50	200-0	150-0	450-100	200-50	700-300	800-200	1000-700	900-50
Water	Middle	Middle	Middle	Near	Exist	Exist	Middle	Exist	Far	Middle	Near
Wind	3.66-2.34	4.98-3.22	5.42-3.66	4.54-3.22	6.29-3.66	5.86-3.66	4.10-3.21	4.54-3.66	6.29-4.10	4.10-3.21	5.86-2.78
Effect of Dunes	No	No	Middle	Middle	Strong	Strong	Low	Strong	Strong	Middle	Middle

To normalize the values of performance table, we use the following equations:

Positive influence: $N_i = (A_i - A_{min})/(A_{max} - A_{min})$

Negative influence: $N_i = (A_{max} - A_i)/(A_{max} - A_{min})$

Table 4.8: Normalization

Criteria	N 1	N 2	N 3	M 1	M 2	M 3	SE 1	SE2	SW	S 1	S 2
Irradiation	0.000	0.000	0.124	0.254	0.539	0.680	0.124	0.680	0.680	1.000	0.124
Surface	0.000	0.088	0.211	0.139	0.095	0.269	0.135	0.176	0.542	0.282	1.000
Distance to Roads	0.889	1.000	0.667	0.667	0.778	0.556	0.556	1.000	0.000	0.444	0.222
Distance to Grid	1.000	1.000	0.929	1.000	1.000	0.857	0.929	0.571	0.714	0.000	0.929
Water	0.333	0.333	0.333	0.667	1.000	1.000	0.333	1.000	0.000	0.333	0.667
Wind	1.000	0.667	0.501	0.667	0.000	0.414	0.750	0.501	0.584	0.834	0.501
Effect of Dunes	1.000	1.000	0.333	0.333	0.000	0.000	0.667	0.000	0.000	0.667	0.667

a. Equal weights preference

Table 4.9: Values of equal weights criteria

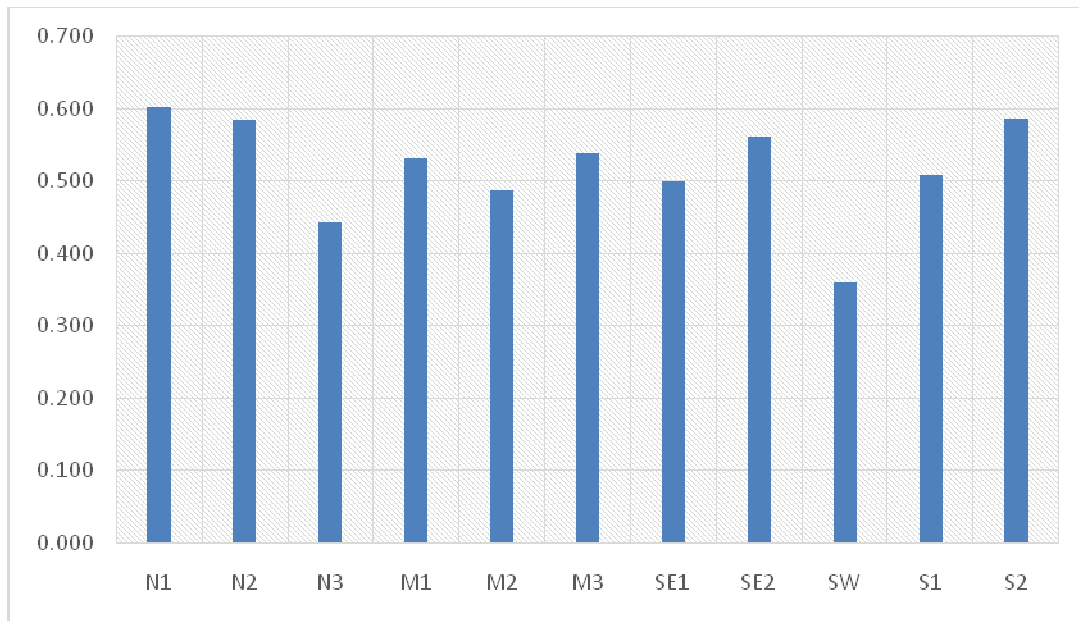| Criterias	Irradiation solar	Surface	Distance to Roads	Distance to grid	Water	Wind	Effect of dunes
Weight	0.14	0.14	0.14	0.14	0.14	0.14	0.14

Figure 4.12: Alternatives scores -Equal Wight preference scenario

b. Capacity preference (irradiation)

Table 4.10: Values of criteria in Capacity preference scenario

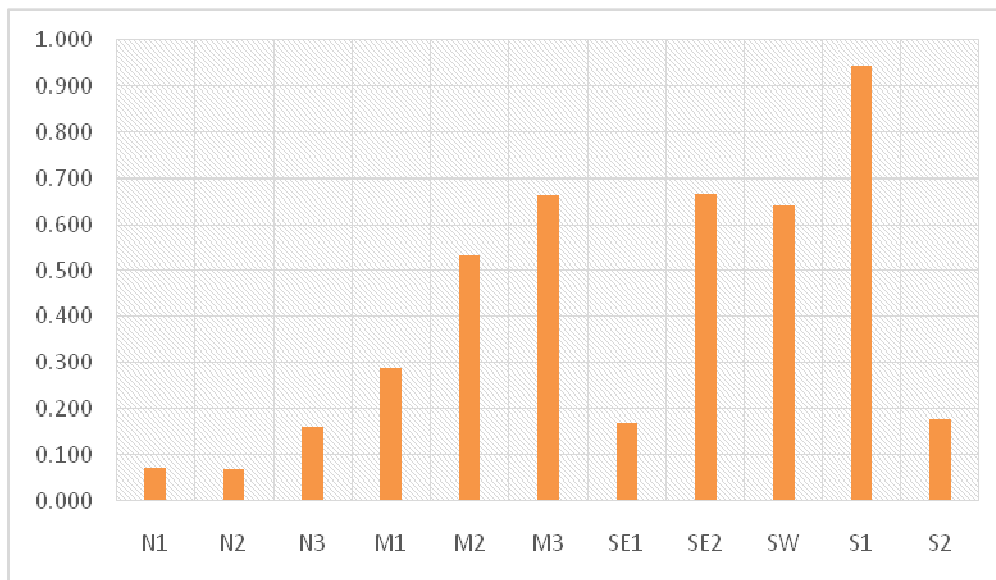| Ccriteria's	Irradiation solar	Surface	Distance to Roads	Distance to grid	Water	Wind	Effect of dunes
Weight	0.90	0.02	0.02	0.02	0.02	0.02	0.02

Figure 4.13: Alternatives scores -Capacity preference scenario

c. Grid Stability preference (Grid, irradiation)

Table 4.11: Values of criteria weighting grid stability scenario

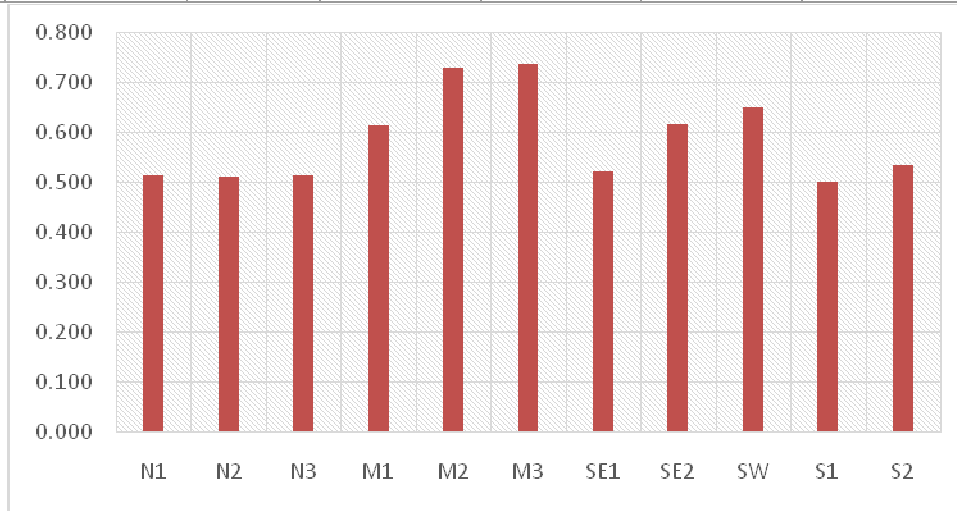| Citerais	Irradiation solar	Surface	Distance to Roads	Distance to grid	Water	Wind	Effect of dunes
Weight	0.45	0.02	0.02	0.45	0.02	0.02	0.02

Figure 4.14: Alternatives scores -Grid stability scenario-

d. Operating and maintenance preference (Roads)

Table 4.12: Values of criteria in operating and maintenance scenario

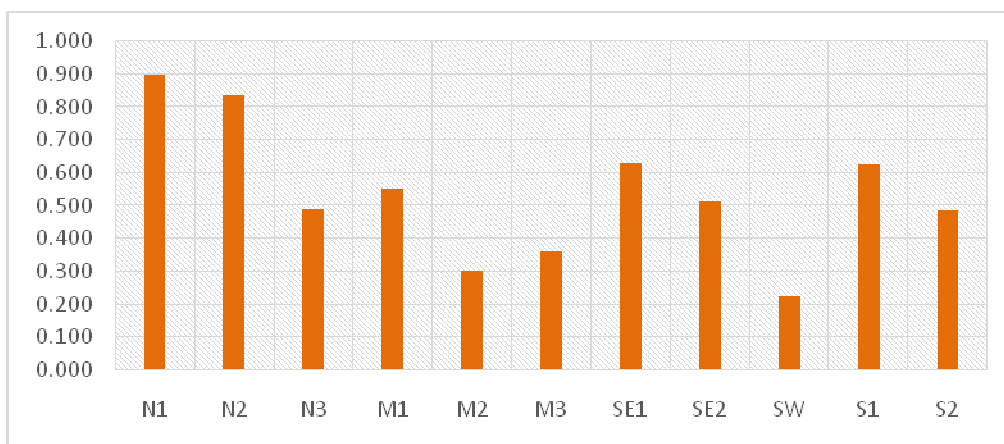| Citerais	Irradiation solar	Surface	Distance to Roads	Distance to grid	Water	Wind	Effect of dunes
weight	0.03	0.03	0.30	0.03	0.03	0.3	0.3

Figure 4.15: Alternatives scores -Operating and maintenance scenario-

The equal weight preference scenario resulted in MCDA scores (Figure 4.12) ranging from 0.36 (North with the lowest solar radiation and surface area values) to 0.6 (South with max values). The rank order from highest (most preferable) to lowest (least preferable) is as follow: N1, S2, N2, SE2, M3, M1, S1, SE1, M2, N3, SW.

By changing the input values of weight preference to capacity prefence senario (Figure. 4.13), the rank order changed, S1 (0.94), SE2 (0.66), and SW (0.64) regions have the highest scores which is very logical due to the highest sollar irraduation in this regions, followd by M3 (0.66) and M2 (0.53). Unlike the first senario, South and middle regions outrank the north regions.

The third senaio (the Grid stability preference) shows that middle regions (M1 (0.61), M2 (0.73) and M3 (0.73) have higher scores comparing to the others because of moderate irradiations and acceptable distance to grids.

The fourth senaio is the operating and maintenance scenario, where the north regions, particularly, N1 (0.90) and N2 (0.83) outrank the other regions. The main reason is their lowest effects by sand dunes and a short distance to roads.

Conclusion

Solar thermal and photovoltaic electricity generation are two promising technologies for climate-compatible power with such enormous potential that, theoretically, could cover much more than just the present worldwide demand for electricity consumption.

Photovoltaic systems have advantages for low-power demand, stand-alone systems and building-integrated grid-connected systems. Solar thermal power plants are best operated in large grid-connected systems. Due to the higher direct solar irradiation in the South.

South Algeria, technically and economically is a great potential for solar power exploration, with about 170 Twh per year. In the industrial scale is so promising, and by keeping this frequency, it can feed the domestic electricity demand in 2030.

ArcGIS and Google Earth are flexible and powerful softwares to manipulate and create maps, import and export data in different formats, also, they have many different options to work in collaboration in purpose of making the user's work easier. Arcgis is used to define location districts or find potential and perform many other tasks. Maps present several types of information about an area at once; ArcGIS finds hidden information by adding layers to a map and treating the ensemble.

After gathering the desired ArcGIS and google Earth data, we finished by selecting 11 appropriate areas that have the most needed factors. These areas considered as candidates to select and rank by applying MCDA method.

We conclude from the work executed in this work that the result and decision we get through this MCDA method, is related to several factors; the most important are:

- Determine the ideal method (MCDA) to make the right decision,
- The accuracy of data related to the criteria for this study.

MCDA is helpful for synthesizing sustainability data, the usefulness of the results is dependent on the availability and quality of data, as well as clear decision maker preferences. Additional criteria (i.e., Population, Energy needs per region) may be required to more accurately represent decision-maker preferences and could change the MCDA results and conclusions. preferences among these decision-makers vary by location and other factors. Future MCDA studies should include more specific data and the society outlook. More work is needed in smaller scale to localise the results.

References:

[1] M.I. Roldán Serrano, Concentrating Solar Thermal Technologies, Green Energy and Technology, 2017, DOI 10.1007/978-3-319-45883-0_2

[2] www.nrel.gov

[3] Patel R.," Wind and solar power systems: design,analysis, and operation " , Taylor Francis, 2006

[4] Michael Geyer, Franz Trieb, Manuel Jesus Blanco, Solar Thermal Power Plants, January 2002, 225007894

[5] Solae Thermal power,2020exploiting the heat from the sun to combat climate change,2010

[6] Renewable Energy and Energy Efficiency Program, March 2011

[7] www.american.edu/provostcctrl/202-885-3862

[8] http://www.springer.com/978-3-540-74756-7

[9] Wang J-J, Zhang C-F, Jing Y-Y, Zheng G-Z. Using the fuzzy multi-criteria model to select the optimal cool storage system for air conditioning. Energy and Buildings (2008).

[10] Afgan, N.H., Carvalho, M.G., 2002. Multi-criteria assessment of new and renewable energy power plants. Energy 27, 739–755.

[11] Kata Tisza, GIS-based suitability Modeling and multi -criteria Decision analysis for utility scale solar plants in four states In the southeast u .s. May 2014.

[12] Juan M. Sánchez-Lozano, Renewable and Sustainable Energy Reviews 24 (2013) 544–556.

[13] Hwang CL, Yoon K. Multiple attribute decision making-methods and application: a state-of-the-art survey. (1981).

[14] Bodin, L. and S. Gass (2004), "Exercises for Teaching the Ana- lytic Hierarchy Process," INFORMS Transaction on Education, Vol. 4, No 2

[15] www.springer.com/978-1-85233-756-8