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Topic:

Study of Potential Sites for Solar PV Power Plant Implementation in the City of Niamey Using GIS Approach

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DECLARATION

I hereby state all information in this document under the direction of Dr MADOUGOU Saïdou and Mounkaila Mohamed has been obtained with academic deontology and rules. I further state that the material and the results that are not our property in this thesis are fully referenced.

ABSTRACT

Nowadays, the daily debates, conferences, and news are about climate energy and environmental issues in the world. The consumption of fossil fuel is the main cause of global warming due to the release of greenhouse gases into the atmosphere leading to a change in the climate system. Niger is an under developed country and has significant energy potential, rich and varied that is weakly exploited due to political issues. Most of the energy used in Niger is sold by Nigeria Using renewable energy in the city of Niamey which contributes to over 50% of the total national electricity demand in Niger (NIGELEC, 2016) will reduce the power-cuts that have been observed. The main goal of the study was to determine suitable locations for PV installation in Niamey for socio-economic development. The multi criteria analysis and satellite images were classified and used to generate different maps used in this study. Tree sites had been selected among the best suitable places: sites A with 22.5% of the best suitable place (12.154km^2), sites B 53.33% of the best suitable place (28.82 km^2) and site C 10.23% of the best suitable place (5.53 km^2). Electric power generation potential per year for the selected sites was found to be 45.13*10^6 kwh/day based on the calculated average annual solar radiation per unit surface area per day, the total suitable area, and the efficiency of the PV panel.

Key words: Niamey, GIS, Solar farm, Suitability, Weighted Linear Combination (WLC).

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DEDICATION

To my late parent's memory.

ACRONYMS

AM:After Meridien

AHP: Analytic Hierarchy Process

BCE: Bank Centrale Europeenne

CCE: Climat Change and Energy

CNES : Centre National de l’Energie Solaire

CSP: Concentrated Solar Power Plant

DEM: Digital Elevation Model

ECS: Eau Chaude Sanitaire

EIA : Energy Information Administration

EU: European Union

GIS: Geographic Information System

GWe: Gigawatt electrical

GWth: Gigawatt thermal

GWh: Gigawatt hour

IEA: International Energy Agency

INS: Institut Nationale de le Statistique

IPCC: Intergovernmental Panel on Climate Change

IRENA: International Renewable Energy Agency

KWh: Kilowatt hour

MCA: Multi Criteria Analysis

MCDA: Multi Criteria Desition Analysis

MRP: Master Research Program

Mw: Megawatt hour

NAIADE: Novel Approach to Imprecise Assessment and Decision Environment

NASA: National Aeronautics and Space Administration

NIGELEC: Société Nigérienne d’Électricité

NREP: National Registry of Environmental Professional

PM: Post Meridien

PV: Photvoltaic

RES: Renewable Energy System

RRA: Renewable Readiness Assessment

SOMINA : Société des mines d’Azielic

SOPAMIN : Société de Patrimoines des Mines du Niger

WAPP: West Africa Power Pool

WB: World Bank

WLC: Weight Linear Combination

INTRODUCTION

1. Background

During the last century, human's existence as well as all other living organisms, have occupied the environment in which they have been able to adapt and to make themselves prosperous. Nevertheless, any quick fluctuation or change of the climate is uncertain for all living organisms. Not long ago, many observations and experiences gave rise to the term "climate change" as a science which studies the earth climate variations. One of the most planetary environmental challenges nowadays is climate change, with implications of nexus between food production, water supply, energy and health, etc.

It refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007). Climate change has an impact on the environment and the Earth system as whole. The increasing demand for energy, the depletion of fossil fuel reserves, the forced events taking place on the international scene (local armed conflicts, natural disasters like earthquakes, tsunamis, floods, hurricanes, etc.) that have the potential to partially cripple the energetic systems, proves that the energy security and diversity is a serious aspect that the policy makers should consider when deciding short and middle term energy policy.

The one primary factor contributing to global warming is the combustion of fossil fuels (Dai et al., 2015). However, energy and transport (emissions coming from the fossil fuels) are the major sectors which release a lot of greenhouse gas into the atmosphere (Cristóbal, 2010). Of all the renewable energy resources, solar energy is the most promising option because of its inherent advantages and availability The utilization of solar energy can be categorized in two ways: solar heating/cooling and solar electricity. This energy can be converted into electrical energy with the use of photovoltaic panels. It has a huge potential for conversion into electrical power. So, in order to mitigate the effect of global warming without jeopardizing our ability for energy generation, there is a need to shift towards renewable energy resources. The conversion of solar radiation into electrical energy by Photo-Voltaic (PV) effect is a very promising technology because of the absence of the mechanical part (A. Goetzberger V.U. Hoffmann,2004). It is clean, quiet, and authentic, with very small maintenance costs and small ecological impacts. The interest in the PV conversion systems is visibly reflected by the exponential increase of sales in this market segment. According to recent market research carried out by European Photovoltaics Industry Association

(EPIA), the total installed power of PV conversion equipment increased from about 1 GW in 2001 up to nearly 23 GW in 2009 for conversion into electrical power.

Africa's energy sector is shared in three parts: oil and gas are the main sources of energy of North Africa. South Africa depends on coal and the rest of Sub-Saharan Africa uses largely biomass. In fact, Africa's reserves of renewable energy resources are the highest in the world (IRENA,2015). Most of the renewable energy sources of Africa are still under-used (Karekezi and Kithyoma, 2003). Africa's energy sector is very important for its development.

The expansion of renewable energy technologies in Africa will contribute: increase electricity production to eradicate energy shortage, to electrify remote areas and to ensure energy security. Even if, the contribution of CO_2 emissions per capita is small compared to other countries (Canadell et al., 2009), Africa remains the continent that is most vulnerable to climate change.

The development of Solar PV is possible throughout Niger where the average annual insolation level is 5 to 7 kWh/ m^2/ day with an average of 8.5 hours per day (CNES). Employment of a Geographic Information System (GIS) allows for the identification of suitable places for solar energy development. In recent years, it has become a more common practice to use GIS to investigate potential of solar energy development. ESRI's ArcGIS spatial analyst was employed to estimate the solar energy potential of rooftops building (ESRI, 2008). To promote solar energy in the city of Osnabruck in Germany, GIS tools were used to map potential sites for solar energy development. (ESRI, 2009). The Environmental Protection Agency (EPA) uses GIS to investigate and creates maps for grid-connected utility potential solar energy as well (EPA, 2010).

In the 21st century, renewable energy is used as an energy alternative for electricity production in many countries. Using renewable energy in Niger at a large scale will help the country to increase electricity access rate and its diversification in the country. This research it will be assess of solar energy potential for the town of Niamey that will be a great contribution to the identification of new energy sources for Niger and for the West African region in general. There are different ways for identifying suitable sites for solar energy development in a given area. The most common method for identifying suitable locations for solar energy generation was used in this research and will be detailed further, later in this report. The study will contribute to the research field of renewable energy, especially for solar energy development in Niger. The study was designated to find suitable locations for solar PV implementation in Niamey.

This study will use GIS-based on Multi-criteria analysis to identify suitable sites to implement solar PV in order to meet the energy demand of Niamey by taking into account Physical approach (solar insulation), environmental approach (land cover, digital elevation model) and socio-economic (protected area, population density, transmission lines and roads network) approach are the parameters used to conduct this study.

2 Problem statement

Nowadays, access to electricity is a big challenge for West African governments. Some institutions have been put in place to solve this problem such as the West African Power Pool (WAPP). In almost all West African countries including Niger, periodic and unscheduled power cuts are observed. There is thus, a high level of concern for the energy sector. Niger is a landlocked country and has significantly rich and varied energy potential. Today, renewable energy is the option for electricity production in many countries throughout the word. Using renewable energy in the city of Niamey which contributes to over 50% of the total national electricity demand in Niger (NIGELEC, 2016) will reduce the power-cuts that have been observed. At the end of this study, potential areas will be identified for the solar PV electricity generation.

This work intendeds to determine areas where there is possibility to implement solar PV power plants to meet the energy demand of Niamey, by taking into account physical and socio-economic constraints.

2.1 Importance of Study

Africa is the "darkest" continent in the world even though, Africa is considered and referred as the "sun continent "or the continent where the sun's influence is greatest, we continue to suffer with energy issues (WB, 2014). The West African energy sector is very weak due to the lack of diversity in energy sources. Africa and especially West Africa receives many more hours of bright sunshine during the course of the year than any other continent of the earth (NASA). Niger is among these shiniest places on the planet. Despite the large solar energy potential, penetration rate of solar power in the African energy sector is still low. By taking into account climate change and lack of electricity, renewable energy is the solution to these double issues. The results from the present study can be used to determine the ideal locations for a solar power facility and facilitate the construction of a solar PV power plant to supply electricity for the city in order to meet the energy demand of the country especially for Niamey which has the highest energy demand in the country. This study could then be replicated in other parts of the country. This study will help policymaker to easily put in place this kind of projects. The study of the suitable places for solar PV power implementation using GIS approach is the use of the geographical information systems including the multi criteria analysis by considering some criteria such us: topography, proximity to the transmission lines, road proximity and some location constraints location (urban area, agriculture land, protected area) to choose the sites for solar PV implementation.

2.2 Objectives of the thesis

The target of this study was to identify solar PV energy potential for Niamey. The main goal of the study was to determine suitable locations for PV installation in Niamey for socio-economic development. The specific research objectives include:

1. To identify solar energy profile and availability in the city of Niamey.
2. To determine the capacity of solar energy production for Niamey.
3. To see how is this place is going to destroy or not the environment.

2.3 Research questions

1. What are the suitable sites for solar PV power plant implementation in Niamey?
2. How much energy can this suitable place produce?
3. Where and how the best place for solar PV implementation looks like?

12.5 Outline of the thesis

We will find four chapters. In the first chapter, we have the literature review. The second chapter will be reserved for some theory related to solar radiation. The methodology of the study is explained clearly in the chapter 3. In the chapter 4 represents results and discussions, illustration of the results as graphs, tables and maps and discussed as well. In the last partr of this thesis that is conclusion and recommendation, a brief summary of the thesis and some recommendations are given to integrate the implementation of solar PV for Niamey.

Chapter I

Literature review

1.1 Renewable energy

Natural gas, coal and oil (fossil fuels) are the main sources of energy in the world. Fossil fuels are not environmentally friendly because their combustion releases a lot of greenhouse gas into the atmosphere that contribute to the enhancement of greenhouse effect. Global warming comes from as a result of increased in concentration of greenhouse gases in the atmosphere. Nowadays we observe its consequences around the planet. Challenges such as limitation of fossil fuel, environmental pollution, importance of energy mix diversification, and possibility of earning more value from fossil resources have encouraged governments all over the word to promote an increase the renewable energy shares in their energy portfolio. However, energy demand and related services to run into social and economic development and improve human well-being and health are booming. All social classes require energy to meet the basics needs and to serve productive processes (IPCC, 2011). Because of the reduction of the energy sources, we need to find other alternative sources of energy that will last longtime.

The energy sources that are continually regenerated by the nature for instance sun, water, wind, the Earth's heat and plants are known as renewable energy. According to (Karekezi and Kithyoma, 2003) the use of renewable energy technologies could play a crucial role in national developments in terms of income generation, job creation and protecting local environment.

Manly in developing countries, around 1.3 billion of people do not have access to electricity and 2.7 billion of people depend on traditional use of biomass for cooking (IEA, 2014). Therefore, enabling access to renewable energy services could directly reduce the lack of access to electricity and improve the welfare of millions of people as well.

Solar energy is one of the renewable energies which have the ability of contributing to the reduction of foreign energy dependence as well as energy-related environmental impacts (IPCC, 2011; Panwar et al. 2011). Solar energy is considered environmentally and socio-economically beneficial with a proper design, planning, sitting and management. According studies done by Tampakis et al. and Tantopoulos et al, also enjoys favorable public acceptance.

1.2 Development of solar energy

1.2.1 Historical background

The history of solar energy is as old as humankind. In the last two centuries, we started using sun's energy directly to make electricity. In 1839, Alexandre Edmond Becquerel discovered that certain materials produced small amounts of electric current when exposed to light. Solar energy is transmitted to the earth in the form of electromagnetic radiation, which is comprised of photons. The amount of irradiance reaching a location on the earth's surface over a specific time period varies depending on global, local, spatial, temporal and meteorological factors.

The power of the sun is what makes life on Earth possible. Effort to harness solar energy in concentrated form has long been a human pursuit. Solar technology has existed since the 19th century and has received substantial government support since at least the 1970s. The development of solar cell technology, begun during the industrial revolution when French physicist Alexandre Edmond Becquerel first demonstrated the photovoltaic effect, or the ability of a solar cell to convert sunlight into electricity in 1839. The process of how light produces electricity wasn't understood until Albert Einstein wrote a paper explaining the photoelectric effect in 1905, which won him a Nobel Prize in physics in 1921(the Nobel Prize,1921).

The photovoltaic (PV) technology has been known for many years but its large-scale use began only in the last few years, with impressive growth rates. Global installed capacity went from 5 GW in 2005 to 40 GW in 2010 (IRENA, 2013). Costs went down rapidly, and will continue to do so in all likelihood. PV electricity, already competitive in remote sites, will start to compete for distributed on-grid electricity generation at peak demand times in various regions of the word during this decade.

The use of solar heat is sometimes tracked back to Archimedes, who is said to have set fire to attacking Roman vessels with a giant mirror concentrating sunrays but there is no contemporary account of the siege of Syracuse to confirm the story. René Descartes thought the feat was impossible – but in April 1747 Georges Buffon set fire to a fire plank, besmeared with pitch, with 128 glasses concentrating sunrays. In 1878, Augustin Mouchot and Abel Pifre built several concentrating solar systems, based on dishes, one producing ice in 1878, another the following year running a printing press in the Jardin du Palais Royal in Paris. They then built small solar desalination plants in Algeria. The American engineer John Ericsson built similar devices in the United States around 1884, based on parabolic troughs. In 1904, Manuel Gomez, a Portuguese Jesuit nicknamed Padre Himalaya, aiming at synthesizing fertilizers, obtained a temperature of 3

800°C from concentrating sunrays in his ‘Pyreheliophoro’ In the last 20 years, scientists in Europe, Israel, Japan and the United States have been working on gaseous, liquid or solid “solar fuels “manufactured from carbonaceous feedstock or water.

The top installers of 2016 were China, the United States, and India. There are more than 24 countries around the world with a cumulative PV capacity of more than one gigawatt (Eric Wesoff, 2017). Austria, Chile, and South Africa, all crossed the one gigawatt-mark in 2016. The available solar PV capacity in Honduras is now sufficient to supply 12.5% of the nation's electrical power while Italy, Germany and Greece can produce between 7% and 8% of their respective domestic electricity consumption(CleanTechnica, 2014).

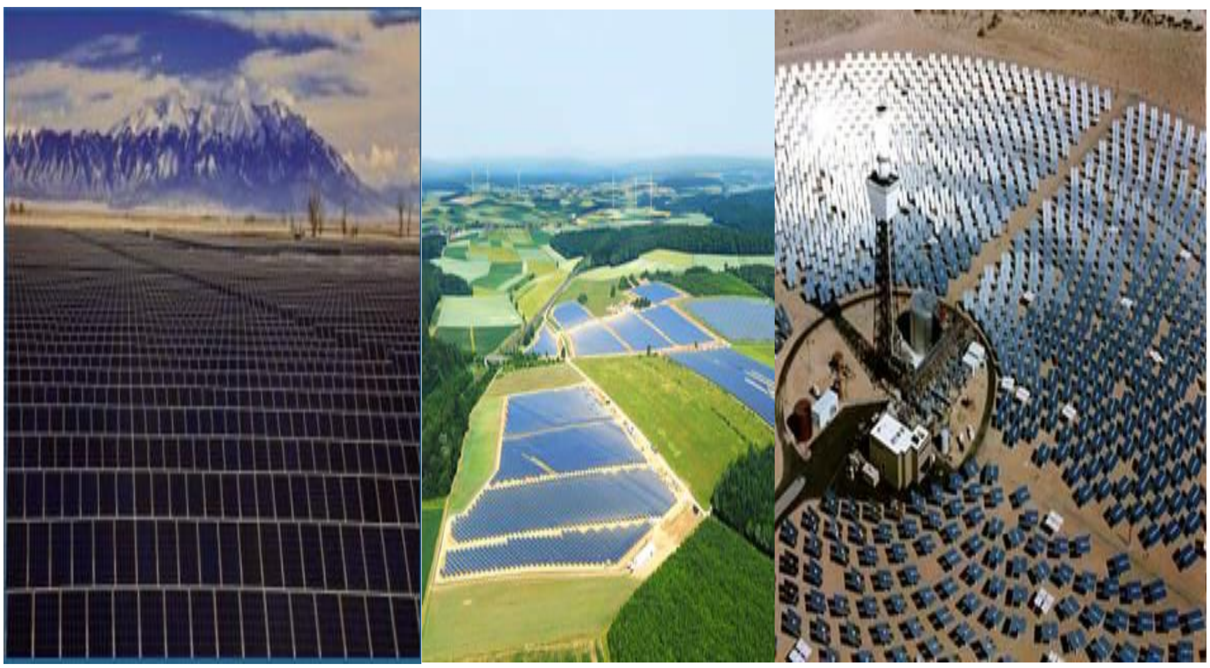


Figure 1:*Solar power plant throughout the word(*CleanTechnica, 2014*)*

1.2.2 Solar energy implementation

Investments in solar PV capacities are now rapidly growing in both grid connected and off grid mode. Solar generation has been a reliable source for supplying electricity in regions without access to the grid electrcity for long. However, the penetration rate of solar energy as a grid connected power source has increased significantly only in the last decade. Thus, the overall share in net energy generation still remains low at only 1% (2015) globally and is bound to only increase in future (IRENA, 2015).

Global installed capacity for solar-powered electricity reached around 227 GWe at the end of 2015 (IRENA, 2015), while total capacity for solar heating and cooling in operation in 2014 was estimated at 406 GWth IEA solar heating and cooling program (2015). Photovoltaic (PV) has been the mainstream solar power technology as shown in Figure 2 below.

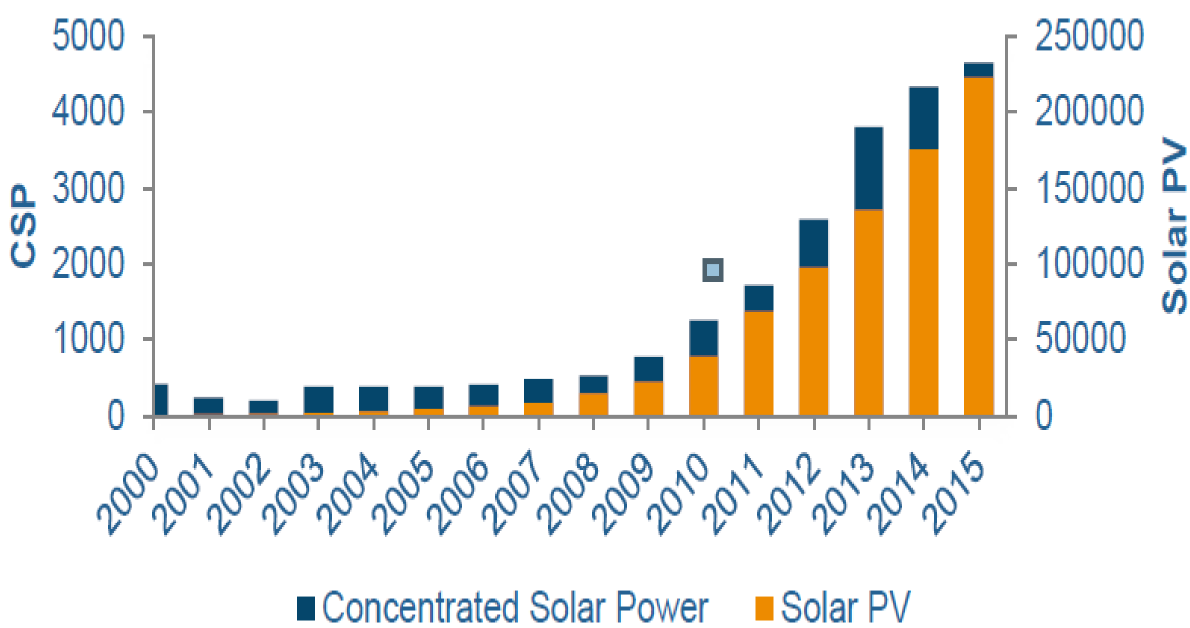


Figure 2: *GLOBAL INSTALLED SOLAR POWER CAPACITY, 2000-2015 (MW)*

Source *(IRENA, 2015)*

China is a leader in PV installations, followed by the USA, Japan, Germany and Italy as shown in Figure 3 below.

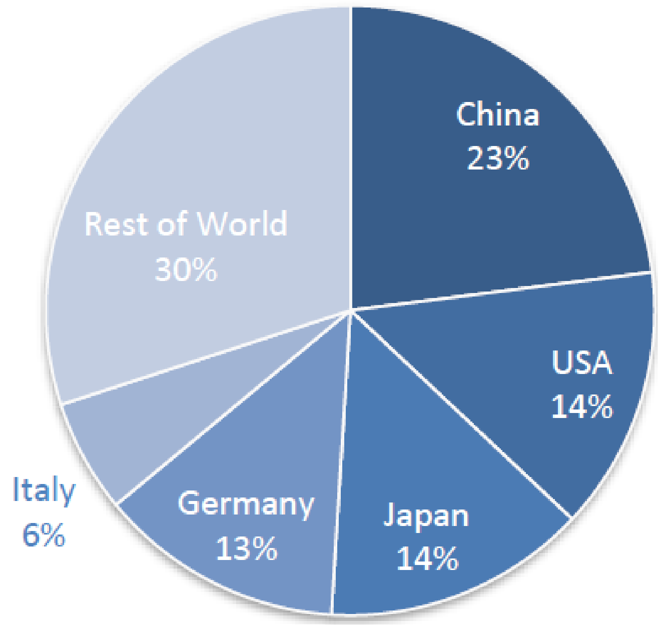


Figure 3: *Cumulative global PV installations 2016*

Source: *(IHS, 2016)*

Concentrated Solar Power (CSP) remains with very limited capacity (4 GW today and 70 to 256 GW in 2040 according to the IEA scenarios), i.e. less than 3% of global capacity. As shown in Figure 3, Spain is the leader in CSP deployment with 2,362 MW installed capacity in 2016, followed by USA with 1,804 MW, India 454 MW and all other countries have a small contribution to the total capacity installed across the globe. According to the Climate Investment Fund, the largest CSP project in the world until January 2016 is North Morocco and global operational power stands at 4,705 MW.

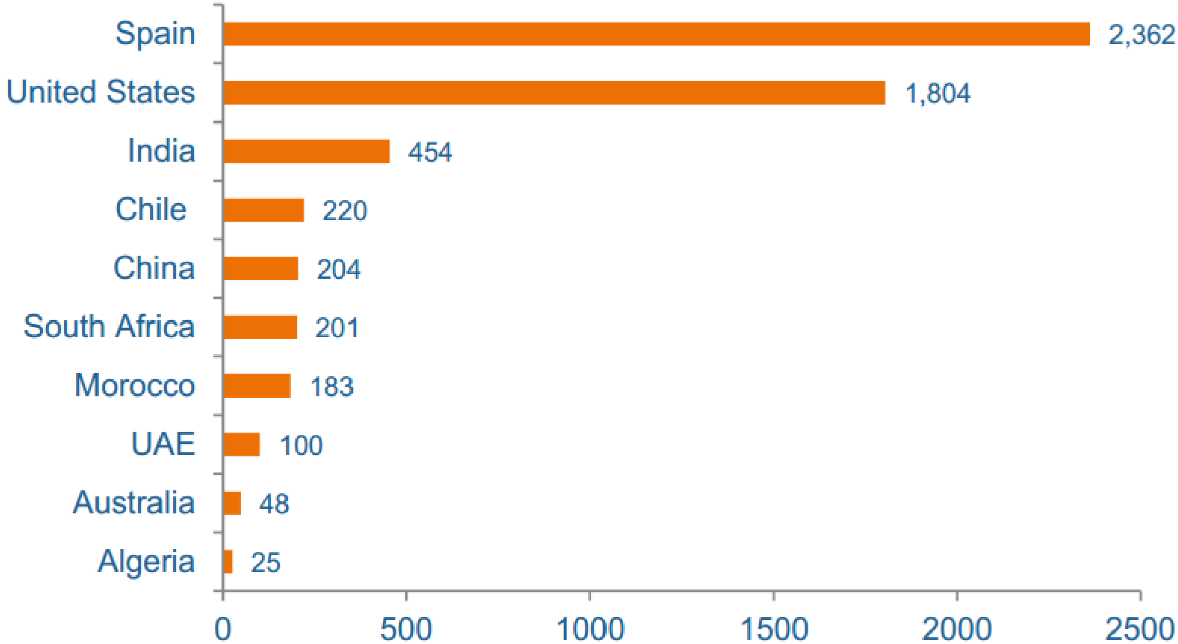


Figure 4: Global installed solar heating / cooling capacity, 2000-2015

Source: (Statista, 2016)

According to Tampakis and al, (2013)the total energy consumed in the EU must be produced from RES. Solar energy is one of the renewable energies capable of contributing to the reduction of foreign energy dependence as well as energy-related environmental impacts (IPCC, 2011; Panwar et al. 2011). According to Eurostat data (Eurostat, 2012), Germany was the largest producer of solar energy in Europe in 2012, with 2.26 Million toe (tonnes of oil equivalent) produced, followed by Italy (1.62 Million toe), and Spain (0.7 Million toe). Other countries with high suitability for solar energy generation, such as France, Greece and the United Kingdom produced much more modest amounts in 2012, with respectively 0.345, 0.145 and 0.102 Million toe. Supporting the deployment of solar energy systems, NREP (National Renewable Energy Plans) details the Member states strategies and measures to meet the binding 2020 target for the total solar energy installed.

The whole continent has a long duration of sunshine, excluding the large areas of tropical rainforests (the Guinean Forests of West Africa and much of the Congo Basin), since desert and savannah regions of Africa stand up as Earth's largest cloud-free area (Talor & Francis,2014) .Africa is dominated by clear skies even beyond deserts (example : Sahara, Namib, Kalahari),(The weather network, 2017*)*. The eastern Sahara/northeastern Africa is particularly noted for its world sunshine records. The area experiences some of the greatest mean annual duration of bright sunshine, as the sun shines bright during approximatively as much as 4,300 hours a year,(*Du*nlop, S. (2008*)* which is equal to 97% of the possible total. This region also has the highest mean annual values of solar radiation (*Riordan, P.; Paul G. Bourget;*) (the maximum recorded being over 220 kcal/cm^2*(*Wadsworth, F.H.; United States. Forest Service,1997*)*.

The distribution of solar resources across Africa is fairly uniform, with more than 85% of the continent's landscape receiving a global solar horizontal irradiation at or over 2,000 kWh/ m^2 year (Solar GIS) Also, the theoretical reserves of Africa's solar energy are estimated at 60,000,000 TWh/year, which accounts for almost 40% of the global total, thus definitely making Africa the most sun-rich continent in the world (Liu, Z. 2015).

Declining solar equipment costs are expected to significantly increase solar installations in Africa with an industry projection forecasting that the continent's annual PV market will expand to 2.2 GW by 2018 (IRENA, 2016). Future installations for harvesting solar energy in Africa will tend not to be found within the equatorial and subequatorial climate zones, that are located in the western part of Central Africa usually near the equator but that extend as far north and south as the 8th or 9th parallel in both hemispheres, since they are systematically linked with almost permanent cloud cover and only intermittent bright sunshine. Therefore, countries that entirely lie in this wet-humid zone such as the Republic of the Congo, Equatorial Guinea, Gabon, Rwanda, Uganda, Burundi, Liberia and Sierra Leone are by far the least favored in solar power of all the continent and except for these eight quoted nations, each other African country experiences over 2,700 hours of bright sunshine on at least a part of its territory. Many perpetually sunny African nations like Egypt, Libya, Algeria, Niger, Sudan, South Africa and Namibia for instance could rely on developing their tremendous solar resources on a large scale thanks to the immense surface of their territory and at reduced prices. 50 MW photovoltaic power plant is planned for Garissa in Kenya, a city located at the equator where the sun is said to shine for about 3,144 hours each year on average, and it is expected to produce approximately 76,473 MWh/year (the-star.co.ke). 155 MW photovoltaic power plant is planned for Ghana, and is expected to be completed in 2015 (*bbc.co.uk*,*2017*). The Kingdom of Morocco's solar plan, which is one of the world's largest solar energy projects and estimated to cost about $9 billion, was introduced in November 2009 with the aim of establishing 2,000 MW of solar power by 2020. Five sites have been selected for the development of solar power plants combining a number of technologies including concentrated solar power, parabolic through as well as photovoltaics, with the 500MW phase one solar power complex at Ouarzazate being the first to be developed (I*EA* , 2017.) The first part of the 500MW project is set produce 160MW of power by 2015 (*Reuters Editorial*,2017*)*.

Nowadays, some studies had been done by many researchers throughout the world concerning solar energy implementation. We did not find a study carried out for the solar suitability at regional scale but a lot of researches had been carried at continental scale for instance the study conducted by Ehsan Noorollahi et all in Iran have considered technical, environmental, geographical and GIS and fund that 14.7% of Iran's land has a suitability level of excellent, 17.2% are in good level, 19.2 are in fair level,11.3% are in low level and 1.8 have poor level. The work carried by Mevlut Uyan in Turkey, to conduct this study residential areas, land use, roads, slope and transmission lines information were collected for the study area from different sources ,and then groups the final index model in four categories groups such as" low suitable" "moderate", "suitable" and "best suitable and discovered that 15.38% (928.18 km^2) of the study area has low suitability, 14.38% (867.83 km^2) has moderate suitability , 15.98% (964.39 km^2) was suitable and 13.92% (840.07 km^2) has the highest suitability for solar farms area. 40.34% (2434.52 km^2) of the study area was not suitable for solar farm areas. One the same way , **G**hazanfar Khan and Shikha Rathi carried out a study in India using GIS to create series of maps to illustrate possible locations for large-scale SPV power plant. Resulting locations have been analyzed by exclusion criteria. The area which is situated at 26.920N, 70.9000E with the maximum summer temperature of 43C has been chosen as most suitable site for SPV plant in Rajasthan. Nevertheless Bonkaney et all study has studied the impact of dust and temperature on the efficiency of PV module in Niamey and find that the dust accumulation has the greatest impact on the performance of the PV module followed by temperature, relative humidity and cloud cover exposed during 23 days the energy output reduced by 15.29% and the power output and the conversion efficiency of the PV module dropped by 2.6% and 0.49% respectively .Another study conducted in Niamey by Maigargue Dankassoua show that Niamey has a considerable solar potential despite the disturbances of clouds and dust.

1.2.3 GIS tools based on MCDA support systems

The study of the potential site of solar PV power plant implementation is not an easy task, because of the different parameters you have to take into consideration. GIS-based on multi-criteria decision analysis approaches have been used for over fifteen years now as a tool to solve this problem (Malczewski, 2006). Therefore, GIS is best defined as a decision support system including the integration of spatially referenced data in a problem-solving environment (Cowen, 1988). The main method used for multi-criteria decision analysis include (Velasquez and Hester, 2013):

- Outranking methods, such as the Elimination Et Coix Traduisant la Realite (ELECTRE) family (Roy and Vincke, 1981; Vincke, 1992), the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) I and II methods (Brans and Vincke, 1985), and Regime Method Analysis (Nijkamp et al., 2013);
- Value or utility function-based methods, such as the Multi-Attribute Utility Theory (MAUT) (Keeney et al., 1979), the Simple Multi-Attribute Rated Technique (SMART) (Von Winterfel et al., 1986); the Analytic Hierarchy Process (AHP) (Saaty,1980); and
- The most elementary multi-criteria technique, the Simple Additive Weighting (SAW); and other methods like Novel Approach to Imprecise Assessment and Decision Environment (NAIADE) (Munda, 1995), Flag Model (Nijkamp and Vreeker, 2000); Stochastic Multi objective Acceptability Analysis (SMAA) (Lahdelma et al., 1998).

The Geographical Information System (GIS) reached a high level of maturity and emerged as a powerful tool to build solar energy strategies and to integrate large amounts of PV into flexible, efficient and smart grid. GIS is able to handle a large quantity of spatial data and underpinning decision making for the spatial deployment of PV. Using GIS and Multicriteria Analysis (MCA) together provide a fine lens for the optimal site selection for plants intallation. GIS-based MCA is commonly used to solve the conflicts of location suitability and harmonizing the tradeoffs. Application of GIS and renewable energy resource planning include wind farm sitting, photovoltaic electrification, biomass evaluation, visual impact assessment, etc. (Ramachandra and Shruthi, 2007; Tegou and al, 2010). The analytic hierarchy process (AHP) method that was introduced by Saaty (1980) is a flexible and easily implemented MCA technique and its use has been in the literature with many examples in locating facilities and land suitability analysis (Georgiou et al, 2012). Ghazanfar Khan and Shikha Rath showed that the area which is situated at 26.920N, 70.9000E with the maximum summer temperature of 43°C has been chosen as most suitable site for SPV plant in Rajasthan.

1.2.4 Current energy and energy projection in Niger

Niger has significant energy potential, rich and varied, that is weakly exploited. It consists of biomass (firewood and agricultural residues, the main source used by households for cooking), uranium, mineral coal, oil, natural gas, hydroelectricity and solar energy (Niger energy sector,2015). Proved reserves of uranium in the north region of Agadez are estimated at about 450 000 tones. The exploitation of Niger's uranium began in the 1970 by two companies of the French group AREVA. They are the Mining Company of the Air (SOMAIR), founded in 1968, whose capital is held by the AREVA Group and the State of Niger respectively with 63.4% and 36.6%, and the Mining Company of'Akouta (COMINAK) created in 1974 and owned 34% by AREVA, 31% by SOPAMIN (State Society of Niger). 25% by OURD (Overseas Uranium Resources Development Company Ltd, Japan) and 10% by ENUSA (Empresa Nacionaldel Uranio SA, Spain).

Third mine was opened in 2010 by the Society of Mines of Azelik (SOMINA), created in 2007 following Niger's policy of diversification of partners in the exploitation of its natural resources. It's ownership is 37.2% by the China National Nuclear Corporation (CNNC), 33% by the Company's mining heritage of Niger (SOPAMIN), 24.8% by Chinese society ZXJOY Invest, and 0.5% by company Korea Resources Corporation (KORES).

Production began in 2011 with 100 tons of uranium metal, 200 tons in 2012 and 300 tons in 2013 before reaching normal capacity of 700 tons per year from 2015. The three companies accumulate an average annual production of about 5 000 tons, making Niger the first uranium producer in Africa and the fourth worldwide, after Australia, Canada and Kazakhstan.

Mineral coal reserves located in northern Niger are over 90 million tons. Around 70 million tons are in Salkadamna, in the Tahoua region. A project for their development should start soon, for the production of electricity and coal briquettes for cooking energy. Another deposit of 18 million tons has been in operation since 1976 in Anou Araren of the Agadez region. It is used on-site in a thermal power plant that supplies the northern area with electrical energy. Other significant deposits exist on the site Solomi, in the same region of Agadez.

Natural gas is part of the riches contained in soil of the Niger, but its exploitation has not yet begun. Reserves are estimated to be about 18.6 billion m^3.

The hydroelectric potential, meanwhile, is estimated at approximately 280.5 MW, including 130 MW in Kandadji, 122.5 MW on the River Niger in Gambou and 26 MW in Dyondyonga on Mekrou. In addition, several sites suitable for micro hydro are identified on seasonal rivers (Goulbi Maradi and Tahoua Maggia) and tributaries of the Niger River (Sirba, Goroubi, Dargol).

Solar energy is possible throughout the territory where the average insolation level is 5 to 7 kW/ m^2/ day with an average of 8.5 hours per day(CNES). Wind speeds, ranging from 2.5 m/s in the south to 5 m/s in the north, are in favor of wind turbines to pump water.

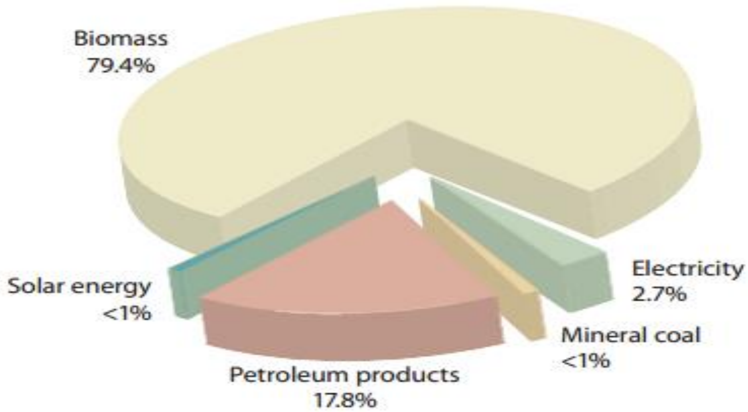
Table 1: Energy resources (2015)

Resources	Reserves
Uranium	450 000 tonnes (Reserves proven)
Mineral coal	90 million tons
Crude oil	1.18 billion barrels oil in place
Natural gas	18.6 billion m^3
Hydropower	280 MW
Solar energy	6 to 7 kWh/m^2/day

Source: SIE/MEP

The valuation of this important energy potential would ensure a regular supply of sufficient and sustainable energy for the country, and even to other countries in the sub region. Despite this rich potential, access to energy is still a challenge for the authorities. Final energy consumption in Niger is estimated at 0.15 toe per capita, one of the lowest in the world (Salifou Gado, 2015). The weakness of this value is mainly due to limited access of Niger's households to modern energy and its diversification.

Indeed, over 90% of Niger's households use wood as fuel for cooking. Access to modern cooking fuels and other modern energy is still very limited (ECS, 2015). According to the energy balance of 2012, total primary energy supply in the country is estimated at 2747 ktoe, of which over 70% comes from biomass.



Source: SIE/MEP.2015

Figure 5: Distribution of finale Primary Energy Consumption

The National Electricity Company (NIGELEC) founded in 1968 which has a monopoly on transmission and distribution, and the Coal Company Anou Araren (SONICHAR), which produces electricity in a thermal coal power plant. The electricity produced by SONICHAR is transported and sold to mining companies and NIGELEC. Niger is highly dependent on imports, covering more than 75% of its national electricity needs. Its power supply is ensured by 5 interconnection lines from Nigeria (Salifou Gado, 2015).

Table 2: interconnection lines(2015)

Interconnection line	Voltage (kV)	Capacity (MW)
Birni N'Kebbi-Niamey	132	120
Katsina-Gazaoua	132	60
Damasak-Diffa	33	5
Kamba-Gaya	33	5

Source: SIE/MEP

• Zone 1: Zone River supplied by the 132-kV interconnection line Birnin Kebbi (Nigeria) - Niamey (Niger), with a contract capacity of 120 MW but currently limited to 80 MW;

• Zone 2: Niger Central East Zone (NCE), which includes the regions of Zinder, Maradi and Tahoua and is supplied by the interconnection line 132 kV Katsina (Nigeria) - Gazaoua (Niger) with a contractual power of 60 MW currently limited 40 MW;

• Zone 3: The North Zone, which supplies the towns of Agadez, Tchirozérine, Arlit, as well as mining companies with a 132 kV transmission line;

• Zone 4: the East Zone of the Diffa region supplied by the network with 33 kV at Damasak in Nigeria;

• Zone 5: Zone Gaya / Malanville supplied by a 33 kV interconnection transmission line at Kamba in Nigeria.

There are three categories of production costs in Niger. They consist of the NIGELEC domestic power plants (USD 0.22/kWh), coal-fired plants (USD 0.12/kWh) and electricity imports from Nigeria (USD 0.04/kWh) (RRA, 2013).

Niger enjoys high solar radiation conditions in all eight of its regions. Average solar radiation is 5-7 kWh/m^2 per day (figure 9), and there are seven to ten hours of sunshine per day on average. April to August is the period of high insolation, when the diurnal variation between minimum and maximum radiation values is small the lowest radiation values are observed in December and January. The rainy season coincides with the high solar radiation summer months. Although solar radiation levels are high in all four meteorological stations, there appears higher variability over the year in cities of Arlit and Agadez located in the northern and central regions respectively. Niamey and Zinder, located at lower latitudes, show less variability across the year, hence making them excellent locations for harnessing solar energy.

PV solar electric power: 20 MW in the Niamey area is under negotiations and under way, for more detail see the literature review of the RRA 2013.the figure 6 gives the detail about the insolation throughout the country.

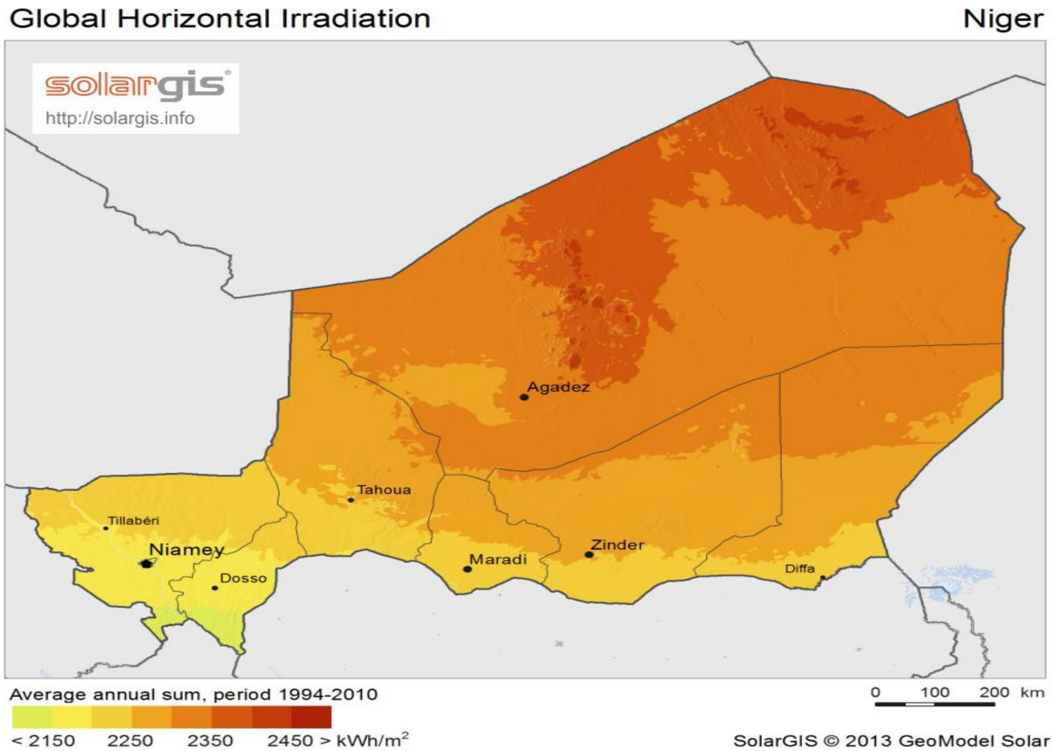


Figure 6: Niger global horizontal irradiance

Chapter 2

Solar radiation fundamentals

2.1 Electromagnetic spectrum of the sun

The sun emits energy in form of electromagnetic waves which are propagated in space without any need of a material medium and with a speed of; 3 x 108 ms-1. Electromagnetic radiation emitted by the Sun reaching out in waves extends from fractions of an Angstrom to hundreds of meters, from x – ray to radio waves. Electromagnetic radiations are usually divided into groups of wavelengths. The wavelength regions of principal importance to the earth and its atmosphere are the:

- Ultraviolet (UV) – (300 – 400 nm) representing 1.2%
- Visible (VIS) - (400 – 700nm) representing 49%
- Infrared (IR) - (740 – 4000 nm) representing 49%

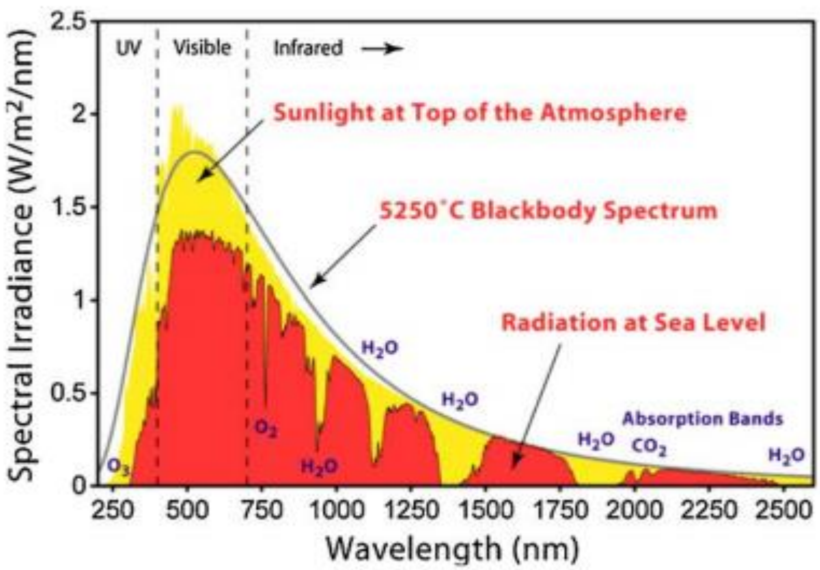


Figure 7: Solar radiation spectrum regarding to its wavelength.

2.2 Factors affecting the amount of solar radiation received on the earth surface

2.2.1 Astronomical factor

Only a tiny portion of the energy of the sun reaches the earth's surface. The sun-earth distance constitutes one of the factors affecting the amount of solar energy available to the earth. The earth is known to be orbiting round the sun once in a year and at the same time rotates about its own axis once in a day. The two motions determine the amount of solar radiation received on the earth's surface at any time and any place. For example, the shortest distance of the Sun from the earth is called the perihelion, and is 0.993AU. (Astronomical unit of distance (AU) =1.496 ×-10^8km). It takes place on December 21st. On 4th of April and 5th of October the earth is just at 1AU from the sun, while on 4th of July, the earth is at its longest distance, 1.017AU from the sun; this position is called Aphelion. Thus, the variation in the sun-earth distance causes variation in the amount of solar radiation reaching the earth surface.

The eccentricity **(Eo)** of the elliptical orbit is expressed in terms of the sun-earth distance (r) and the average, r_0 of this distance over a year. It is given by:

$$\mathbf{E_o = (r0/r)^2 = 1+0.033\ cos(2\pi d_n/365)} \qquad (1)$$

where d_n is the Julian day number in the year. For example, d1=1 on January 1 and

d365 =365 on December 31.

The season we experience on earth is caused by the elliptical motion of the earth round the sun, and its rotation about its own axis determines the diurnal variation of the amount of radiation received. The amount of solar radiation received on a unit horizontal surface area per unit time at the top of the atmosphere is known as the Extraterrestrial Radiation Ho, and is given by:

$$\mathbf{Ho} = 24/\pi\ Isc\ \mathbf{Eo} \cos\phi \cos\delta\ (\sin\omega s-(\pi/180)\ \omega s \cos\omega s) \qquad (2)$$

This equation gives the average daily value of extraterrestrial radiation, Ho on a horizontal

surface at the top of the atmosphere, while

$$\mathbf{I_o}=Isc\ \mathbf{E_o} \cos\phi \cos\delta\ (\cos\omega i-\cos\omega s) \qquad (3)$$

gives the average hourly value of the extraterrestrial radiation.

where ϕ is the latitude of the site,

δ is the declination angle of the sun

ωi is the hour angle

ωs is the sun set hour angle

2.2.2 The atmospheric factor

Solar radiation however has to pass through the atmosphere to reach the ground surface, and since the atmosphere is not void, solar radiation in passing through it is subjected to various interactions leading to absorption, scattering and reflection of the radiation. These mechanisms result in depletion and extinction of the radiation, thus reducing the amount of solar radiation we receive at the ground surface of the earth. Several atmospheric radiation books describe and discuss these radiation depletion mechanisms.

2.2.3 **Other radiation and atmospheric related parameters**

The background of radiation parameters, such as cloudiness index, clearness index, turbidity, albedo, transmittance, absorbance and reflectivity of the atmosphere through which the solar rays pass to the ground surface is very necessary for the utilization of solar energy. Also, the knowledge of the meteorological parameters such as number of sun shine hours per day, relative humidity, temperature, pressure, wind speed, rainfall etc. is desirable and important for accurate calculation of parameters of some solar energy devices. For example, it is needed to know the average number of sun shine hours per day for accurate calculation of PV (photovoltaic) power needed in sizing solar power electrification for any location. In Niamey, for example, we have an average of 8.5 hours of sunshine in a day.

2.2.4. Global solar irradiance

Global solar irradiance, H, which is the total sw-radiation flux, measured on a horizontal surface on the ground surface of the earth, comprising the direct sw- solar irradiance, Hb and diffuse sw-sky irradiance, Hd . In simple mathematics, the three fluxes are connected as in the following

$$H = Hb + Hd \qquad (4)$$

2.2.5. Direct solar irradiance, Hb

The direct solar irradiance or solar beam Hb, is the component of the total solar irradiance H, which comes directly from the top of the atmosphere, through the atmosphere, to the ground surface not deviated, nor scattered nor absorbed.

2.2.6. Diffuse sky irradiance, Hd

This radiation flux is also known as the sky radiation. It is short wave radiation, coming from the sky covering angular directions of 180^0 to the sensor. It is incident on the ground surface as a result of scattering and reflection by particles in the atmosphere.

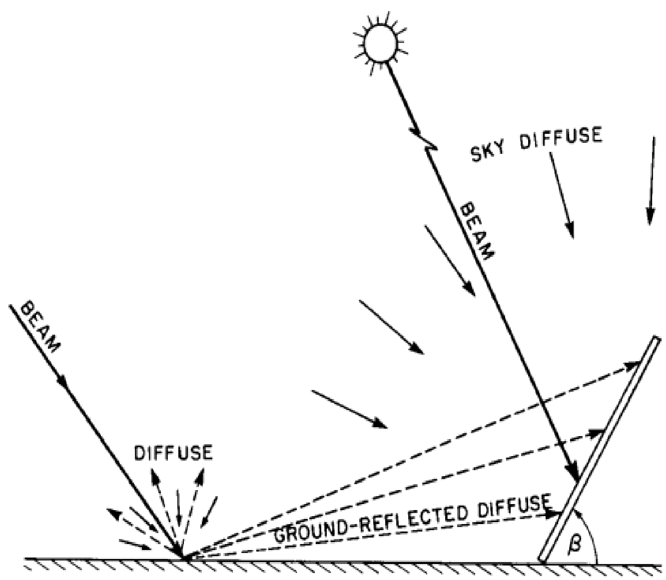


Figure 8: Incidence of beam, sky diffuse, and ground-reflected radiation on an inclined (Muhammad Iqbal,1983)

2.2.7 Air mass

Another important parameter to consider is the air mass. For an evaluation of extinction processes in the atmosphere it is necessary to know the total mass or optical path of atmosphere which the beam traverses on its way to the surface (or the level in question). When the solar radiation passes through the atmosphere, it collides with dust, aerosols and gases such as water vapor, ozone, carbon dioxide. During these collisions, a part of photons energy is absorbed by these particles. The solar irradiation is attenuated in relation to the path length of the irradiation, the shortest path occurs when the sun is at the highest point in the sky (the zenith). At this point the power density of the irradiation equals to 1353 W/m^2 and it is defined as solar constant. By definition, the AM0 is the case of extraterrestrial radiation (i.e. no air mass at all). AM1.5 is commonly used as a reference air mass in data sheets of PV modules.

During the sunrise and the sunset, the zenith angle becomes higher resulting to a higher air mass value. The higher air mass coefficient the lower the direct irradiation and the higher the diffused irradiation because of the absorption and collision. Figure 8 shows the various air mass values for different zenith angle.

The longer the path, the greater the air mass between the sun and the surface. For a given zenith, the real air mass is given by the equation, $AMreal = 1$

$cos\ \theta Z$, with θZ the zenith angle given by the equation:

$$\theta Z = cos{-}1(cos\ (\emptyset) * cos(\delta) * cos(\omega) + sin\ (\emptyset) * sin(\delta) \quad (5)$$

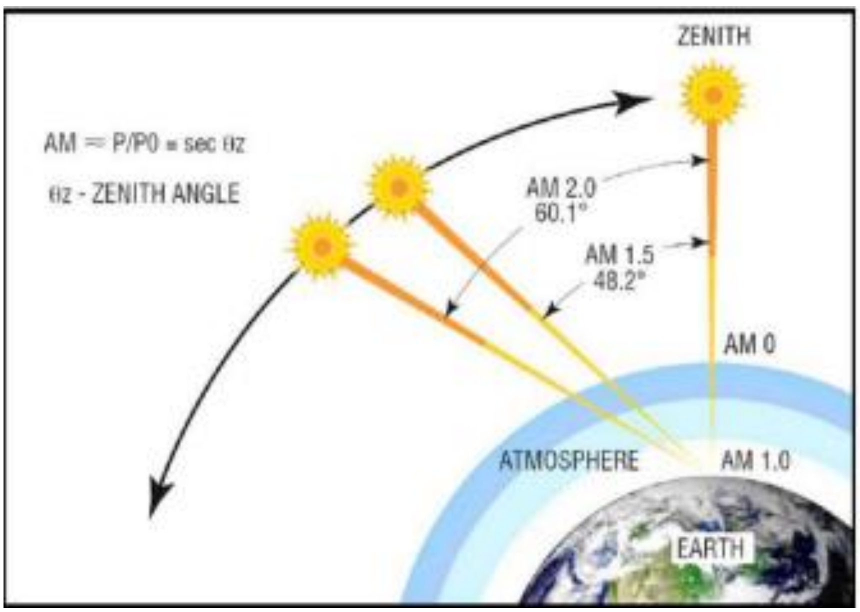


Figure 9: *Various air mass.*

2.2.8 sun's geometry

One parameter influencing the amount of solar energy reaching the earth is the solar geometry. The specific astronomical situation of the earth's revolution around the sun and its rotation around its polar axis are the dominating effects.

The earth revolves around the sun in a plane called ecliptic plane. The earth's axis is inclined at 23.45° (constant in time) with respect to normal of the ecliptic plane. This angle is called solar declination δ**.**

The declination angle is the angular position of the sun with respect.

For practical purpose, a constant value for a given day the following formula can be used:

$\delta \cong 23.45 * \sin(360+(284+n)/365)$ (6)

n is the number of the day in the year.

Daily variation of solar radiation is usually calculated on the basis of solar time which is defined in the following way:

A solar day is the time interval between two consecutive crossings of the sun's path with the local meridian. The length of this interval changes from day to day (deviation<30sec) and its mean value equals to 24h.

Solar noon is the time of the crossing of the sun's path with the local meridian.

The difference between the solar time and the local mean time is expressed by the empirical equation of time E,

$E \cong 9.87 * \sin(2B) - 7.53 * \cos(B) - 15 * \sin(B)$ (7)

E is in minutes with

$B = 360 * (n-91)/360$ (8)

The solar time differs from standard time (time determined by the time zone) due to:

variations of the length of the solar day, and A difference between the local longitude and the standard longitude of the appropriate time zone.

Solar time = local time +E, where the local time is a function of local longitude.

The true solar time (TST) is calculated from local time (LMT).

$TST = LMT + E$ (9)

$TST = LST - DST + 4(ls - l)$ (10)

With DST = 1 during daylight saving time and 0 otherwise.

To calculate the irradiance on any plane the position of the sun with respect to that plane (precisely: to the normal to that plane) must be known. The sun's position in the sky can completely be described by two quantities: the solar altitude (elevation above the horizon) and the solar azimuth.

The sun's altitude is given by the spherical trigonometry:

$\sin \alpha = \sin(\boldsymbol{\delta}) * \sin(\Phi) + \cos(\boldsymbol{\delta}) * \cos(\Phi) \cos(\omega)$ (11)

The solar azimuth is given by:

$\cos \psi = (\sin \alpha * \sin(\Phi) - \sin(\boldsymbol{\delta})) / (\sin\alpha \cos(\Phi))$

(12)

w is the hour angle and is given by the formula below:

$$w = (LST-12) * 15° \quad (13)$$

$$LST = UTC + 1.\ h.\ Ll / 15° \quad (14)$$

Ll is the local longitude of the selected sites.

2.2.9 Solar energy applications

The major areas of application of solar energy are in the provision of low and high grade heat, direct conversion to electricity through Photovoltaic cells and indirect conversion to electricity through turbines.

2.2.10 Solar energy thermal conversion application

1. Production of hot water for domestic use.
2. Cooling and Refrigeration.
3. Solar passive drier in;

- Agriculture drying.
- Wood seasoning.
- Mushroom culturing or growing
- Production of pure water- distillation.

2.2.10 Solar electrical conversion application

1. Thermal to electricity conversion.
2. Solar electric power systems (PV) Photovoltaic cell.

- Solar water pumping.
- Hydrogen Fuel.

There are some other types of solar electric power systems based on different technologies. Some of which are in practice and some are under development. Some of them are:

- Crystalline silicon
- Thin films
- Concentrators
- Thermo-photovoltaic
- Organic solar cells

2.3 PV cell operation

A PV cell is a semiconductor p-n junction photodiode that can generate electrical power when exposed to light (Said, et al. 2012). There are several types of semiconductor materials used for PV cells manufacture. The most common types known commercially are mono-crystalline, polycrystalline and amorphous silicon (Si) (Said et al. 2012). The principal operation of a PV cell is based on the photovoltaic effect.

The photovoltaic is a combination of the Greek word photos, (light,) and the name of the Italian physicist Alessandro Volta (1745-1825). He is the first who discovered the functional electro-chemical battery and the unit of electricity, Volt is named after him. Hence, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible light or other radiation.

Subsequent separation of the photo-generated charge carriers in the junction, Collection of the photo-generated charge carriers at the terminals of the junction.For the photons which have less energy than the energy of the band gap (which is 1.1eV for the silicon) no electrons is ejected. But when the photon has energy greater than the energy of the band gap, one electron will be moved from the valence band to the conduction band creating an electron-hole pair. The electrons created in the conduction band are able to move freely. The free electrons have to move in a particular direction by the action of the electric field present in the PV cells. These flowing electrons compose a current, which can be drawn from external use by connecting a metal plate on top and bottom of the cells. Finally, current and voltage, created because of its built-in electric field, generate electric power (Said, et al. 2012). The rate of generation of electric carriers (electrons and holes) depends heavily on the flux of incident light. The figure below shows the principle of this conversion.

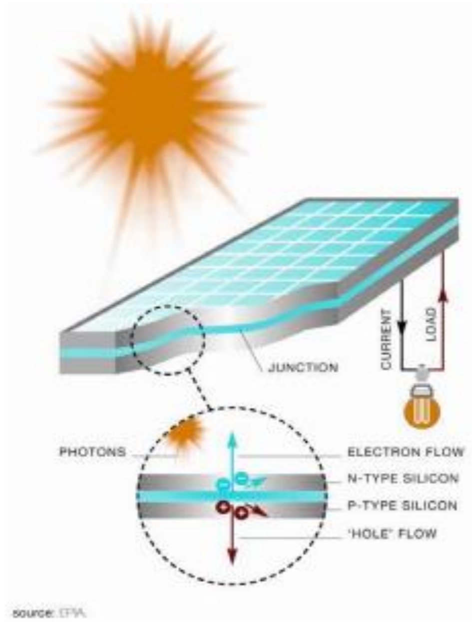


***Figure** 10:photovoltaic effect*

Chapter 3

Method and material

3.1 Material

3.1 .1 Study area

The area selected for present study is the city of Niamey with geographic extension of 13°30'49’’N Latitude and 2°06’35’'E Longitude, with and area 1062.355 km^2 (Mairie de Niamey) and has a population of around 1 302 810 inhabitants (INS, 2016). It has five urban areas (commune urbane: Niamey I, Niamey II, Niamey III, Niamey IV, Niamey V). the selected site for the case study covers moderately populated area, agricultural area, vegetation area, etc.…

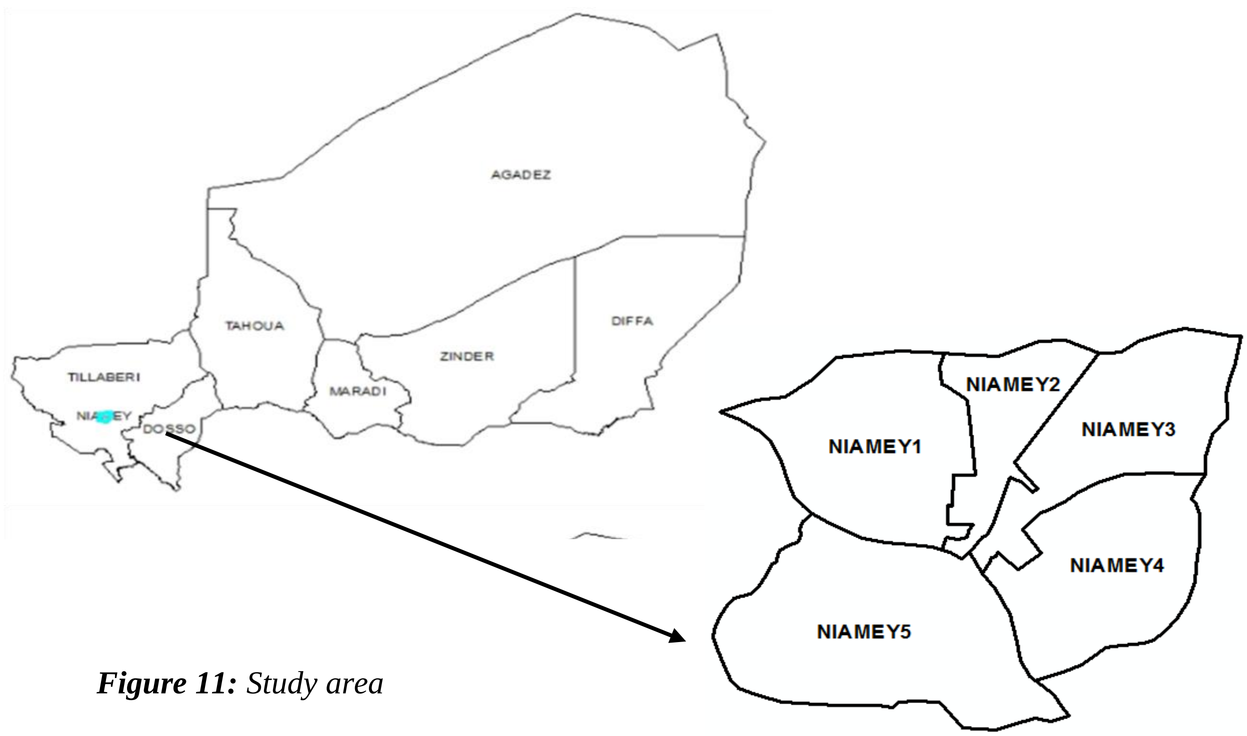


Figure 11: *Study area*

3.1.1 Meteorological characteristic of the study area

The study area has a semi-arid climate such that two major seasons can be clearly identified which greatly influence the daily weather patterns. These two seasons are named wet season with a duration of 3 to 4 mounts (June, July, August, September) and dry season from October to May.

The harmattan is cold and dry and starts usually from November to February with strong dust and wind.

3.1.3 Historical trend of temperature and global solar radiation over Niamey

Before the installation of solar PV system in one place we have to know the solar potential of this place. Niamey is a nice candidate for such project because the global solar radiation is between 7 to 4 kwh/m^2/day. The graph below shows the variation of the temperature and the horizontal global radiation during the last thirty years. The figure below indicates that the temperature is increasing over Niamey. This increase of the temperature leads to the warming effect which is the consequences of climate change. But for the solar radiation the trend is not the same because the figure shows a decreasing trend between the year 1884 to 1999 and an increasing trend between 2000 to 2013.

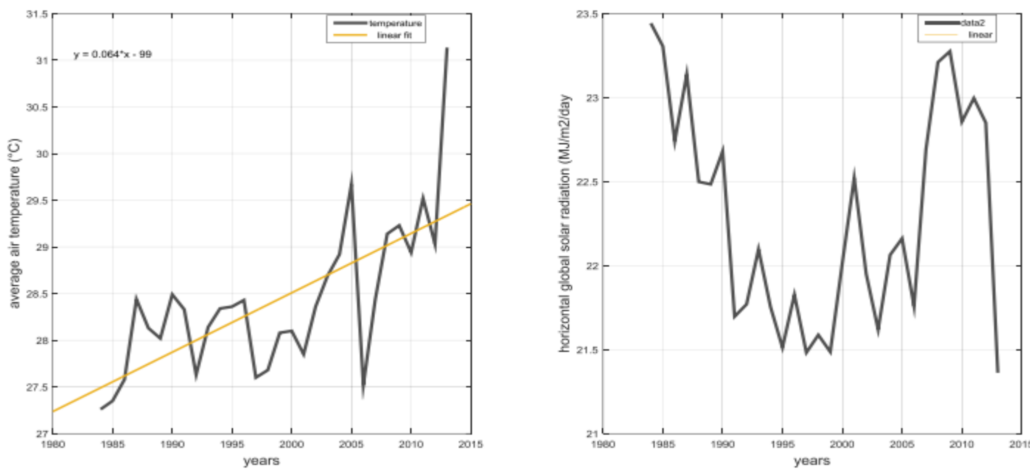


Figure 12: Historical trend of temperature and horizontal global solar radiation over the area of study(2015)

Source: Abdullatif WASCAL MRP CCE Thesis

3.2 Method

For the solar radiation, we are going to go on the base that Niamey has the potential to give solar PV energy because the ground measurement gives 6.104 kWh/m^2/day as ten years mean global solar radiation and (CNES, 2016) and the daily sunshine is fluctuating between 9.75 to 12.83 hours during the day (CNES,2014). Eight years of monthly solar radiation were collected from the National center of solar energy (CNES).We have used also the DEM of Niamey for the solar analysis throughout the town to see how the topography influences the solar radiation repartition.

There are several multi-criteria analysis methods. In this study, the weighted combination linear (WLC) technique was used. The flowchart below shows the process followed to determine suitable places for the implementation of solar PV power plant in the city of Niamey.

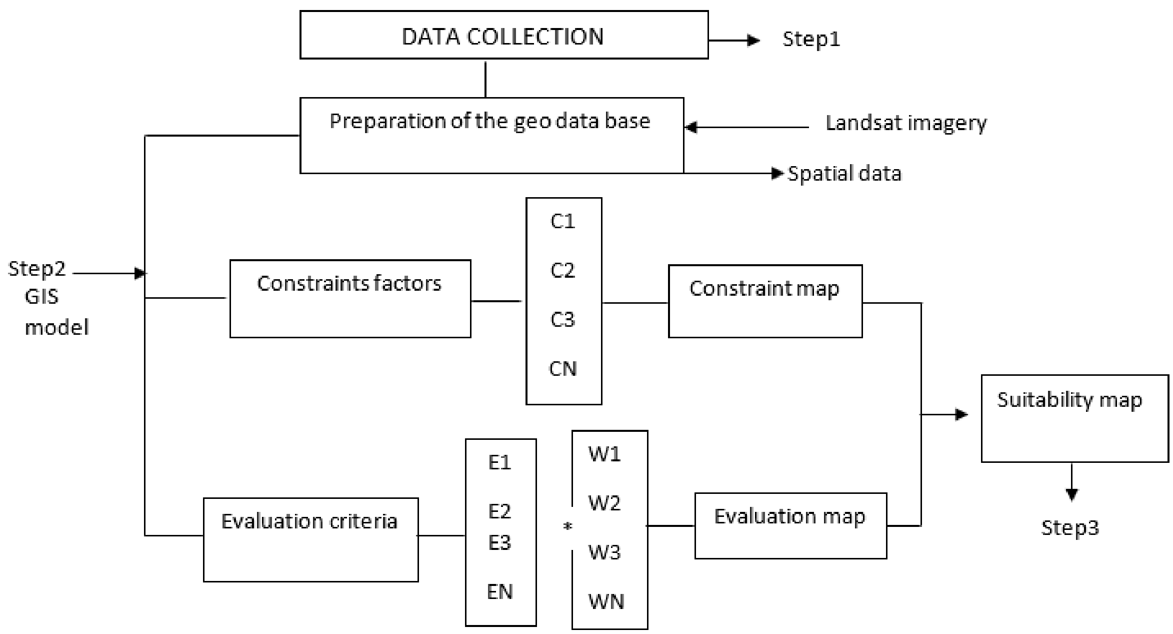


Figure 13: Flow chart of the methodology

3.2.1 Data measurement method at CNESS

For the measurement of the global solar radiation, CNES uses three kinds of pyranometer. They consider the one which gives the most accurate values (less error). From these devices solar radiation is recorded each 5 minutes from the sunrise to the sunset these records are stored with a data. After every month, the recorded data in excel format is directly transferred from the data logger to a computer on which the data are converted to daily scale. The figure below shows the apparatus used for the measurements.

Figure 14: Apparatus of solar radiation measurement of CNES

Table 3: Geographic coordinate of apparatus emplacement

sites	Longitude	Latitude	Elevation (above the sea in m)
CNES	2°6’17’’E	13°31’25’’N	213

3.2.2 Data Preparation and analysis

For the solar radiation data was obtained from National Center of Solar Energy (CNES) for eight years. From the daily data obtained, the monthly and annual solar radiations were computed. For this study, monthly solar radiation was used. In fact, monthly solar radiation distribution can be used to examine the seasonal variations. In terms of variation solar radiation is considered as stable comparing to the other climate variables.

3.2.3 GIS modelling

Based on preferences, specifics requirements or predictors of some activity, land use suitability analysis is defined as the most relevant spatial pattern for future land usage. The mapping and analysis of suitable land use for any study is the most helpful application in GIS (Collins et al., 2001). GIS is a computer-based system that manages information quantifying the domain and gives spatial analysis operators. The various alternatives can be quantified and the considered project can be taken into account using such tools. GIS tools address three domains. The first one as information database, the second one for modelling where maps can be derived and the last one, for decision support systems (Eastman et al., 1991). GIS links with MCDA can be used to investigate the suitable area for any purposes.

Weighted linear combination (WLC) and Boolean overlay operations such as intersection (AND) and union (OR) are seen as the simplest and widely used in GIS environment (Malczewski, 2004). This method has been employed for Optimal site selection for sitting a solar park (Andreas Georgiou, 2016). The land suitability analysis using WLC approach and the Boolean constraints based on GIS as the multi-criteria decision analysis (MCDA) was used in this study.

3.2.4 Reparation of the geo-database

Using GIS for land suitability analysis for solar PV implementation required data layers and software. All the GIS data used in this study are summarized in the table below. ARCGIS 10.3 was used to conduct this study. This study aims to develop a framework model using a GIS system, using satellite imagery and both raster and vectors as input data. For the land use map of Niamey, it is ownership.

Table 4 : *GIS input Data*

Data	Description	Source	Format	Resolution
Niger boundary	Country outline and administrative	AGRIHMET	Vector (polygon)	-
Transmission lines	Transmission lines	African Development Bank Group	Vector (line)	-
Roads	Roads	Digital Chart of the World	Vector (line)	-
Elevation	Digital Elevation Model	STRM	Grid	30m
Land use	tif file	ownship	Raster	-

3.2.5 Classification of the Landsat8 image

3.2.5.1 Landsat8 image

Landsat 8 is the last launched satellite in the series of Landsat imagery. The Landsat imagery contains data hidden in each pixel, which when unlocked gives a lot of information. The Landsat 8 imagery is composed of 9 spectral band and 2 thermal band which are helpful for measuring and monitoring vegetation, moisture, biomass, soil, etc.

3.2.5.2 Landsat8 image downloading

For downloading landsat8 image we went to the Earth explorer website. By understanding the image code that we have used to get our area of concern image, you can easily get the image you are searching .**LC08L1TP19051-20170720-2017072801** is the code of the image we used for our study.

3.2.5.3 Image Preprocessing

For that QGIS was used. First, we imported the 11 bands of the Landsat image that we have downloaded, and then to facilitate this preprocessing step we activated the semi-automatic classification package which is a free open source plug-in for QGIS that allows semi-automatic classification of remote sensing images. After the image gotten after the semi-automatic classification we have used it to extract the area of our study.

3.2.5.4 supervised classification

For this step, we have imported the result gotten from QGIS in ARCGIS to do the classification. For that, we have used the combination of the bands (band 5, band 4, band 2) which is close to the natural image. The training manager tools in ARCGIS was used for the classification. To build one class, polygons were drawn in the places which have the same color. After the drawing, we have selected them and merged in one entity in the reflectance image. Water is represented by the color blue, vegetation is represented by the color green, build-up area is represented by the color red etc. At the end, the image is classified in 6 classes such us: water body, build-up area, bare surface, rock area, farm land, vegetation. To facilitate the Boolean overlay and the weighted sum process the model builder was used. In model builder to finalize the suitability analysis for the sites, the layers had been converted into raster. The coordinate systems was projected to World Geodesic System 1984-Universal Transverse Mercator Zone 31 North. All the process is summarized in the model builder figure.

3.3 Identification of criteria

To implement solar PV project, we need to know the environmental characteristics of the area. So, identification of some criteria is necessary. The criteria of solar PV implementation should consider several aspects such as economic feasibility, environment problems that can happen, and physical aspect. To conduct this study, we followed the work done by Mevlut Uyan, Based on the results and the data availability, the sites for solar PV implementation in the city of Niamey are proposed in the table 5.

Table 5: Criteria for selection PV power plant (Mevlut Uyan,2013*)*

N^0	**Criteria**	**consideration**
1	Solar radiation (most insulated area)	technical
2	Land use (barren land, agricultural land)	financial
3	Distance from road <2000m	Financial/technical
4	Slope less than 3%	technical
5	Distance from transmission line < 1000m	Financial/technical
6	Distance from residential area< 2000m	social

3.4 Boolean overlay

Boolean variables serve to delineate area that is not suitable for consideration and helpful to use as constraints (Eastman, 1999). Based on Boolean logic, the buffer zones were employed and the CON tools are used to assign a true (assigned to 1) or false (assigned to 0) value to the criteria.

The criteria used in this study for forbidden zone are:

- Build up area to avoid the proximity to inhabitants;
- Vegetation area to avoid deforestation;
- Agriculture land to avoid the reduction in the productivity

3.5 Determination of weights.

Weighted linear combination or simple additive weighting (SAW) approach is based on the concept of a weighted average and the most commonly used decision rule. The procedure of WLC is based on three (3) pillars. In the first place, the normalization of the suitability maps is needed. After that, you need to assign the weights of relative importance to the suitability's maps. Finally, using the combination of the weighted and normalized maps, the overall suitability map score is obtained. This method is given by the following equation:

$$S = \sum wi\, xi \tag{15}$$

Where S is the suitability, wi is weight factor of i and xi is the criterion score of factor i. By applying the Boolean constraints, the procedure is modified by multiplying the suitability calculated from the factors by the product of the constraints (Eastman, 1999):

$$S = \sum wi\, xi \,.\, \prod cj \tag{16}$$

Where cj is the criterion score of the constraint of j.

3.6 Evaluation of the criteria

In all the case selecting the criteria are normally studied in the form of different groups including environmental, economic, geographical, demographic, land use, technical, etc. In this study, based on other studies and by reviewing the criteria in terms of position of solar farm through MCA method. Once the criterion of factors are established on the same scale, the combination of all factor maps can be made (Drobne and Lisec, 2009).

3.10.1 Solar radiation

To evaluate the optimal location to install a PV system, solar radiation is one of the most important factor that determine whether the candidate location will receive sufficient sunlight throughout the year. Generally, PV system efficiency is higher in sunnier region, as a rule of thumb, a PV system require a minimum solar radiation of 1300 kWh/m^2/year for economical operation (US EPA & Nrel,2013). For Niamey, the solar radiation can go beyond 2000 kWh/m^2/year according to the data we have analyzed.

3.6.1 Land use

An important environmental factor to consider when choosing locations for solar farm siting is the land use (Ehsan Noorollahi,2016).In this study land use was evaluated for six levels as: water body, vegetation, build up area, farm land, bare land, rock outcrop. Bare land is considered the best area for solar PV farm, and the farm land has the lowest priority for exploitation of solar farms.

3.6.2 Distance from road

Construction of new access roads for transportation of goods and equipment is very expensive and is one of the unavoidable factors in the construction of solar plants (Ehsan Noorollahi,2016). Certainly, the easier the access to the plant, the lower the cost of plant construction and maintenance will be. Many studies considered the distances between 500m to 10000m from the transmission line such as the study done by (Justin Robert Brewer, 2014), (Mevlut Uyan, 2013).

3.6.3 Distance from transmission line

For the selection of solar farm sites, the distance from the transmission line is economically very important this is because in general, electric power transmission lines influence the positioning of solar farms in terms of safety, network security, and quick accessibility for installing equipment and potential repairs. An important criterion in siting of solar farms is thus the distance from transmission lines. Ghazanfar Khan, Shikha Rathi suggests that, the solar farm should not be located further than 10000 m from transmission lines. The study done by Ehsan Noorollahi, Dawud Fadai consider a distance of 50 km away from the transmission lines as not suitable for solar farms establishment. An ideal location should be close to the transmission line.

3.6.4 Slope

To create the slope, we used the Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM). The slope plays a key role in the choosing of sites for solar farms. Solar energy implementation cost is higher in hilly areas than is flat areas. In general, lands with a slope greater than 4% have a lower priority since panels shadow the next row and adversely affect the system efficiency (Ehsan Noorollahi & Dawud Fadai,2016).

3.6.5 Distance from residential area

Due to the potential unfavorable environmental impacts on populated areas and urban growth, we consider in this research, the distance of solar farms from residential areas is as one of the important criterion in solar PV farms site selection. In the study done by Mevlut Uyan, a considers the distance of 5000 m from residential areas is considered as suitable for solar PV implementation (Mevlut Uyan.2013).

3.7 Determination of weights

A weight can be defined as a value assigned to each criterion factor on its importance relative to other criterion factors. These assigned values are based on human judgment. However, these judgments should not be subjective or arbitrary but, they must be objective and based on the expert's knowledge. The higher the weight for a given factor, the more important the factor is within the total system utility (Malczewski, 1999). The sum of all criterion weights should be equal to one.

$$\sum_{i=1}^{n} w_i = 1 \tag{19}$$

Where wi represents the weight of a given criteria

i and n is the number of criteria.

The pairwise comparison method is used in this current study to determine the weight for each criterion factor based on judgments. The technique of pairwise comparison was introduced by Saaty in the context of Analytical Hierarchy Process (AHP) (Saaty,1977).

Several researchers utilized the AHP method and presented a framework for prioritizing the alternatives (Uyan, 2013). Pairwise comparison requires a creation of ratio matrix (Malczewski, 1999) and the weight is obtained by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria (Drobne and Lisec, 2009). The value given to each criteria was based on the judgment proposed by Saaty according to their importance as shown in table below.

Table 6: Relative importance scale (Saaty, 1980)

Intensity of importance	**Definition**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
5	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	comparison

After making the pairwise comparison matrix, the weight of each criteria is produced by following procedure (Saaty, 1977)

- Sum the values in each column of the pairwise comparison matrix;
- To normalize the values, each cell is divided by its column total; and
- The weight is determined by making the mean values of the rows.

Based on the literature and judgments, the pairwise comparison is presented in the table below:

Table 7: Pairwise comparison matrix

Criteria	solar radiation	slope	distance from road	distance from transmission line	Land-use
solar radiation	1	5	9	8	8
slope	1/5	1	2	3	4
distance from road	1/9	1/2	1	2	7
distance from transmission line	1/8	1/3	1/2	1	2
Land-use	1/9	1/4	1/7	1/2	1
Σ	1.54	7.083	12.64	14.5	23

Following the procedures given above, by taking into account the table above we got the normalized matrix and the weighted presented in the table 7.

Table 8: Normalized matrix and the weighted determination

Criteria	solar radiation	slope	distance from road	distance from transmission line	Land-use	Calculated weight
solar radiation	0.646	0.705	0.172	0.551	0.339	0.483
slope	0.129	0.141	0.158	0.206	0.173	0.161
distance from road	0.0718	0.070	0.079	0.137	0.304	0.130
distance from transmission line	0.081	0.047	0.039	0.068	0.0869	0.064
Land-use	0.072	0.035	0.011	0.034	0.0434	0.039

After determining the weight, the consistency ratio was determined. This which will allow to validate or reject the normalized matrix. It is mathematically given as : **CR=CI/RI** (20)

Where RI is the random index which depends on the number of elements being compared shown in table 8, and CI represents the consistency index which provides a measure of departure from consistency and expressed as:

$$CI = \frac{\lambda - n}{n - 1} \tag{21}$$

Where, λ is the average value of the consistency vector, and n is the number of criteria. The CR should not be greater than 0.1, otherwise the pairwise comparison matrix has be revaluated.

Table 9: random index (Saaty, 1980)

ni	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	**0**	**0**	**0.58**	**0.9**	**1.12**	**1.24**	**1.32**	**1.41**	**1.45**	**1.49**

After the calculation of we found CR= 0.088 it means that CR=<0.1 and so the condition to accept the normalized matrix is fulfilled.

3.8GIS tools

3.8.1 Solar radiation calculation

Inputs to this process are a digital elevation model (DEM), the latitude of the scene center, and the date and time that we wish to accumulate insolation. We have used the SOLAR ANALYST tool to accumulate the energy striking the surface for the different months in the year of a Landsat8 image. For that, the other required inputs are the Julian day and the local time of day of image acquisition. As a reminder, the Julian day of year is simply the sequential number from 1 to 365 (or 366 if a leap year)

3.8.2 Boolean overlay maps

From the administration shape file of Niger, the shape file of Niamey was extracted, then from the satellite, Niamey reflectance was treated in QGIS and was clipped using CLIP tools. From the Niamey reflectance map, we classified this image in five classes (water body, vegetation, build-up area, bare and farm land) then water body, vegetation, build-up area, farm land was derived using the SELECT tools in ArcGIS. Getting each criterion constraint layer, the raster calculator in ArcGIS tools was used to get the final Boolean map for solar PV power plant implementation for Niamey using the model builder tool in ArcGIS.

3.8.3 Suitability solar farm lands maps

Transmission lines and road networks was buffered according to their criteria mentioned above. The Euclidian Distance in ArcGIS tools was applied for this purpose. With DEM and to create the slope layer, the SLOPE tool was used after making the previous step. In order to facilitate the decision making for making subjective assessment with numbers, a set of linguistic terms are used for accessing a criteria's weight. According to the weight of each criteria, the Weighted Overlay tool was applied to get the weighted linear combination map. The site suitability for solar farm implementation lands was obtained by using the TIMES tool in ArcGIS. The methodology used for this study is summarized in the figure bellow:

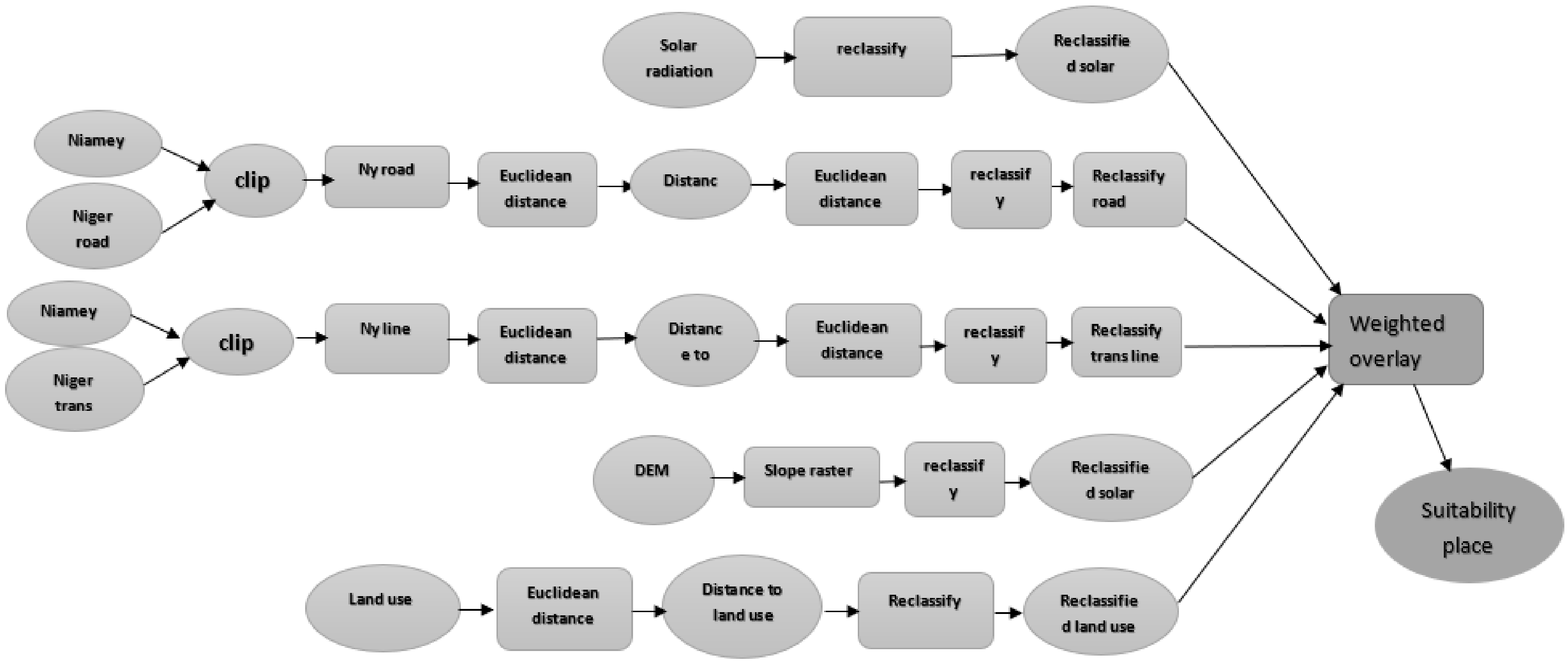


Figure 15: Model Builder Model Showing Final Stages of Suitability Workflow for Niamey

3.9 field visit to validate the model

To validate our model, we have visited the sites selected. Longitude and latitude of the sites allow us to go and see the physical characteristics of the sites and to take some values of the insolation of the places. After the sites analysis, we have done some measurement of the solar radiation of the sites. This measurement was done with an electronics device shown in figure16

Figure 16: Solar power meter

Chapter IV

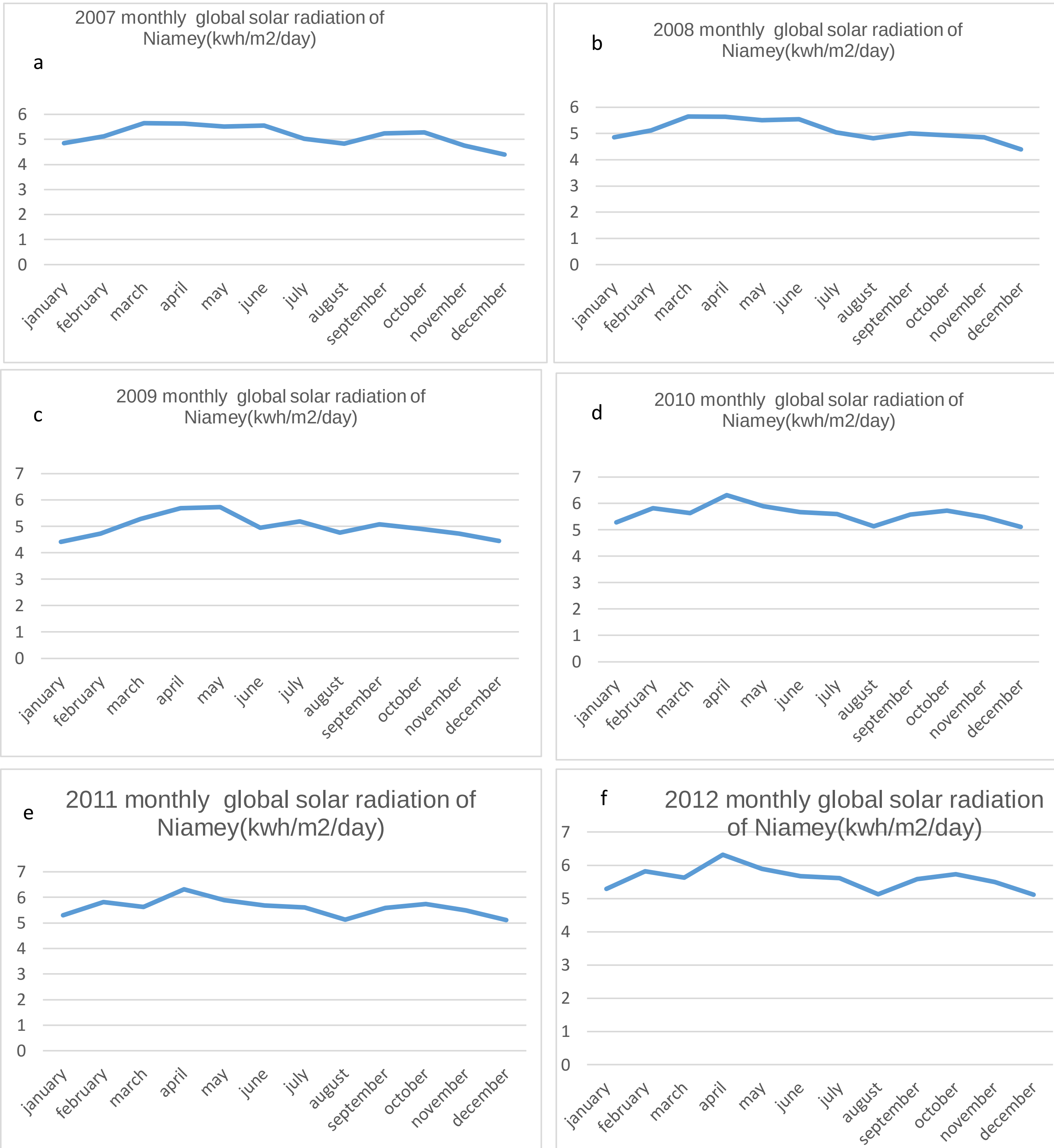
RESULTS AND DISCUSSIONS

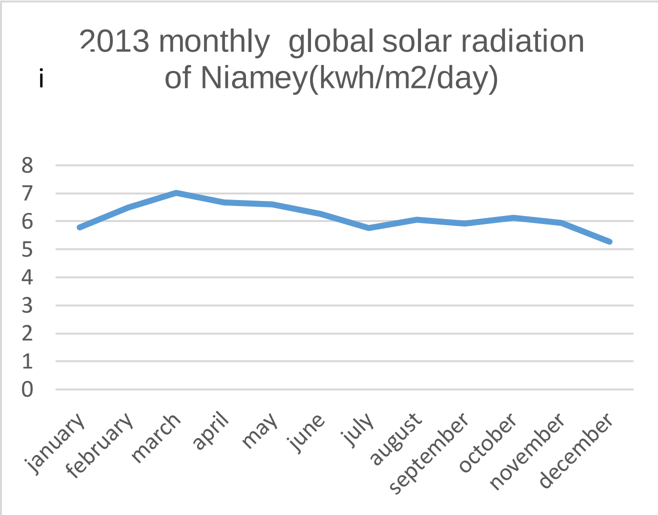
4.1 Solar radiation throughout Niamey

Five years of solar radiation has been collected from CNES. This solar radiation was in daily time steps and so from this, the monthly mean solar radiation was calculated. We have used the ARCGIS software to calculate the area of solar radiation through the different months of the year. The results of the data from CNES are plotted in figure17 and the area of solar radiation for the year 2016 is given by the figure18.

According to these graphs represented by fig17, the solar radiation's variation is not so important throughout the different years. The lower solar irradiance is observed during the rainy season from June to august and December due to the effect of clouds and aerosols which have a strong effect on global irradiance reaching the earth; the higher irradiance is observed between March April, May, June, September and October. The maximum irradiance is generally observed in April reaching a monthly mean of 7 kWh/m^2/day and the minimum is generally observed in August with a monthly mean of 4 kWh/m^2/day.

The results obtained from the solar radiation variation over the year are due to the seasonal variation of the climate. Niamey has a subtropical steppe semi-arid hot climate (koppen-Geeiger classification). It consists of three kinds of seasonal variation: hot season from March to May followed by rainy season from June to early September then finally a cooler season starting in October and lasting until February. Moreover, the dry season can be classified in three (3) parts: the cool season (from November to February), the hot season (from March to May) and the post-rainy season is in October (Sanon, 2007). From March to May the aerosol in the atmosphere is very low reason we observe high irradiance value over Niamey between March to June going beyond 7 kWh/m^2/day. Also in October, we observe significant irradiance values reaching about 6 kWh/m^2/day. The low values observed in the other months especially during the rainy season is due to the very cloudy atmospheric condition. But for the solar energy projects, there is not an extra difference between the higher and the lower values of irradiance fluctuating between 6 and 5 kWh/m.


a
2007 monthly global solar radiation of Niamey(kwh/m2/day)
0 1 2 3 4 5 6
january february march april may june july august september october november december
b
2008 monthly global solar radiation of Niamey(kwh/m2/day)
0 1 2 3 4 5 6
january february march april may june july august september october november december
c
2009 monthly global solar radiation of Niamey(kwh/m2/day)
0 1 2 3 4 5 6 7
january february march april may june july august september october november december
d
2010 monthly global solar radiation of Niamey(kwh/m2/day)
0 1 2 3 4 5 6 7
january february march april may june july august september october november december
e
2011 monthly global solar radiation of Niamey(kwh/m2/day)
0 1 2 3 4 5 6 7
january february march april may june july august september october november december
f
2012 monthly global solar radiation of Niamey(kwh/m2/day)
0 1 2 3 4 5 6 7
january february march april may june july august september october november december



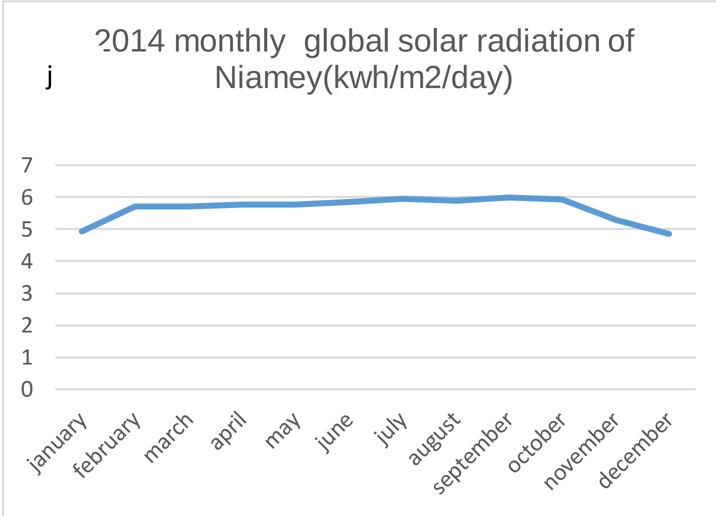


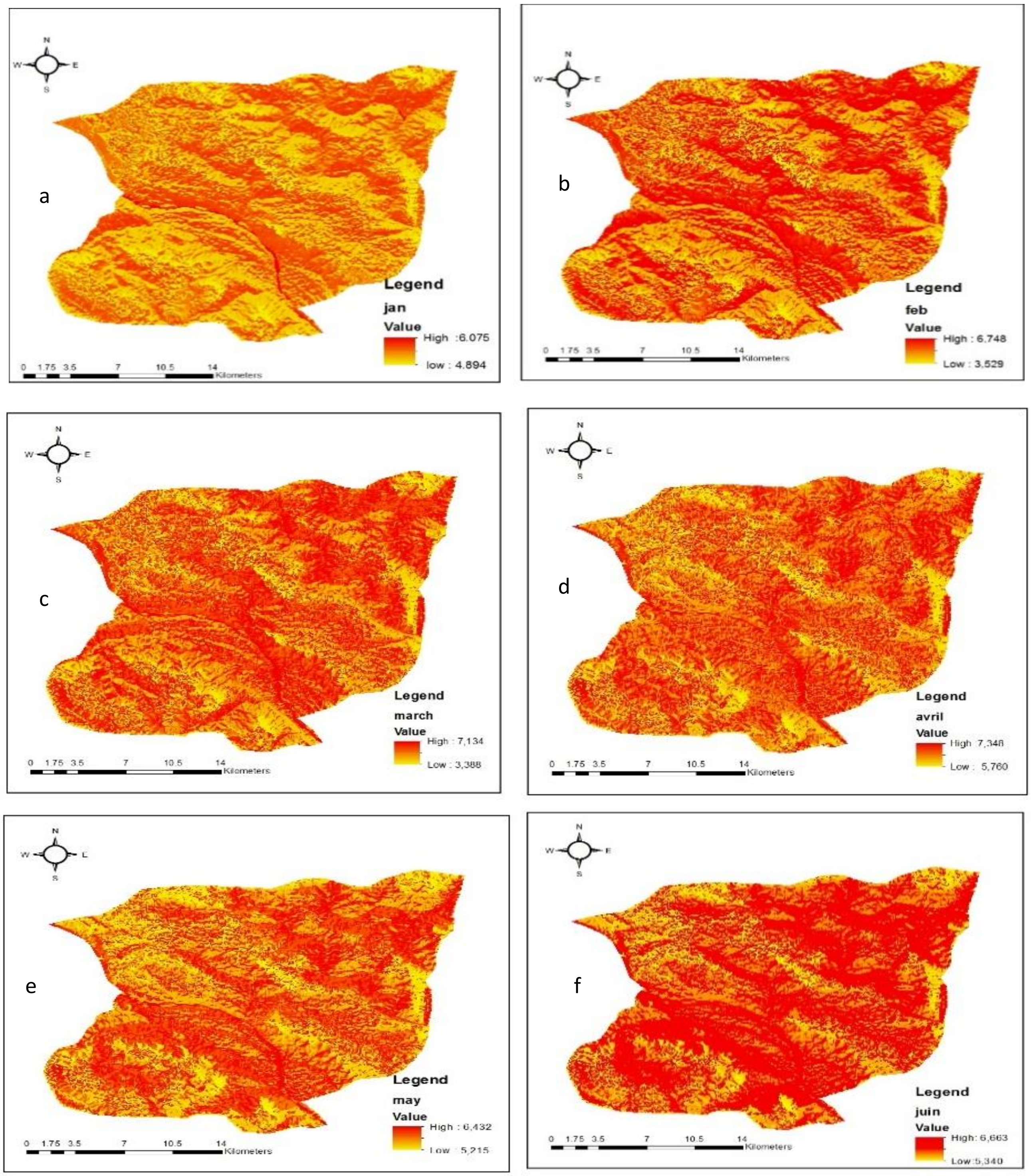
Figure 17: Monthly mean solar radiation from 2007 to 2014

4.2.GIS application

4.2.1 Area solar radiation of Niamey

The annual solar irradiance area of Niamey is obtained by calculating the monthly mean irradiance through the year. Variation in elevation, orientation (slope and aspect), and shadows cast by topographic features all affect the amount of insolation received at different locations. This variability also changes with time of day and time of year, and in turn contributes to variability of microclimate, including factors such as air and soil temperature regimes. Incoming solar radiation (insolation) originates from the sun, is modified as it travels through the atmosphere. The average solar insolation in the whole selected region is 6.841 kWh/m^2/day annually while for each month is different. The generated maps of monthly solar insolation are presented in the figure 18.

As we can see in the different maps the variation of the solar insolation depends on the month of the year. The moth of April has more insolation with a monthly maximum mean of 7.340 kWh/m^2/day and minimum of 5.760 kwh/m2/day followed by March with maximum of 7.134 kWh/m^2/day and 3.368 kWh/m^2/day as minimum. The lowest insolation occurs in August with a minimum of 2.522 kWh/m^2/day and December with a minimum of 3.664 kWh/m^2/day, due to the cloudiness in August and fog formation in December respectively.


a
Legend
jan
Value
High :6.075
low : 4.894
b
Legend
feb
Value
High : 6,748
Low : 3,529
c
Legend
march
Value
High : 7,134
Low : 3,388
d
Legend
avril
Value
High 7,348
Low : 5,760
e
Legend
may
Value
High : 6,432
Low : 5,215
f
Legend
juin
Value
High: 6,663
Low:5,340
0 1.75 3.5 7 10.5 14
Kilometers

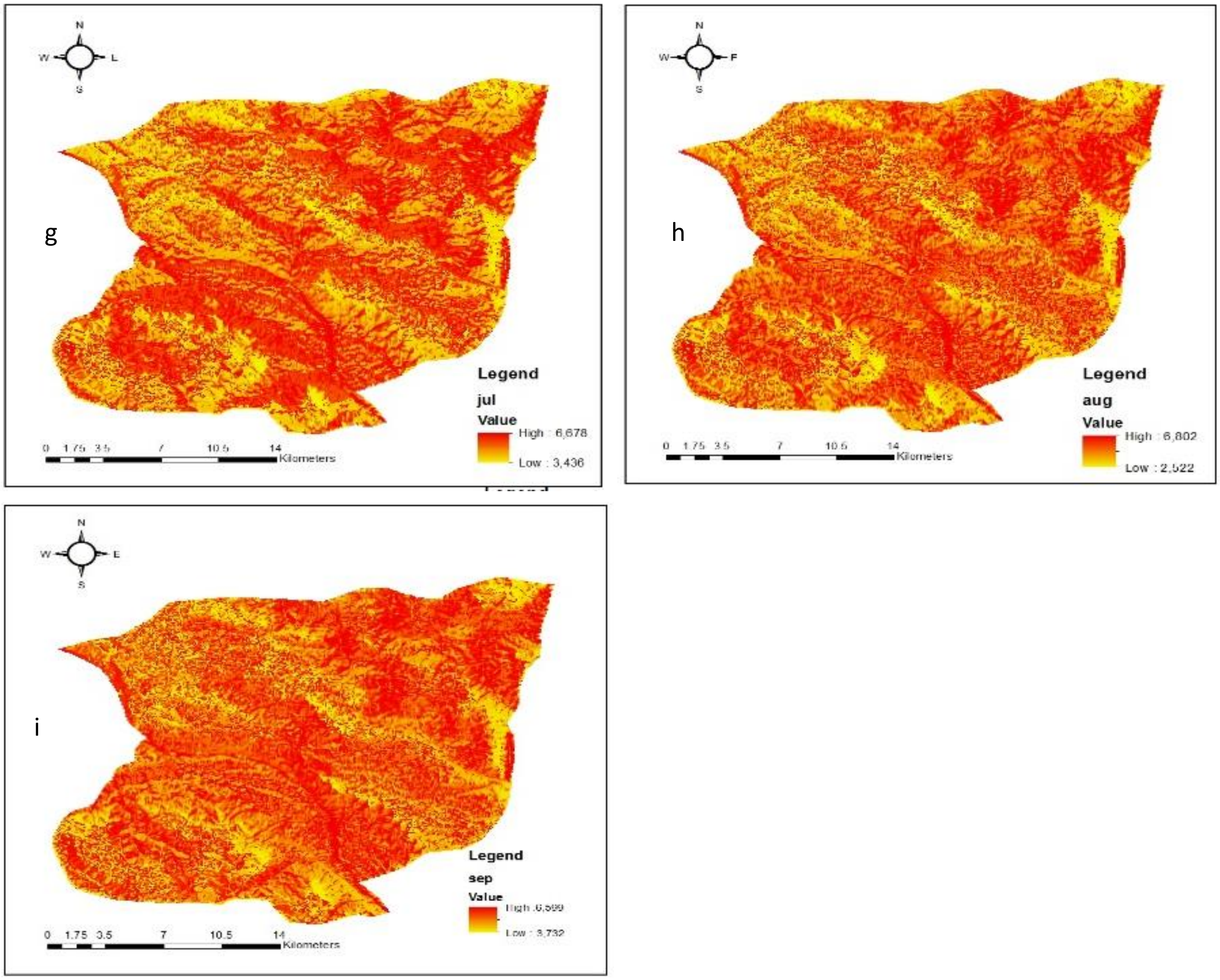


Figure 18: Monthly Solar Insolation(ArcGIS 10.3)

5.2.2 Suitability mapping

The constraint map obtained in this study took into account some criterion which have been described in the previous chapter. The constraint map used in this current work took into account the water bodies, build-up area, farm land, vegetation. A constraint layer regrouping all the unsuitable areas was created. Map algebra function of ArcGIS was used to merge and reclassify the layer maps. The unsuitable areas were attributed by 0 and the suitable with 1. The constraint areas occupy about 23.17% which is 246.227 km^2 of the study area as shown in figure 19. As result, the remaining area was assessed to select the best site to implement solar PV power plant in Niamey.

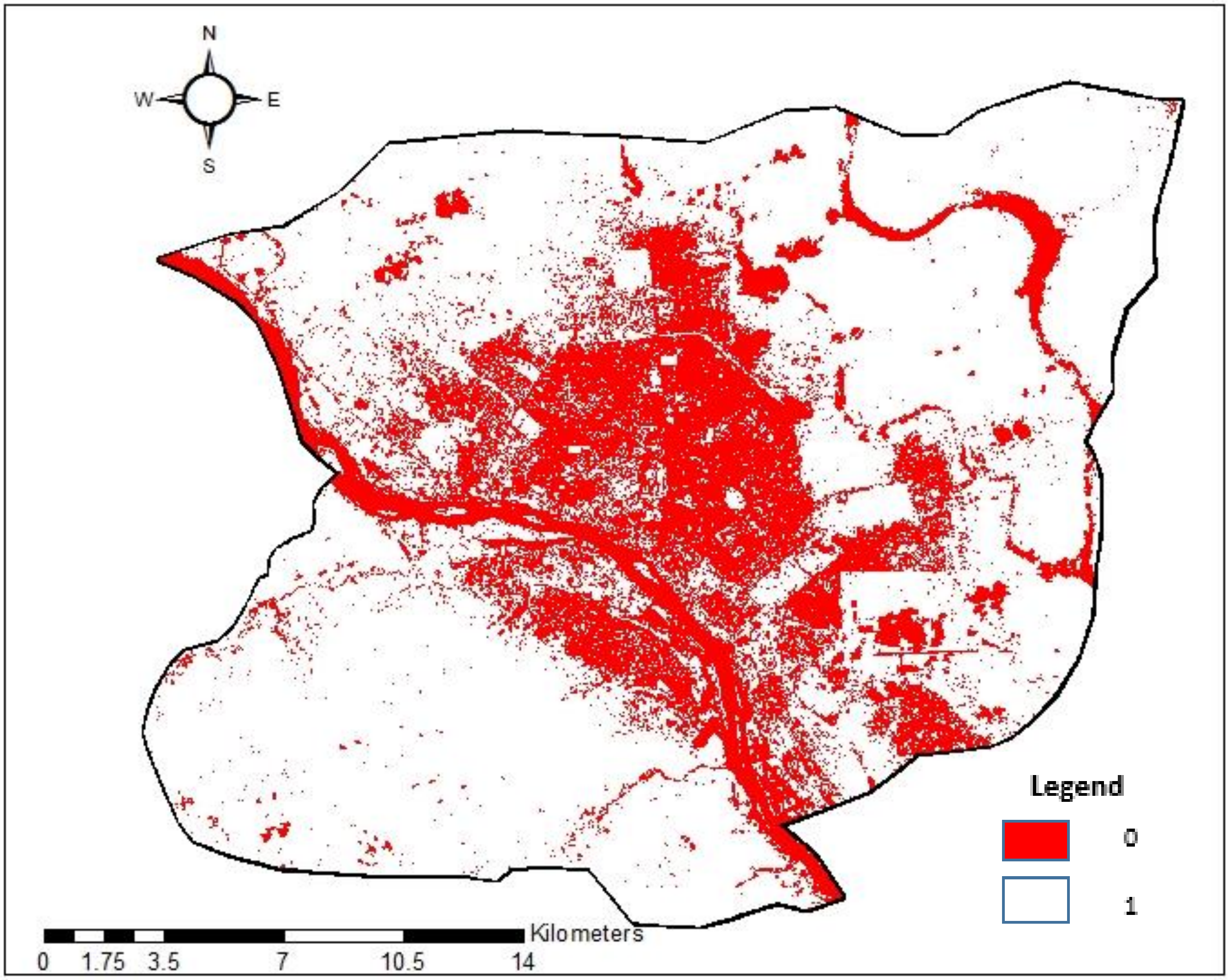


Figure 19: Constraint map for suitability solar PV for Niamey

The different criteria which were taken into account in this study including proximity to the transmission line, proximity to road network, slope factor and solar radiation are presented respectively in Figure 23 which are the Fuzzy membership layers. Road accessibility layer had values from 0.90 to 1. About 57% of Niamey area had value of 1. This range of fuzzy value showed that all of Niamey area has good accessibility to roads. In terms of access to power transmission lines, 58% of all selected area had a fuzzy value of 1. Minimum value of grid accessibility was 0.64. Most of Niamey city is flat so about 97.25% of the land have a slope less than 5% i.e. the fuzzy membership value is equal to one. For the Solar irradiance values, it was redefined by 9 evenly distributed categories from 4.317 to 7kwh/m2/day.

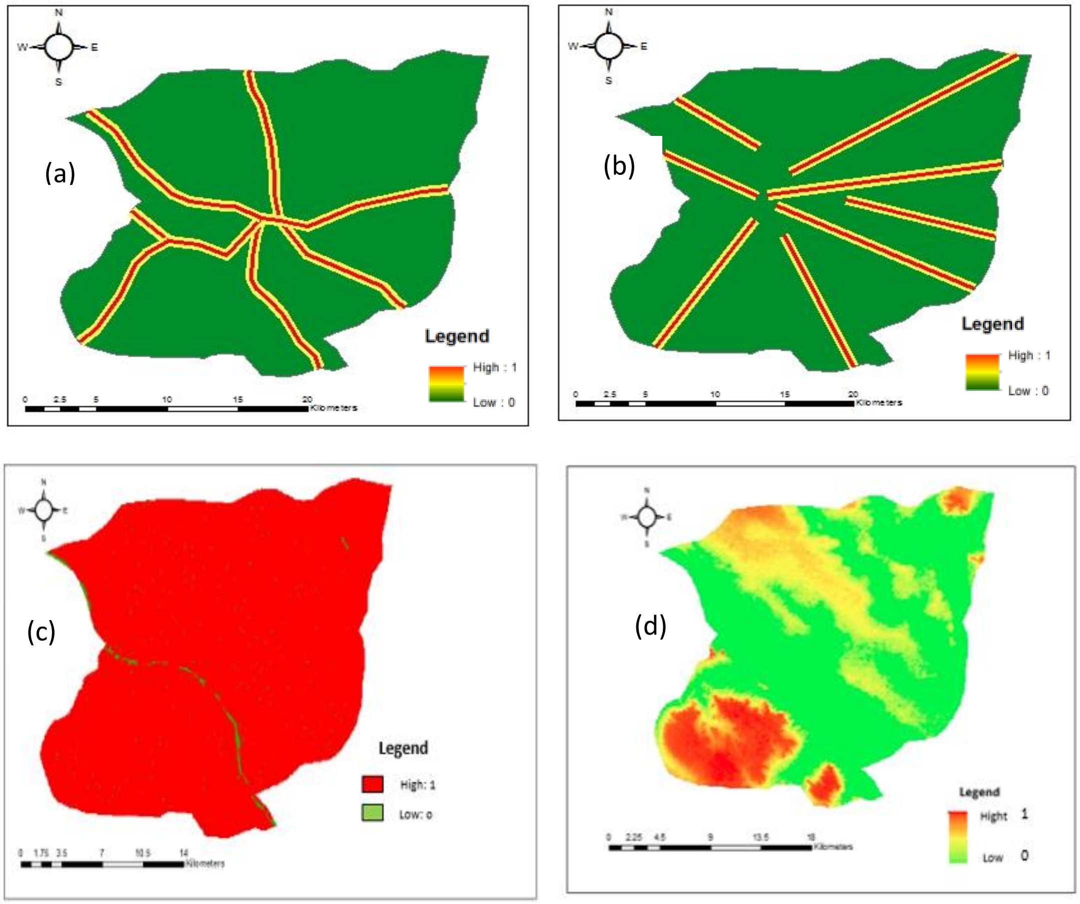


Figure 20: Standardized factor of road network(a), transmission line(b), slope(c) and solar radiation(d)

From satellite image wehave generated the land use map of niamey illustrated in the figure 24 .This map shows us the clear idea about the land use of Niamey.This land use map is classified in five classes, the buil-up area which is composed of houses and infrastructures,the water body represents the Niger river crossing Niamey and some small lakes,the vegetation represents all the places occupied by concentration of trees and grasses during the rainy season or places close to watershead, the bare land composed of sandy area, rock mountain and then the farm land used for agricultral activities.

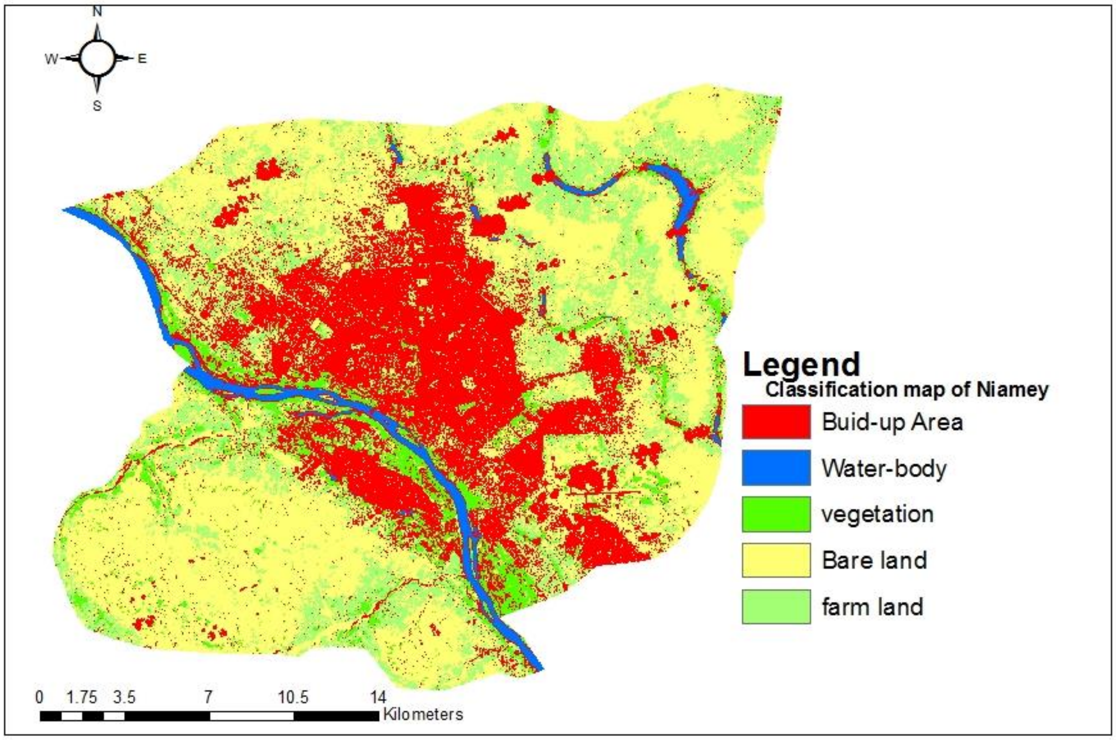


Figure 21: Land use map of Niamey

A land suitability map was determined by combining AHP with GIS for the logical location of solar farms site in city of Niamey in Fig. 25. In order to obtain the suitability maps, the evaluation criteria shown in Fig23 was used. The final index model was grouped into five classes such as low suitable, moderate, suitable and best suitable with an equal interval classification method. As a result, 65.27 % (693.4169 km^2) of the study area has low suitability, 3.68 % (39.1208 km^2) has moderate suitability, 2.78 % (29.5482 km^2) has high suitability and 5.08 % (54.0417 km$^{2)}$ has very high suitability for solar farms area 23.17 % (246.227 km^2) of the study area is not suitable for solar farm areas these results are summarized in table10.Then three sites had been selected among the very high suitability places: sites A with 22.5% very high suitability site (12.154km^2), sites B 53.33% of the very high suitability site (28.82 km^2) and site C 10.23% of the very high suitability site (5.53 km^2) the table11 gives more information of the sites.

Table 10: Land used by each score

score	classes	land use km2	land used %
0	constrains	246.227	23.17
1	low	693.4169	65.27
2	moderate	39.1208	3.68
3	suitable	29.5482	2.78
4	best suitable	54.0417	5.08

Table 11: Statistical summary of factor variable of the candidate sites

Factor variable	Site A	Site B	Site C
Geographic coordinate (longitude and latitude in decimal degree)	(1.997,13,458)	(2.05,13.452)	(2.111,13.424)
Distance from the transmission line(m)	1038.42	641.73	508.49
Distance from road network(m)	788.13	619.61	539.02
Area (km2)	12.154	28.82548	5.531585

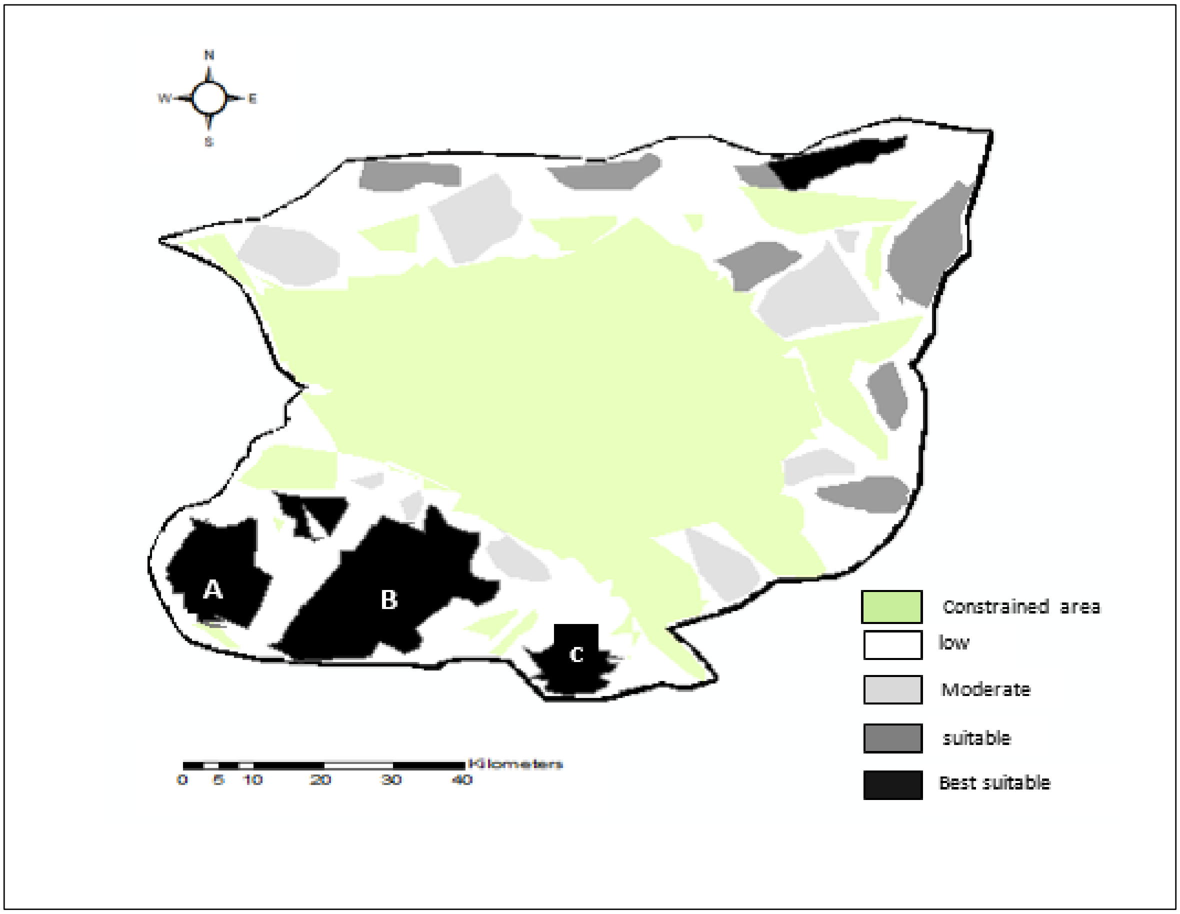


Figure 22: Suitability solar PV in Niamey

5.2 Model validation

5.2.1 Physical characteristics the selected sites

The sites selected are plateau and composed of three types of field: sandy area, shrub area and stones as we can see in the figure26 below. These places are located in the city of Niamey on the right side of Niger river on Say's road situated in the southern part of Niamey. For solar PV project implementation, it is not going to have a negative impact on the environment because the places are bare land so this will not affect the farmlands or vegetation. In fact, that is one of the biggest advantages of the selected sites.

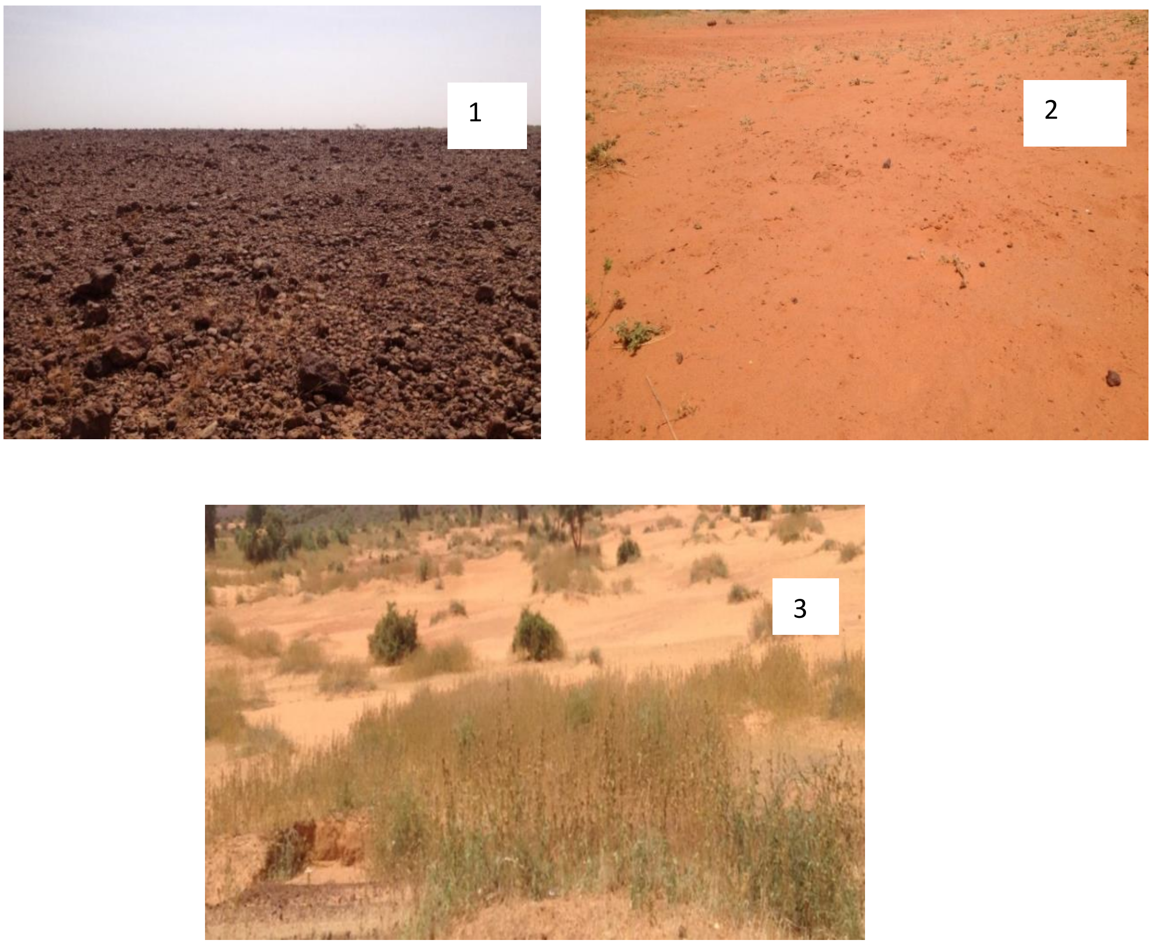


Figure 23:Stony area (1), sandy area (2), shrub area (3) for solar PV implementation

4.2.2 Solar radiation measurement of the selected sites

In this part, the measurement of global solar radiation of the selected sites had been done. The following charts show how the evolution of insolation during the hours of the day. As we can see, the different graphs below show the insolation going from 6 AM to 6 PM of the different sites selected which consist of three types of area: stone area, sandy area and shrub area. Generally, there is increasing in all the sites represented by figure 28 and 27. At noon we observed more irradiance in stony area reaching until 1200 W/m^2.There is a slight difference between shrub area and the sandy area. The figures show us also decreasing in after noon in all three graphs of the different areas. We observed more radiation in the stone area due to its capacity to keep heat and radiates more than the sandy and the shrub area but the sandy and the shrub area have the same trends because there is slight difference of the incoming radiation. The shrub area can be considered us a sandy area because of the presence of trees in the area, the very small size of the trees means there is less concentration of three in these sites. We can also see also some decreases when insolation should it should normally increase. This decrease is due to the presence of aerosols which has a strong impact on the incoming radiation (the decreases observed in the figure of the stone area especially in the site C where we see more radiation at 7 AM then at 9 AM, the insulation at 7 AM should be lower than at 9 AM because the distance between the earth and the sun is lower at this time. There is also variation of the solar variation with the latitude of the place show by figures 29 in which we can see increasing in all the types of area. We can also see that the radiation in the three sites at 12 AM reach till 1200W/m^2 us maximum for the stone area and around 1050 for the sandy area and the shrub area, and in the afternoon around 5 PM the minimum is around 400 W/$m^{2.}$ So, the solar radiation reaching one surface depends on the type of surface, the atmospheric conditions (aerosol effect), the latitude of the place and the time of the day as it is shown in the figures below.

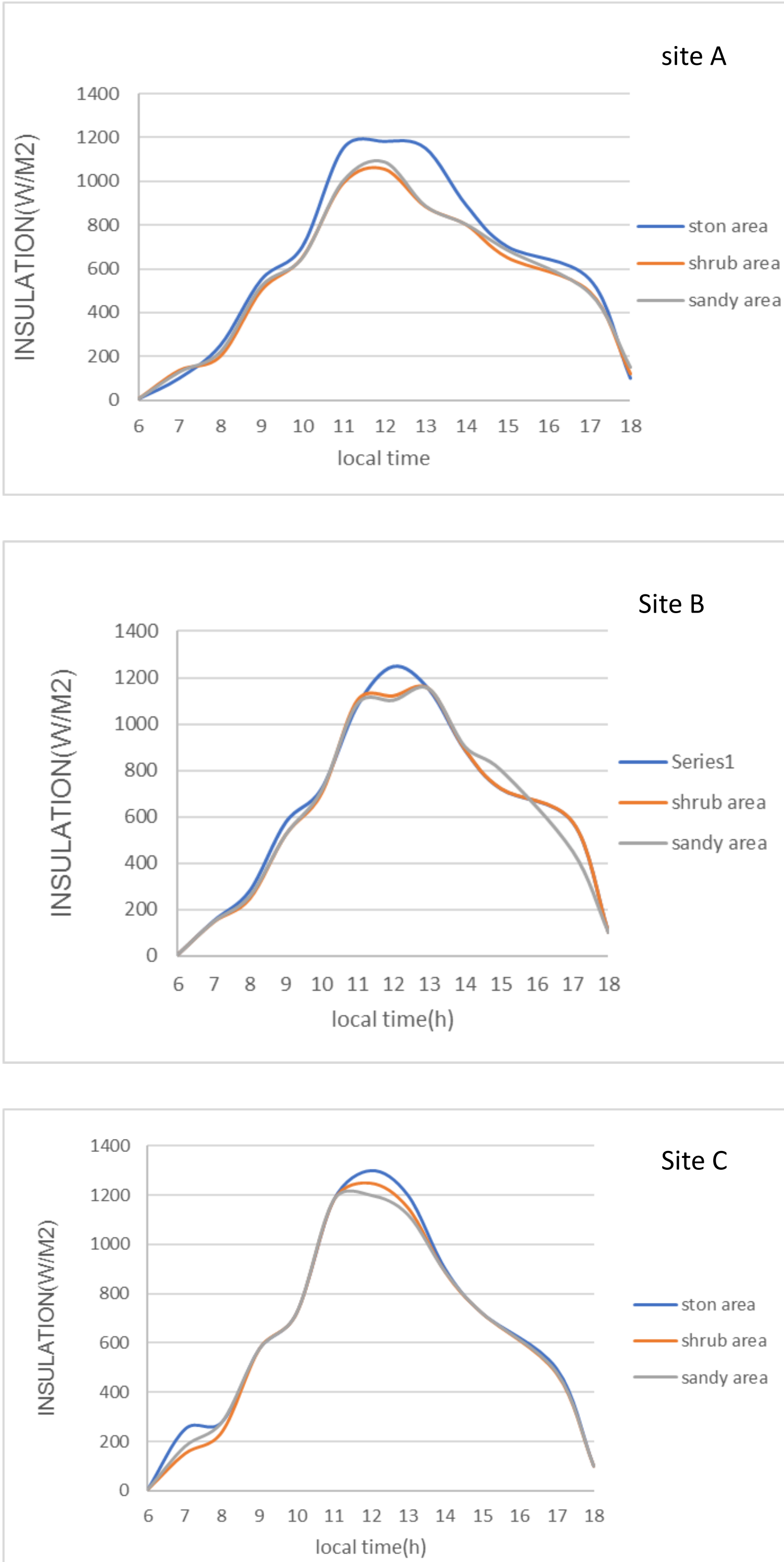


Figure 24 : Insolation as a function of time of the day

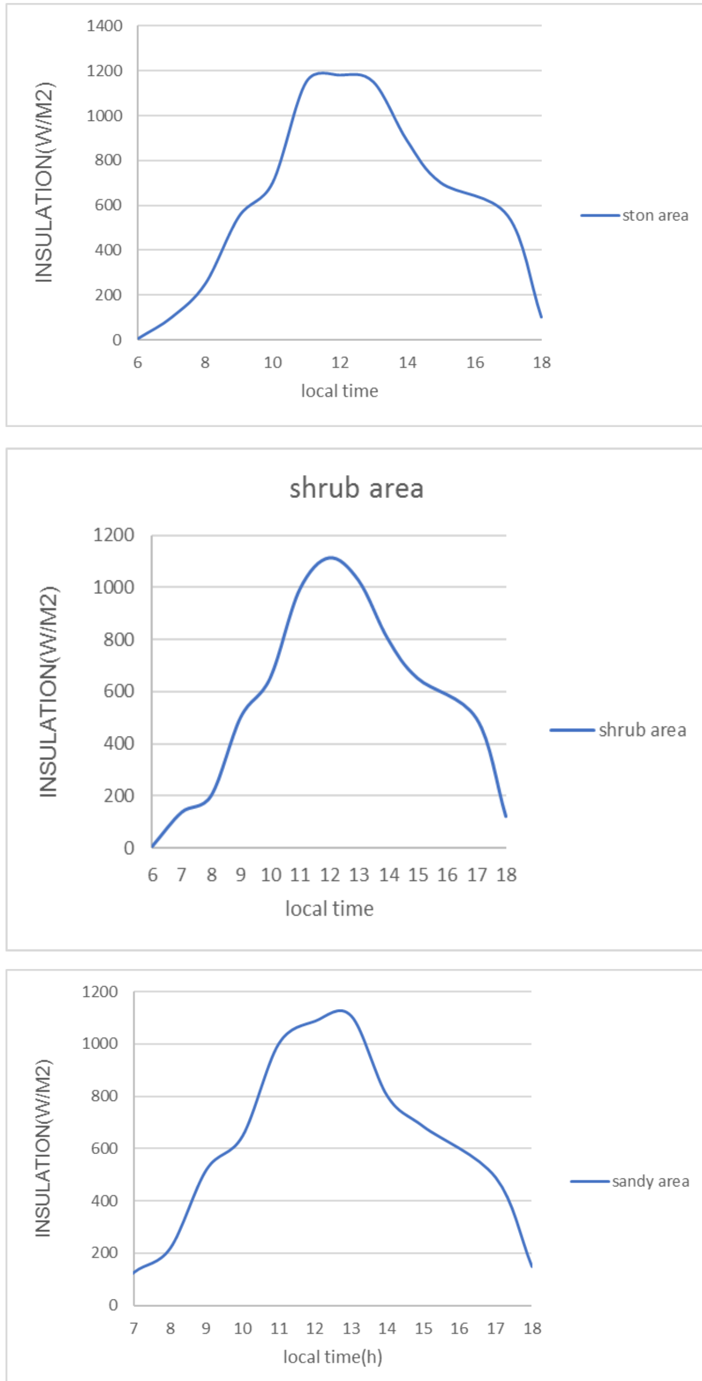


Figure 25: Global solar radiation evolution of the type of area

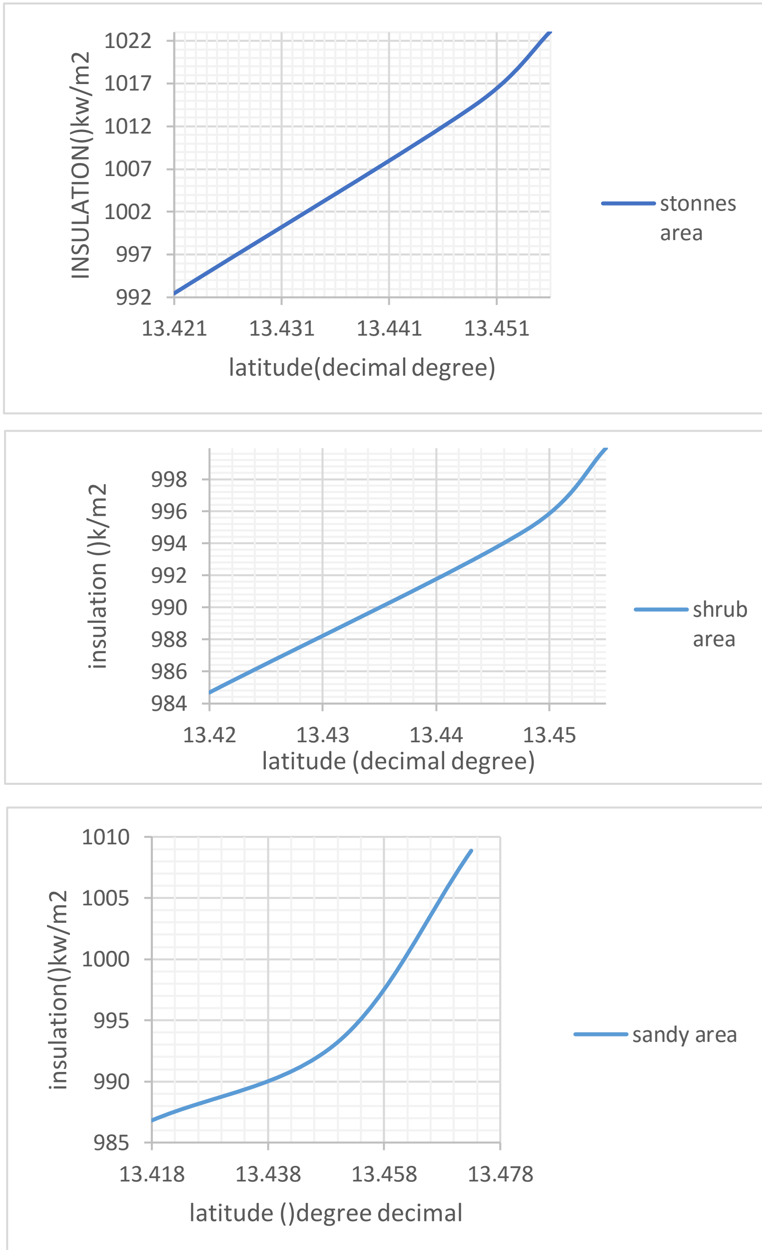


Figure 26: Evolution of solar radiation with the latitude

NB: for radiation measurement, the device used is not well calibrated.

4.2.3 Energy that can be generated by the suitable sites

The electric power generation potential per day for the selected sites can be estimated based on the calculated average annual solar radiation per unit surface area per day, the total suitable area, the efficiency of the PV panel and the area factor. Equation 22 can be used to estimate the yearly solar electric power generation potential (A. Gastli, Y. Charabi,2010).

$$GP = SR \times CA \times AF \times \eta \tag{22}$$

Where, GP = Electric power generation potential per year (kWh/day)

SR = Annual solar radiation received per unit horizontal area (kWh/m^2/day)

CA = Calculated total area of suitable land (m^2)

AF = the area factor, indicates what fraction of the calculated areas can be covered by solar panels

η = PV system efficiency (23)

The potential generation capacities (kWh/day) for the selected sites and for different PV technologies are presented in Table12 (Dr. B D Sharma, 2011). An area factor of AF=70% was selected based on maximum land occupancy of PV panels with minimum shading effect (Adel Gastli, Yassine Charabi, 2010)

Table 12: Generation potential of the selected sites considering different PV technologies

PV technology	Efficiency η (%)	Maximum Area for the selected sites CA (m2)	Mean annual solar radiation In Niamey, SR(kWh/m2/day)	Generation potential, GP (kWh/day) $\times 10^6$
Mono si	15-20%	46.504* 10^6	6.104	33.78
Poly si	15-17%			31.79
a-si	6-9%			13.909
CdTe	9-11%			17.87
GIGS	10-12%			19.87
CPV	26.3-29%			51.66

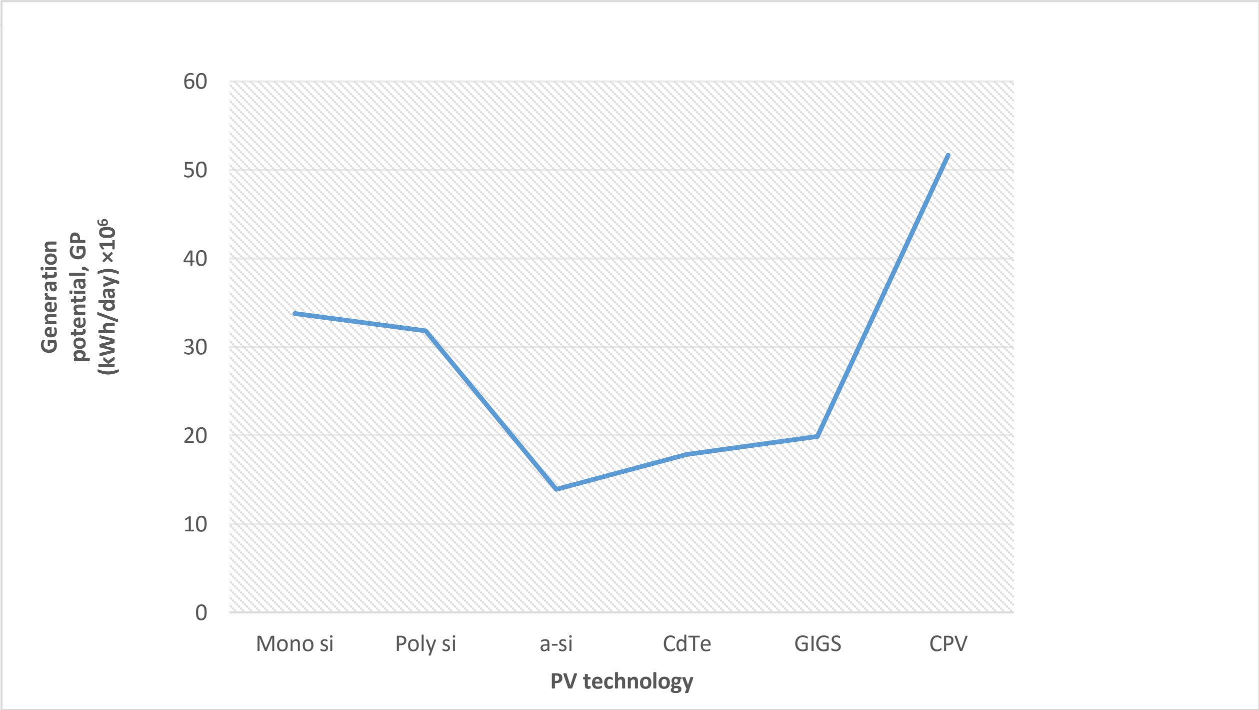


Figure 27: Annual generation potential by technology

4.2.4 Social acceptance for the suitable sites

The lasting implications of this study reside in the dynamic of predicting public acceptance or, more accurately, potential resistance. One of the good things of this study is that after interviewing the major authorities of the places we found that all the sites detected is not yet sold to people, so for the implementation it will not be complicated especially if the project come from the government. The government do not need to struggle with people which is among the biggest issues in finding suitable places for solar PV implementation.

CONCLUSION AND RECOMMENDATION

In spite of its enormous renewable energy resources potential. The African continent continue to struggle with the issue of energy. This continent is still in darkness and is plagued with intermittent power-cuts especially the western part (Sub-Saharan Africa) Niger is among the places where this energy issue is the most felt despite the huge energy potential composed of: uranium, mineral coal, oil, natural gas, hydroelectricity and solar energy. This energy issue is growing fast because of the increasing demand for energy caused by population growth. To overcome this problem and to run the socio-economic development of the country, Niger has to strengthen its energy sector by becoming more independent and diversifying the energy sources.

Taking into account the effect of climate change due to increase of CO2 concentration in the atmosphere from fossil fuel use, solar energy is among the most promising renewable energy energies that should be implemented in Niger and especially in the city on Niamey. In this study, five years daily observation of solar radiation for the city of Niamey has been collected from CNES. This data allowed to plot and to calculate the maximum and minimum annual mean of global solar radiation of five years which are respectively 6.86 and 4.63 $kWh/m^2/day$. To find out suitable sites for implementing solar farms, the threshold of socio-economic and physical criteria has been set according to literatures and judgment. GIS-based weighted linear combination (WLC) and the Boolean logic was the multi-criteria decision analysis techniques used in this study to locate the potential areas for solar PV implementation. During this study, satellite images were also used for differentiating the land use classes of Niamey allowing the identification of the suitable sites for solar PV implementation. The study also combined GIS and for remote sensing techniques for spatial analysis, modeling, and visualization. The suitability map was generated by taking into account the distance from the transmission line, the distance from the road, and the most isolated areas. Results showed that the plateau areas located in the southern part of Niamey are the best places for a such projects of solar PV implementation. The overlay results obtained from the analysis of the resultant maps showed that about 22% of Niamey demonstrate very high suitability for PV farm implementation. Three sites had been identified with a total area of 46.504 km^2.To validate our model we visited these sites and found that they consist of three kind of area such us: shrub area, stone area and sandy area which are very good for solar project because their impact on the environment is low due to the absence of vegetation. Electric power generation potential per year for the selected sites can be estimated. based on the calculated average annual solar radiation per unit surface area per day, the total suitable area, the area factor, the efficiency of the PV panel and the technology used the annual electric power generation per year, the CPV technology gives around 51.66 GWh/day followed by the mono and poly Si giving respectively 33.78 and 31.79 GWh/day.

Through the results obtained, solar energy can be one of renewable energy source which can be used to increase the energy production in Niger especially in Niamey. Regarding the commitments taken up by each country to limit their greenhouse gases emissions, Niger has to increase the energy production coming from renewable. The implementation of solar PV energy could produce electricity to support the growth of energy demand observed each year in Niamey and reduce the consumption of the electricity produced in Nigeria and sold to Niger.

Conformably to these results of solar PV energy implementation in Niamey, the government have to take into account solar energy development in their energy provision. GIS-based multicriteria decision analysis technique proposed in this study to locate the potential areas in the city of Niamey can be used to discover the suitability solar farm lands. The method proposed in this work for the identification of the suitability sites for solar PV implementation can be modified according to the availability of the data. The GIS based multi criteria analyses is a useful tool for assessing any kind of renewable energy project. Furthermore, we suggest that government through the National Meteorological Agency, should begin to take measurements of the solar radiation in some parts of Niamey in order to have more idea in the variation of this parameter many times. This will be of importance to such projects in future. The government of Niger needs to implement renewable energy projects especially for solar energy instead of making expensive project like that of Gorou Banda which is not friendly to the environment. Nevertheless, this method can be used for another suitability of any kind of renewable energy project for instance wind energy assessing throughout Niger, bio energy, hydropower and so on. For example, the suitability mapping of solar energy in Niger can be another work by considering some climatic parameters such us: Temperature Humidity, wind speed, average annual dusty days, average annual dusty days. Another work is also to complete this this study by including the economic study still the price of the kWh once this of project have been implemented.

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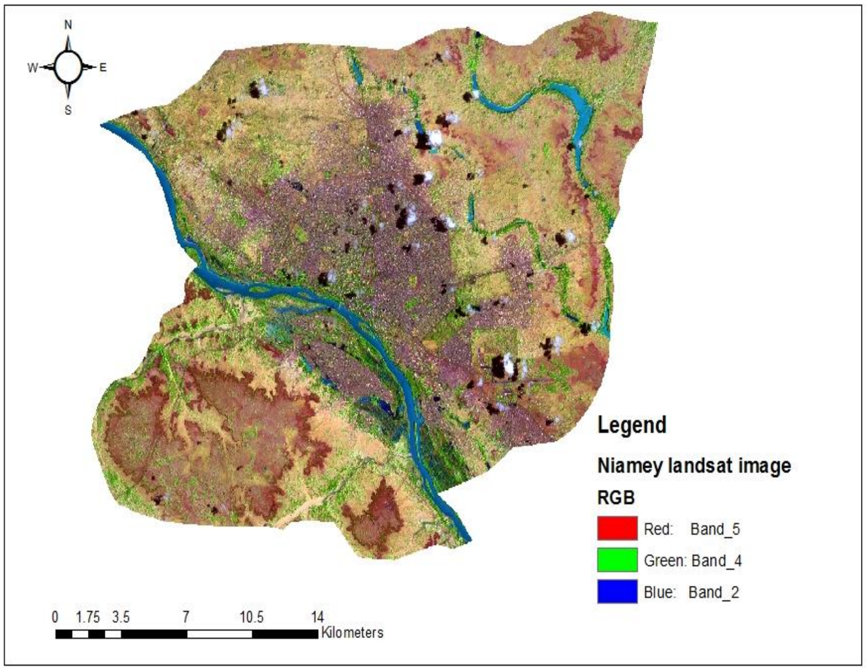
Appendixe1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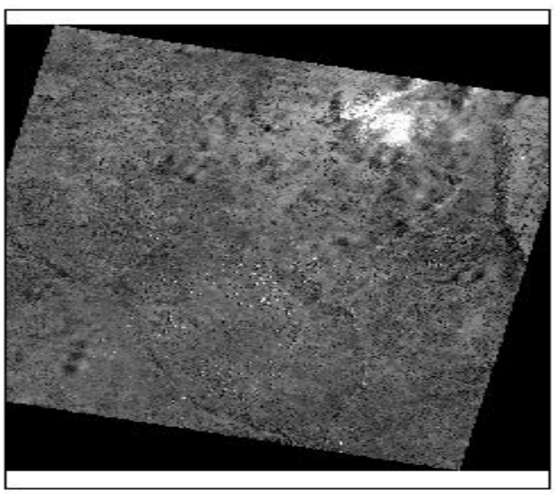

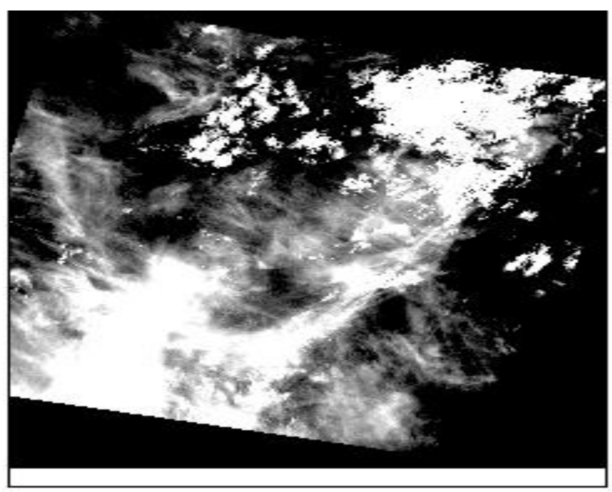

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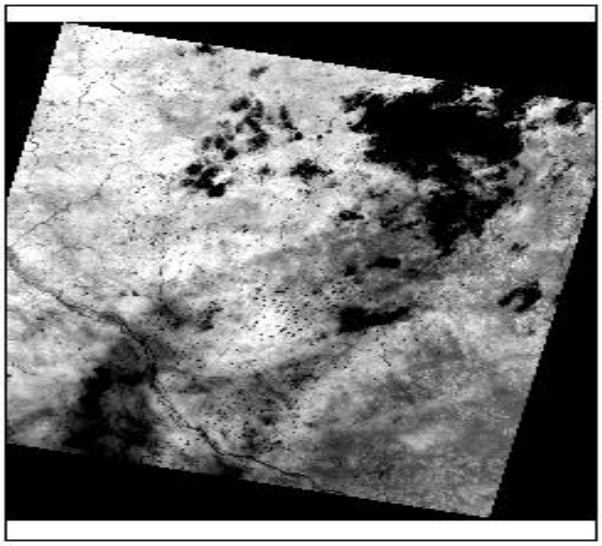

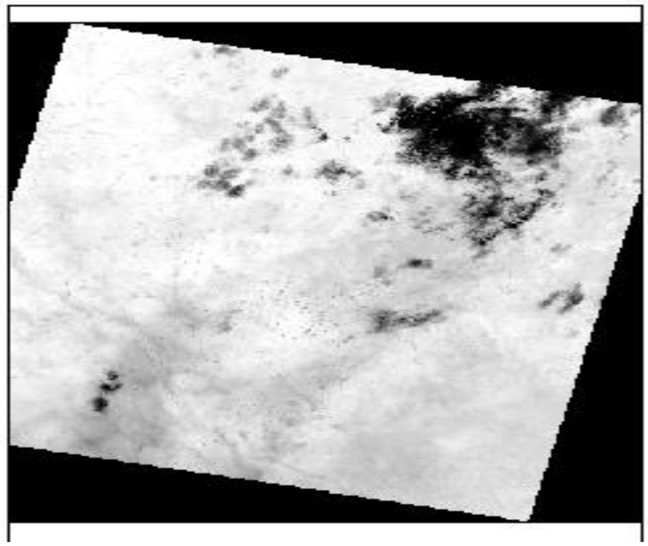

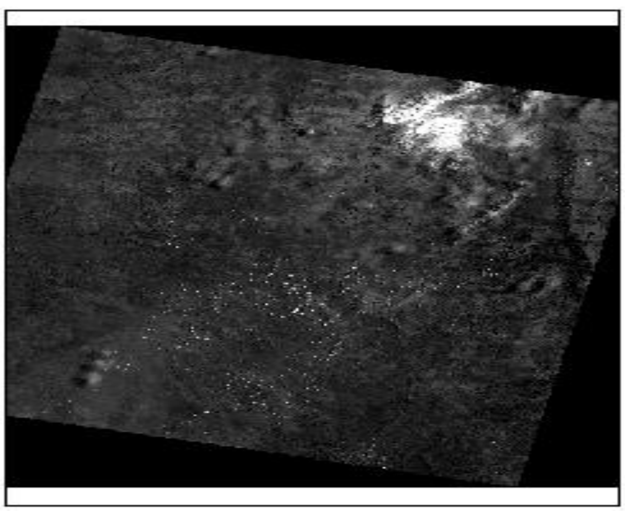

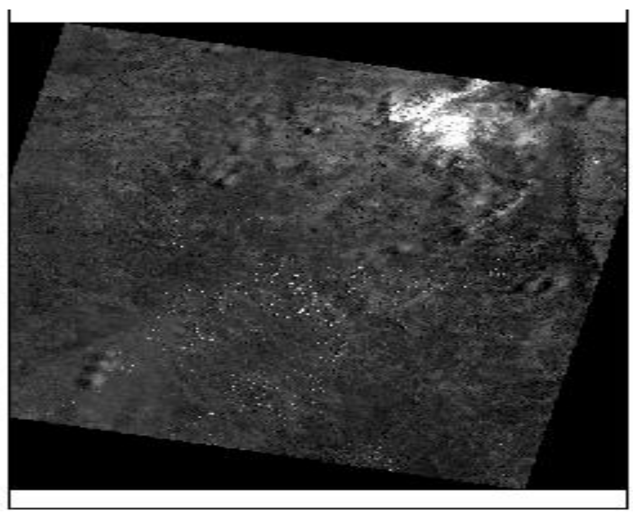

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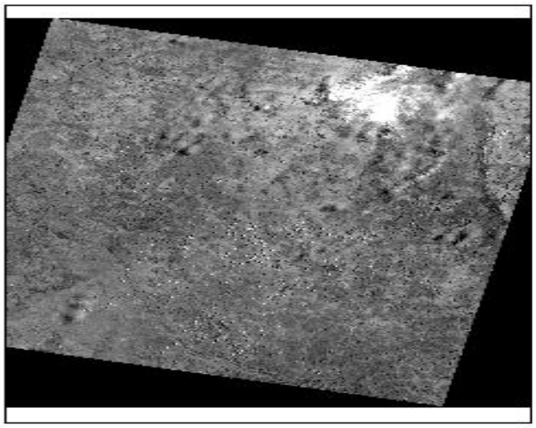

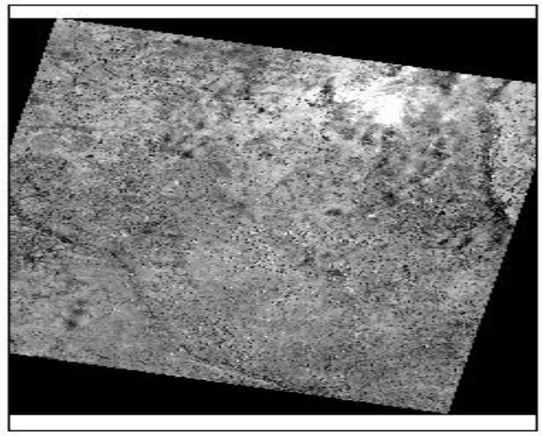

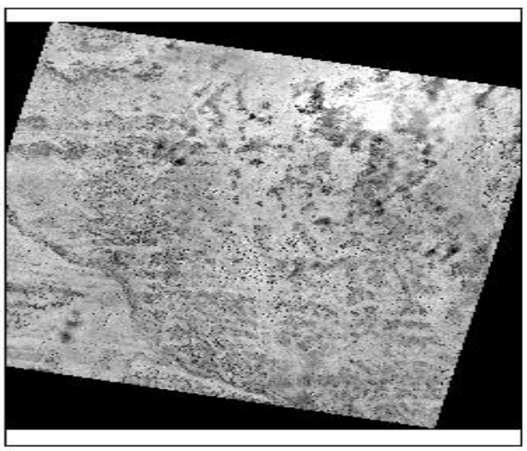

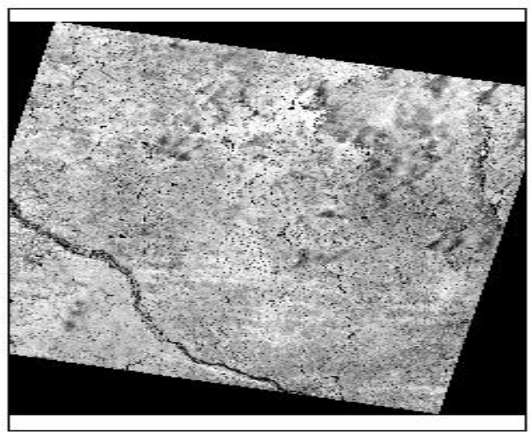

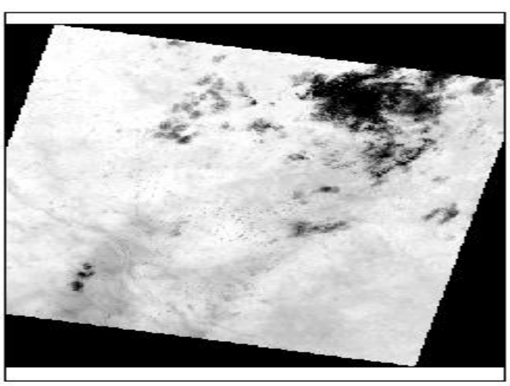

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