Pan African University
Institute of Water
and Energy Sciences

PAN-AFRICAN UNIVERSITY

INSTITUTE FOR WATER AND ENERGY SCIENCES

(Including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfilment of the requirements for the Master Degree in

ENERGY POLICY

Presented by:

Michael Yang'tshi Ndong Olola

IMPACTS ASSESSMENT OF CLIMATE CHANGE ON SOLAR PV SYSTEMS IN NIGER'S DOSSO REGION

Defended on 22th November 2021 Before the Following Committee:

Chair	Abdelhalim Benmansour	Prof.	University of Tlemcen, Algeria
Supervisor	Abdellatif Zerga	Prof	PAUWES, Tlemcen, Algeria
External Examiner	Yao Azoumah	Dr.	CEO Kya Energy Group, Lomé, Togo
Internal Examiner	Noredine Sahouane	Dr.	URER/MS, Algeria

THESIS APPROVAL

Thesis submitted by

Michael Yang'tshi Ndong Olola		
Student	Signature	Date

Approved by Examining Board

Prof. Abdellatif Zerga		23/12/2021
Supervisor	Signature	Date
Examiner	Signature	Date

IN MEMORIAL

To my dearest late mother, of happy memory, the one who lost her life when I began to write this work, the one who encouraged me to continue without actually seeing the results. May she find eternal peace.

DEDICATION

I dedicate this work to my adorable wife, Merveille N'KAWE YANG'TSHI for all the love she never ceases to nourish me, her unwavering support, her selflessness, her courage and also for having endured all my absences during my studies. She is the masterpiece of this work.

Together with her, we dedicate this work to our adorable children

STATEMENT OF THE AUTHOR

By my signature below, I declare that this thesis/dissertation is my work. I have followed all ethical principles of scholarship in the preparation, data collection, data analysis, and completion of this thesis or dissertation. I have given all scholarly matter recognition through accurate citations and references. I affirm that I have cited and referenced all sources used in this document. I have made every effort to avoid plagiarism.

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ACKNOWLEDGEMENT

My thanks go to the African Union place through the African Union Commission for doing me the honor of receiving this scholarship which is so important in my life. For all the financial means at my disposal to carry out this research.

My thanks go straight to **Professor Abdellatif Zerga**, Director of PAUWES, for having accepted, despite his multiple tasks, the supervision of this work by giving it a particular and scientific meaning. May he receive in these lines the expression of my deep gratitude.

My gratitude goes to the United Nations University Institue of Environment and human security (UNU-EHS) for having proposed the theme of this thesis under the frame of RETODOSSO project, and to **Mr. Paul NDUHUURA** for having agreed to guide me as co-supervisor throughout the writing of this work.

It is impossible not to think of all the members of the PAUWES staff for their dedication in the organization of the various university activities as well as all the teachers for their teachings which shaped us in science during our time at PAUWES.

I will not stop feeling indebted and grateful to my birth family for all of the so important support they have given along this long journey. Clémence MUSWAMBA, Marco MAKOLO, Aimée NSUMBU, Mimi MBUYI, Mireille MUKENDI, Daniel MULAMBA, as well as my dear father Florimond YANG'TSHI, may they find here the expression of my sincere gratitude.

They say there is strength in unity. And we confirmed it with our friends who did not release us throughout this ordeal. They have always been there to help us of any kind whatsoever in carrying out this work, especially Meshac NGUNGU, Nathan IRENGE and all the others.

My sincere thanks to the fellow fighters as well as to all the comrades of the sixth class of Pauwes, especially those of Energy Policy.

TABLE OF CONTENTS

LIST OF ACRONYMS

CMIP3: Coupled Model Inter comparison Project Phase 3

CMIP5: Coupled Model Intercomparison Project, Phase 5

CNPC: Chinese National Petroleum Corporation

CORDEX: COordinated Regional climate Downscaling EXperiment for Africa

ECOWAS

ECREEE: ECOWAS Regional Center for Energies Renewables and Energy Efficiency

ESD: Empirical Statistical Downscaling

ESGF: Earth System Grid Federation

EUEI-PDF

GCM: Global Circulation Models

GEF-SPWA

GHGs: Greenhouse Gases

HDI: Human Development Index

IAEA: International Atomic Energy Agency

IEA: The International Energy Agency

IPCC: Intergovernmental Panel on Climate Change

MIROC: Model for Interdisciplinary Research on Climate

NCAR: National Center for Atmospheric Research

NIGELEC: Niger Electricity Company

PANER: development of National Action Plans in of Renewable Energies

PEEC: ECOWAS Energy Efficiency Policy

PERC: ECOWAS Renewable Energy Policy

RAL: Research Application Laboratory

RCD: Regional Climate Downscaling

RCM: Regional Climate Models

RCP: Representative Concentration Pathways

Rsds: surface downwelling solar radiation

SIE: Système d'information énergétique

Tas: near surface air temperature

UNIDO

VIA: vulnerability, impacts, and adaptation

VWS: surface wind velocity

WCRP: World Climate Research Program

WRF: Weather Research and Forecasting

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

As the climate of the world warms, the consumption of energy in climate-sensitive sectors is likely to change. Possible targets include (1) decreases in the amount of energy consumed in residential, commercial, and industrial buildings for space heating and cooling; (2) decreases in energy used directly in certain processes such as residential, commercial, and industrial water heating, residential and commercial refrigeration and industrial process cooling; (3) increases in energy used to supply other resources for climate-sensitive processes, such as pumping water for irrigated agriculture and municipal uses, etc.

The mitigation plans for ambitious climate change call for a significant increase in the use of renewable energies, which requires the development of supply systems in terms of life and resistance to climate change vulnerabilities.

Renewable energy plays a key role in future low-carbon-emission plans that should contribute to the limiting global warming. However, its dependence on climate conditions makes it also very susceptible to the climate change. While the first part of this 'paradox' has been thoroughly studied, the international scientific community has only recently started to investigate the impacts that global climate change may have on energy, in general, and renewable energy, specifically (Dajuma, A. and al. 2016).

From the literature, some findings indicate that the alteration of solar PV supply by the end of this century compared with the estimations made under current climate conditions should be in the range (- 14%; + 2%) (Sonia Jerez, and al., 2015). Whereas solar systems have been promoted largely as a mitigation measure to energy-related greenhouse gas emissions, they are also an important component in the climate change adaptation agenda in some countries such as Niger. However, solar systems are themselves exposed to changing climatic conditions which may affect their effective performance. Therefore, to ensure the proper functionality of solar systems, long-term climate change conditions and their potential impacts on solar system performance must be taken into account during the sizing phase.

It is for this reason that as far as Dosso region is concerned in this work, we have assessed the impacts of future climate change on solar energy production using the appropriate tools and existing climate models.

The results show a negative impact of climate change on the Dosso solar system, due to the increase (or decrease), over time, of some variables playing a very important role in the quantification and production of solar energy, in particular the solar radiation and other meteorological parameters such as Near air surface temperature and wind speed.

RESUME

À mesure que le climat mondial se réchauffe, la consommation d'énergie dans les secteurs sensibles au climat est susceptible de changer. Les cibles possibles comprennent (1) une diminution de la quantité d'énergie consommée dans les bâtiments résidentiels, commerciaux et industriels pour le chauffage et la climatisation des locaux ; (2) diminution de l'énergie utilisée directement dans certains processus tels que le chauffage de l'eau résidentiel, commercial et industriel, la réfrigération résidentielle et commerciale et le refroidissement des processus industriels; (3) l'augmentation de l'énergie utilisée pour fournir d'autres ressources pour des processus sensibles au climat, tels que le pompage de l'eau pour l'agriculture irriguée et les usages municipaux, etc.

Les plans d'atténuation du changement climatique ambitieux font appel à une augmentation significative de l'utilisation des énergies renouvelables, ce qui nécessite le développement de systèmes d'approvisionnement en termes de vie et de résistance aux vulnérabilités du changement climatique.

Les énergies renouvelables jouent un rôle clé dans les futurs plans bas carbone qui devraient contribuer à limiter le réchauffement climatique. Cependant, leur dépendance aux conditions climatiques la rend également très sensible au changement climatique. Alors que la première partie de ce « paradoxe » a été minutieusement étudiée, la communauté scientifique internationale n'a commencé que récemment à étudier les impacts que le changement climatique mondial peut avoir sur l'énergie, en général, et les énergies renouvelables, en particulier (Dajuma, A. et al . 2016).

A partir de la littérature, certains résultats indiquent que l'altération de l'offre solaire photovoltaïque d'ici la fin de ce siècle par rapport aux estimations faites dans les conditions climatiques actuelles devrait être de l'ordre (- 14 % - + 2 %) (Sonia Jerez, et al., 2015). Alors que les systèmes solaires ont été largement promus comme mesure d'atténuation des émissions de gaz à effet de serre liées à l'énergie, ils sont également une composante importante du programme d'adaptation au changement climatique dans certains pays comme le Niger. Cependant, les systèmes solaires sont eux-mêmes exposés à des conditions climatiques changeantes qui peuvent affecter leurs performances effectives. Par conséquent, pour assurer le bon fonctionnement des systèmes solaires, les conditions de changement climatique à long terme et leurs

impacts potentiels sur les performances du système solaire doivent être pris en compte lors de la phase de dimensionnement.

C’est pour cette raison que s’agissant de la région de Dosso dans ce travail, nous avons analysé les impacts du futur changement climatique sur la production de l’énergie solaire en se servant des outils appropriés.

Les résultats montrent un impact négatif du changement climatique sur le système solaire de Dosso, dû à l’augmentation (ou à la réduction), au fil du temps, de certaines variables jouant un rôle très important dans la quantification et la production de l’énergie solaire, notamment la radiation solaire et certains paramètres météorologiques tels que la température de surface et la vitesse du vent.

CHAPTER ONE. INTRODUCTION

1. BACKGROUND

Energy is an important development indicator of any country. In recent decades, energy has become a significant issue in the world. Indeed, fossil fuel resources are decreasing while the world energy demand is increasing considerably. Moreover, the consumption of fossils fuels causes air pollution and contributes significantly to greenhouse gases (GHGs) emission and to climate change. An obvious solution to overcome ongoing threat of air pollution and to promote GHGs emission mitigation and sustainable energy production is the use of renewable energy sources such as solar, wind, hydro and geothermal (Dajuma, A. and al. 2016)

Besides the countries that are already implementing a solar power-based electricity generation, some of them are also likely to join on the list based on their high solar potential, Niger being one of them.

As a part of the World, Climate change is also expected to have certain effects in the region of DOSSO in Niger: a rise in average temperatures in some areas, changes in precipitation amounts and seasonal patterns in many regions, changes in the intensity and pattern of extreme weather events. Some of these effects will have clear implications on solar energy production and use as well. The large-scale change in the climate of the world translates to increased energy use. The more temperature rises, the more energy will be needed for running cooling devices and for electricity generation as well.

In a few years, the energy demand for cooling devices will increase by 20% while the energy consumption for heating will decrease by 15% in USA for instance (Alycia Gordan, 2018). It is the impact of rising temperatures owing to which the world is going to witness a surge in the energy demand. Meanwhile, in some other countries the temperature will instead be decreasing and lead to an increase of energy demand whilst affecting the performance of Solar PV. Analysis based on the warming scenarios outlined by the IPCC predicts in some areas the annual energy output of PV systems may fall by up to 50 kWh per kilowatt installed. (Ian Marius Peters, Tonio Buonassisi, 2019).

Thus, climate change such as global warming may not only affect the solar PV-based energy production, but also boost the need for solar energy, as people are becoming more and more conscious of reducing their carbon footprint.

Due to the vulnerability of the Energy sector and to the continual development of methodologies and data availability, the Research on climate change assessment, its modeling and its impacts on renewable energy are becoming increasingly relevant for Public and private decision-making.

2. STATEMENT OF THE PROBLEM

Because of the lack of research to date, prospects for adaptation to climate change effects by energy providers, energy users, and society at large are speculative, although the potentials are considerable. It is possible that the greatest challenges would be in connection with possible increases in the intensity of extreme weather events and possible significant changes in energy production. But adaptation prospects depend considerably on the availability of information about possible climate change effects to inform decision-makers about adaptive management, along with technological change in the longer term. Given that the current knowledge base is so limited, this suggests that expanding the knowledge base is important to energy provider's users, particlurly in Dosso.

Knowing that the most pronounced climate shifts besides the end of the ice age was a series of climate changes during the ice age where the temperature suddenly rose 10-15 degrees in less than 10 years, the climate change lasted perhaps 1000 years, then the temperature fell drastically, and the climate changed again (University of Copenhagen, 2010). However, though we are in a warming period of climate change (global warming), which is still characterized by unpredicted times and leads to many phenomena, it is uncertain to know what are the next meteorological phenomenas. Actually, this makes it difficult to know what effects exactly the climate change will have on the Solar PV in Dosso.

3. RESEARCH OBJECTIVES

The main objective is to analyse the impacts of climate change on solar PV systems using a case study of Niger's dosso region.

To achieve our main objective, we assigned the following specific objectives which are:

- To examine current knowledge regarding global impacts of climate change on solar PV systems;
- To analyse historical and future climate change in order to predict its long-term effects on Solar PV systems in Niger's Dosso;
- To analyse the Solar PV Potential against the simulated climate change results.

4. RESEARCH METHODS

This work will make use of *secondary data used in the quantitative approach*.

For that, the methodology followed in this work is a quantitative approach that will allow to quantify some of the most important climate variables up to the end of the 21st century.

We will make use of several software to extract data and to forecast them. The results will be compared for each time serie and see its impacts on the PV systems. The type of research design that will be used is the Simulation to make a prediction of climate change over time and simulate the future behavior. This approach will be especially based on both the climate simulation and the PV variability. The projected changes and the time variability of the PV power production series will focus on daily variability.

5. HYPOTHESIS

The hypothesis maintained in this work is that any change on the climate, especially the increase of temperature is likely to have negative impacts on the Solar PV systems.

6. LIMITATIONS OF THE STUDY

This study produced pertinent and helpful results in line with the previous researchs, however, some challenges were encountered in the course of the research and preventend us to go further in the analysis. Those challenges include the fact that the research timeframe and resources could not enable us to purchase primary data. The covid-19 pandemic cancelled the possibility to travel to the case study area for data collection, thereby delaying the process.

7. SIGNIFICANCE OF THE STUDY

This topic is relevant to policy-makers and other decision-makers because most discussions to date of relationships between the energy sector and responses to concerns about climate have been very largely concerned with roles of energy production and use in climate change mitigation. Along with these roles of the energy sector as a driver of climate change, the energy sector is also subject to effects of climate change; and these possible effects – along with adaptation strategies to reduce any potential negative costs from them – have received much less attention (Thomas J. Wilbanks, and al. , 2008). It is meant to provide the possible scientific information to support decision-making and public discussions on key climate related issues and to summarize current knowledge whilst identifying priorities for research, observation, and decision support in order to strengthen contributions in climate change related issues. Besides, following the ECOWAS Renewable Energy Policy (PERC) and the ECOWAS Energy Efficiency Policy (PEEC) which have been adopted by the Member States prepared with the technical support of the ECOWAS Regional Center for Energies Renewables and Energy Efficiency (ECREEE) and a wide range of international partners (UNIDO, EUEI-PDF, GEF-SPWA, Austria and Spain), some policies need to be implemented including a minimum of targets / objectives and scenarios for Renewable Energies (RE) and Energy Efficiency (EE) as well as measures, standards and incentives at regional and national levels, including the PERC forecasts for the development of National Action Plans of Renewable Energies (PANER) by the fifteen ECOWAS Member States, including Niger under the project of Rural electrification by solar PV systems of the localities of the regions of Dosso, Tahoua and Tillabéry (PANER NIGER, 2015).

This work will also attempt to contribute to this vision, Dosso being a region of Niger which is an ECOWAS state member.

8. OVERVIEW OF NIGER

8.1.Geographic situation and socio-economic context

Figure 1: Niger Map

Niger or **the Niger** is a landlocked country in West Africa named after the Niger River. Niger is a unitary state bordered by Libya to the northeast, Chad to the east, Nigeria to the south, Benin and Burkina Faso to the southwest, Mali to the west, and Algeria to the northwest. Niger covers a land area of almost 1,270,000 km² (490,000 sq mi), making it the second-largest landlocked country in West Africa (behind Chad). Over 80% of its land area lies in the Sahara Desert. The country's predominantly Muslim population of about 22 million live mostly in clusters in the far south and west of the country. The capital and largest city is Niamey, located in Niger's southwest corner.

Niger is a developing country, which consistently ranks near the bottom in the United Nations' Human Development Index (HDI); it was ranked 187th of 188 countries for 2015 and 189th out of 189 countries in the 2018 and 2019 reports. Many of the non-desert portions of the country are threatened by periodic drought and desertification. The economy is concentrated around subsistence agriculture, with some export agriculture in the more fertile south, and export of raw materials, especially uranium ore. Niger faces serious challenges to development due to its landlocked position, desert terrain, inefficient agriculture, high fertility rates without birth control and resulting overpopulation, the poor educational level and poverty of its people, lack of infrastructure, poor healthcare, and environmental degradation (wikipedia, 2019).

8.2.Climate of Niger

Niger extends southward from the tropic of Cancer, and the northern two-thirds of its territory lies in dry tropical desert. In the southern part of the country the climate is of the type known as Sahelian, which is characterized by a single, short rainy season. In January and February the continental equivalent of the northeast trade winds, the harmattan, blows southwestward from the Sahara toward the equator. Dust-laden, dry, and desiccating, the harmattan hinders normal living conditions on the southern fringe of the desert. From April to May the southern trade winds blowing from the Atlantic reach the equator and are diverted toward the Sahara where they meet with the harmattan—an encounter that results in violent line squalls and that signals the beginning of the rainy season. The rains last from one to four months, according to the latitude; August is the rainy month everywhere except in the far north, where the rainfall is unpredictable (https://www.britannica.com/place/Niger/Climate).

CHAPTER TWO. LITTERATURE REVIEW

1. ENERGY RESOURCES IN NIGER

According to the energy charter secretariat report by Salifou (2015), Niger has abundant renewable energy resources that are not fully exploited; this includes hydroelectricity, wind, solar energy and biomass (firewood and agricultural residues, mainly used for household use). The hydroelectric potential of Niger is also about 280.5 MW, including 130 MW in Kandadji, 122.5 MW on the river Niger in Gambou and 26 MW in Dyondyonga on Mekrou River. Other identified hydro sites include Goulbi Maradi and Tahoua Maggia and tributaries on the Niger River such as Sirba, Goroubi, and Dargol. The solar energy potential of Niger is tremendous with an insolation rate of between 5 to 7 kWh/ m^2/ day, which translates into 8.5 hours per day of sunshine. Wind speeds, ranging from 2.5 m/s in the south to 5 m/s in the north are also in favour of wind turbines to pump example water for agriculture (Salifou, 2015). Even with the abundant renewable energy potential of Niger, access to electricity and modern cooking is still minimal. Moreover, the access to electricity is likely to be increasing by climate change impacts on renewable energy in general and particularly on solar energy.

In 2012, the Niger River had about 270 MW of undeveloped hydroelectric potential. The hydroelectric production inclued the 125 MW Kandadji project, 200 km upstream from Niamey, the capital, as well as two smaller dams at Gambou (122 MW) and Dyodyonga (26 MW). It is also noticed that small hydroelectric sites in the country had the potential to produce nearly 8 GWh per year, most notably Sirba and Gouroub Dargol (REEEP, 2012).

The UNEP report on Niger energy profile (2012) stated that there is huge potential for harnessing energy from biomass in Niger. It is estimated that the current forest stock stands at about 9.9 million ha and there is also potential from agricultural (crop and animal) waste. The same source stipulates that Uranium is mined in 20 countries and half the world’s production of uranium comes from just six countries, of which Niger is one. In sub-Saharan Africa, Namibia, Niger and South Africa are among the ten-largest uranium resource-holders in the world. Niger provides 7.7 per cent of global production.

Table 1. Resource Availability in Niger

Resource	Potential	Technology
Oil	300 Mbbl of crude oil (Production: 20,000 bbl/d)	Oil-based power plant
Gas	18.6 bcm of natural gas (Production: 44,000 t/y)	Gas driven power plant
Coal	Over 90 Mt	Coal-fired power plant
Hydro	Potential of 400 MW–Niger River	Hydropower dam Run-of-river
Solar	Insolation of 8–9 h/d, average radiation of 5–6 kWh/m^2	Solar photovoltaic system Concentrated solar power system
Nuclear	About 450,000 t of Uranium	Nuclear power plant
Wind	Average wind speed 2–6 m/s at 10 m, increase 20–100% by 50 m	Wind turbine
Biomass	Agricultural residue: 2960 t/y	Biogas plant

Source: (Ramchandra B. and al 2021)

1.1. Energy Production and consumption in Niger

Solar energy has the largest potential among all the above renewable energy sources. The yearly average solar power resource on the earth's surface is 36,000 billion Watts (3.6×10^4 TW) when the wind power resource is 72 TW, geothermal power resource is 9.7 TW. Today, solar energy is captured through two technologies: pure or hybrid photovoltaic (PV) modules and solar thermal collectors. (Dajuma, A. and al. 2016)

Solar energy is one of the largest renewable energy sources throughout Niger where the average insulation level is 5 to 7 kW/m^2/day with an average of 8.5 hours per day according to the CNES. Its applications are various in the country. Recently, there is a growing investment interest in PV off grid especially for the rural electrification as well as grid connection as a result of the falling cost of PV. In 2014, the total installed PV capacity was around 5 MW and distributed among various national sectors in the different regions.

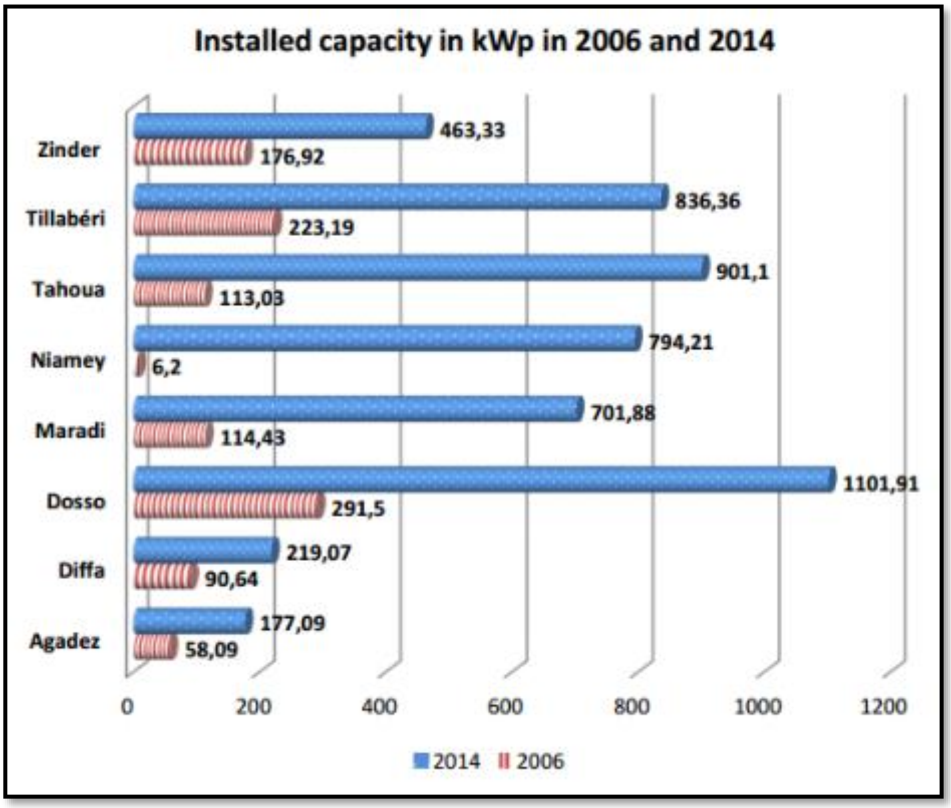


Figure 2: Solar installed capacity in Niger for 2006 and 2014 (kWp)

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. The weakness of this value is mainly due to limited access of Niger's households to modern energy. 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 (Salifou, 2015).

There have been recent discoveries of oil and gas. Oil production started in 2011 in a joint venture with the Chinese National Petroleum Corporation (CNPC). A new refinery with a 20,000 bbl/day capacity has also been built.

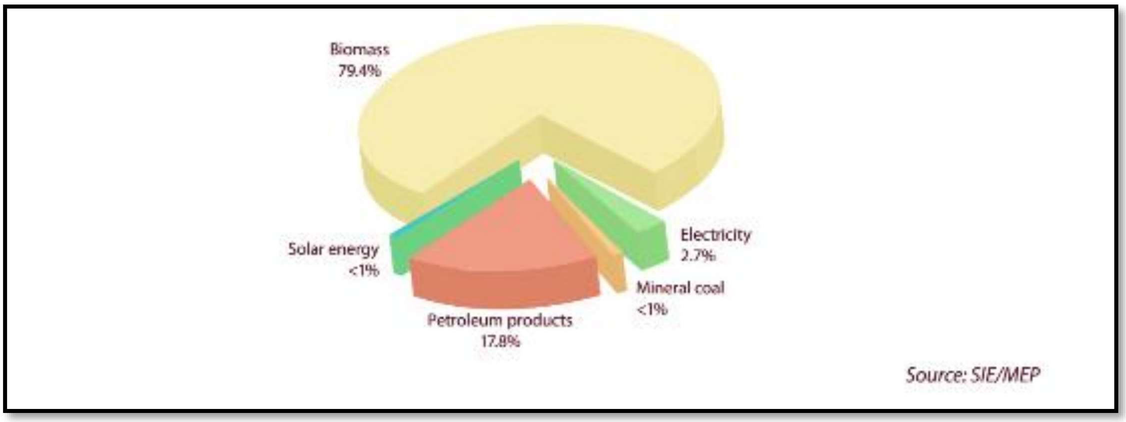


Figure 3: Distribution of final primary energy consumption in Niger

According to Niger's SIE (Système d'information énergétique) in 2016 the energy supply in the energy mix was dominated by the biomass followed by the petroleum products. Indeed, the situation of Niger's energy mix doesn't know a big change: primary energy supply stands at around 2918 ktep in 2015 against 3080 ktoe in 2016. In 2016, biomass represents 74.28% in the energy mix, followed by petroleum products (21.96%). The rest is composed of imports of electrical energy from Nigeria (2.17%) and mineral coal (1.58%) (SIE, 2018). The contribution of photovoltaic energy represents 0%. Although in terms of evolution, the total supply of primary energy in the country has increased by 36% between 2010 and 2016, i.e. a consumption of 2269 ktoe in 2010 to 3079.59 ktoe in 2016, the biomass remains the source the more dominant in the mix.

Total final energy consumption in Niger amounts to 2899 ktoe in 2016 compared to 2835 ktoe in 2015. Biomass remains the most dominant source of energy in Niger's energy mix, accounting for 80% of national consumption. Petroleum products are in second place, accounting for 17% of final consumption, and electricity is in third place, with 3%. Consumption of carbonized mineral coal and renewable energies is still marginal (SIE, 2018).

1.2. Electricity systems

The SIE- Niger (SIE-Niger 2007) report for Niger Republic showed that households' basic electricity consumption was 49%, against 39% for industries, 11% for commerce and services and 1% for agro-water schemes, for a total of 491Gwh. The rural population being 84% of the total population consumed only 1% of the final households' electricity against the urban population, being 16% of the total population, consuming 99% of the total electricity. Solar energy, biomasses, wind energy are very much under-utilized, with firewood used at 84% of the overall domestic energy uses (Oumarou M, 2012).

The electricity supply in the country is mainly provided by domestic production and imports from Nigeria. The domestic production is carried out by the Niger Electricity Company (NIGELEC) with 66.3 GWh and the Niger Coal Corporation of Anu Araren (SONICHAR) with 208.3 GWh in 2010. Imports from Nigeria (supplied by Power Holding Company of Nigeria) in 2010 amounted to 525.0 GW·h. National electricity demand in the same year reached 800 GW·h. The total installed capacity of 138.6 MW was divided as follows: thermal Diesel: 102.6 MW and thermal coal: 36 MW. The import of power from Nigeria to Niger was limited to 130 MW in September 2012 (IAEA, 2016)

2. OVERVIEW OF PAST/CURRENT CLIMATE AND FUTURE PROJECTIONS IN NIGER

2.1. Current climate and past trends

According to the USAID report on the climate trend analysis of Niger, the results of climate trends presented in their work pointed out two divergent climate trends: rainfall has increased since the 1970s and air temperatures have also increased. Whereas, historically (before 1970), increasing air temperatures have been associated with less rain and vice versa (Hoerling and al, 2006). Since 1950, the West African Sahel has experienced three cycles: a wet epoch, a dry epoch and, finally, a moderate recovery (Siebert and al, 2013). The dry epoch (1968–1985), coincides with a period of severe drought, remembered locally as the Great Drought. In this period, the rainfall average annual was 200 mm lower than in the previous 20 years (Lebel and al, 2009). After the drought, the rainfall trend reversed again. Rainfall in Niger declined rapidly between

1950 and the mid-1980s and partially recovered during the 1990s and 2000s. The recent rainfall increases are probably due to a smoothed time series of rainfall from 1900–2009. For eastern and western Niger, rainfall has steadily recovered since the mid-1970s but remains moderately (less than 0.5 standard deviations) below its long-term mean. These time series were based on crop growing regions in western Niger (Tahoua, Tillaberi, and Dosso regions) and eastern Niger (Diffa, Zinder, and Maradi regions). According to Vella Bigi and al (2018), it is well established that after the Great Drought in the 1980s, the Sahel region witnessed a partial recovery in precipitation, but not enough to fill the gap with the period prior to the drought. It is self-evident that the precipitation trend from 1950 will be negative.

For the USAID report on the climate trend analysis of Niger air temperature, temperatures have increased by more than 0.7° Celsius (°C) across much of Niger, with typical rates of warming greater than 0.15°C per decade. Observed changes alone (those between 1960 and 2009) account for 63 percent of the change magnitudes. A time series of air temperatures shows that the magnitude of recent warming is large and unprecedented within the past 110 years. Given that the standard deviation of annual air temperatures in these regions is low (approximately 0.5°C), these increases represent a large (approximately 1.5 standard deviation, 0.7°C) change from the climatic norm.

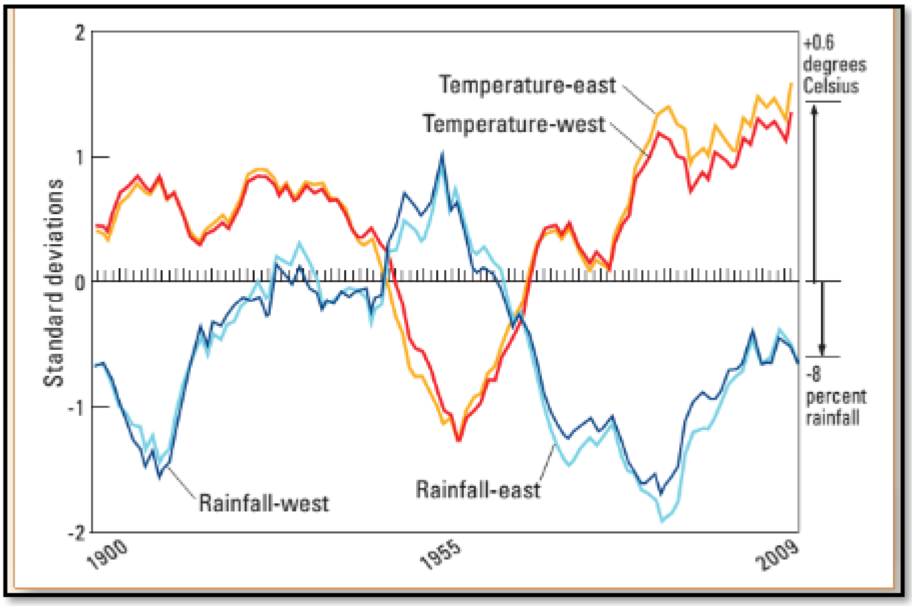


Figure 4: smoothed rainfall and air temperature time series for June–September for eastern and western Niger for 1960–2039

2.2. Climate Models

Simulated climate responses are known as climate projections, as opposed to predictions, since they are generated by models and not interpretations or estimates.

Today, more than 30 GCMs are available from modeling centers around the world, each of them considering unique assumptions and distortions. Not all of them can identify basic concepts and general trends, so it is difficult to choose just one. Esri presented this problem to the Research Application Laboratory (RAL) team at the University Corporation for Atmospheric Research (UCAR) and the National Center for Atmospheric Research (NCAR). The RAL team suggested creating a multi-model set (MME), which provides the means and standard deviations of a selected set of GCMs. The RAL team then selected 10 CMIP5 (Coupled Model Intercomparison Project, Phase 5), GCMs and compiled the multi-model set. This multi-model set includes projections of temperature and precipitation anomalies, which represent the difference between the current climate conditions, or baseline, and a future climate scenario (Esri web)

Various models are to be combined and they include Global climate models also called Global Circulation Models (GCMs), Regional Climate Models (RCM), and Weather Research and Forecasting (WRF) model. However, according to (Adeline Bichet *and al,* 2019) the low resolution (temporal and spatial) of GCMs, limits a precise assessment at a regional scale. A better assessment requires using regional climate models (RCMs), which provide a higher spatial and temporal resolution, and thus a better representation of the topography, coastline, and processes through the use of parametrization schemes.

The World Climate Research Program (WCRP) stipulates that Global Climate Model (GCM) can provide reliable prediction information on scales of around 1000 by 1000km covering what could be a vastly differing landscape (from very mountainous to flat coastal plains for example) with greatly varying potential for floods, droughts or other extreme events. Regional Climate Models (RCM) and Empirical Statistical Downscaling (ESD), applied over a limited area and driven by GCMs can provide information on much smaller scales supporting more detailed impact and adaptation assessment and planning, which is vital in many vulnerable regions of the world (Cordex website)

Global Climate Models (GCM) can provide us with projections of how the climate of the earth may change in the future. These results are the main motivation for the international community to take decisions on climate change mitigation. However, the impacts of a changing climate, and the adaptation strategies required to deal with them, will occur on more regional and national scales. This is where Regional Climate Downscaling (RCD) has an important role to play by providing projections with much greater detail and more accurate representation of localised extreme events.

Many Regional Climate Model (RCM) simulations are already openly available by the coordinated regional Climate Downscalling Experiment (CORDEX) through the Earth System Grid Federation (ESGF) and also through regional data portals (CORDEX data access). These CORDEX simulations are widely used for vulnerability, impacts, and adaptation (VIA) studies which in turn provide guidance for decision-making at regional and local scales (Nikulin1 and Stephanie Legutke, 2016).

Climate models require data on the time-evolving emissions or concentrations of radiatively active constituents, and some have additional requirements for information about the time-evolving paths for land use and land cover. The research community identified a specific emission scenario (including data on land use and land cover) from the peer-reviewed literature as a plausible pathway towards reaching each target radiative forcing trajectory. These were given the label 'representative concentration pathways' (RCPs).

2.3. Representative Concentration Pathways'(RCPs)

Today, scientists are producing future climate projections using GCMs that vary the amounts of greenhouse gases. Since it is impossible to predict the exact concentrations of greenhouse gases, they run these GCMs with several potential scenarios of greenhouse gas concentrations. These scenarios are called Representative Concentration Pathway (RCP) scenarios.

In reviewing literature, two approaches are usually developed. For the first, sequential approach, scenarios were developed and applied sequentially in a linear causal chain that extended from the socioeconomic factors that influence greenhouse gas emissions to atmospheric and climate processes to impacts. For the second, the parallel approach, rather than starting with detailed socioeconomic story lines to generate emissions and then climate scenarios, begins with the identification of important characteristics for scenarios of radiative forcings for climate modeling, the most prominent of which is the level of radiative forcing in the year 2100.

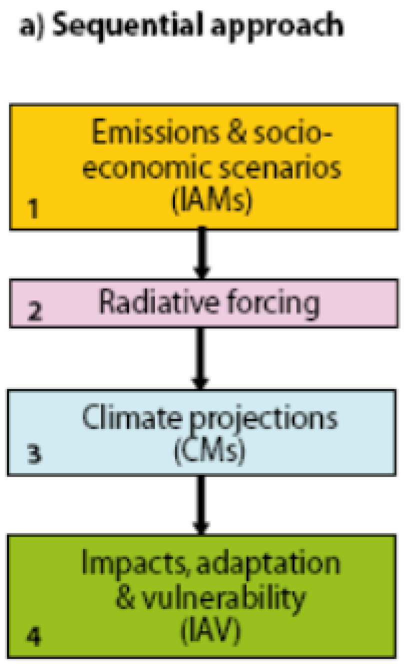


Figure 5a: Sequential approach of the Representative Concentration Pathways'

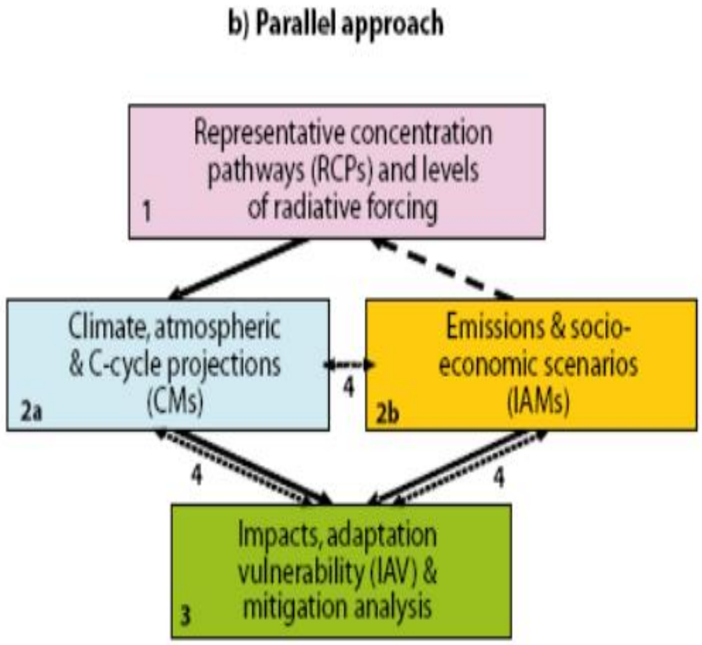


Figure 5b: Parallel approach of the Representative Concentration Pathways'

In 2014, the Intergovernmental Panel on Climate Change (IPCC) adopted four standard RCP scenarios with greenhouse gas concentrations adding the following radiative forcing levels: 2.6, 4.5, 6, 0 and 8.5 W / m². These scenarios represent a range of best (2.6) to worst (8.5) cases of the addition of greenhouse gases to the atmosphere. Most climate scientists use these scenarios to transpose future climate projections in 20-year increments from 2020.

For example, the RCP 6.0 scenario is a stabilization scenario in which radiative forcing levels stabilize without exceeding 6.0 W / m² by 2100. Scenario 6.0 is considered to have a realistic probability. The standard GCM outputs for this scenario include projections for the periods 2020–2039 and 2040–2059. https://learn.arcgis.com/fr/projects/explore-future-climate-projections/terms-concepts-and-common-structures-of-climate-data.htm

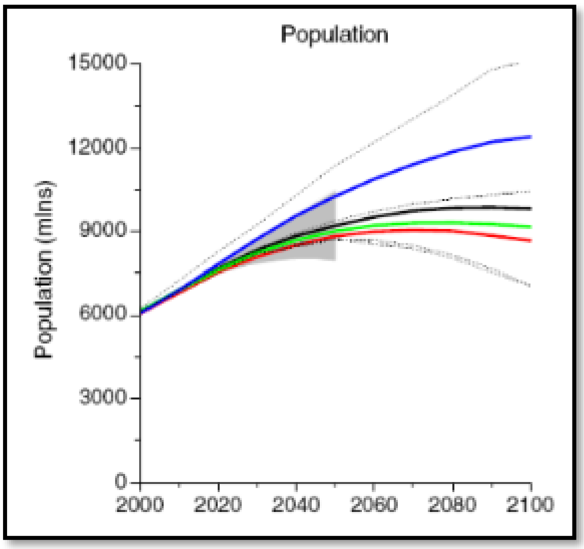
Each of the RCPs covers the 1850–2100 period, and extensions have been formulated for the period thereafter (Detlef P, 2011).

Table 1 Overview of representative concentration pathways (RCPs)x

	Description	Publication
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100	(Riahi et al. 2007)-MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100	(Fujino et al. 2006; Hijioka et al. 2008)- AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100	(Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009) GCAM
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline	(Van Vuuren et al. 2007; van Vurren et al. 2006)-IMAGE

For the four RCPs namely *RCP*2.6, *RCP*4.5, *RCP*6.0 and *RCP*8.5, the associated number corresponds to the radiative forcing reached at the end of the 21st century (Richard Moss and al 2010).

The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents. The four selected RCPs were considered to be representative of the literature, and included one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5/RCP6) and one very high baseline emission scenarios (RCP8.5) (Detlef P, 2011)



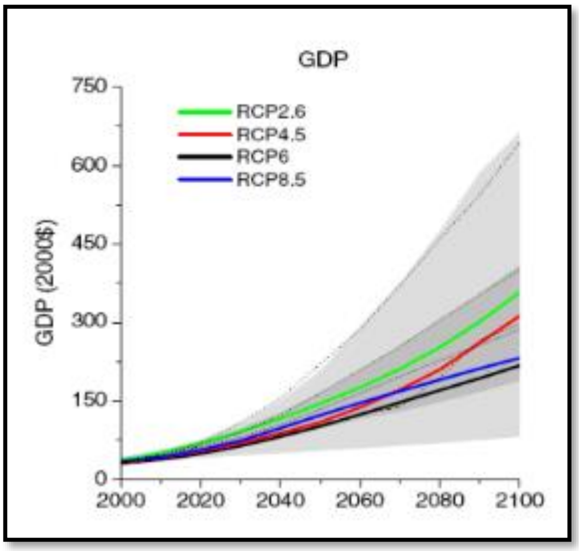


Figure 6: Population and GDP projections of the four scenarios underlying the RCPs.

Source: *(UN 2003) and (Hanaoka and al. 2006).*

The population and GDP pathways underlying the four RCPs are shown in Figure 6. The above figure, as reference, the UN population projections and the 90th percentile range of GDP in the literature on greenhouse gas emission scenarios. It shows the RCPs to be consistent with these two references. It should be noted that, with one exception (RCP8.5), the modeling teams deliberately made intermediate assumptions about the main driving forces as illustrated by their position.

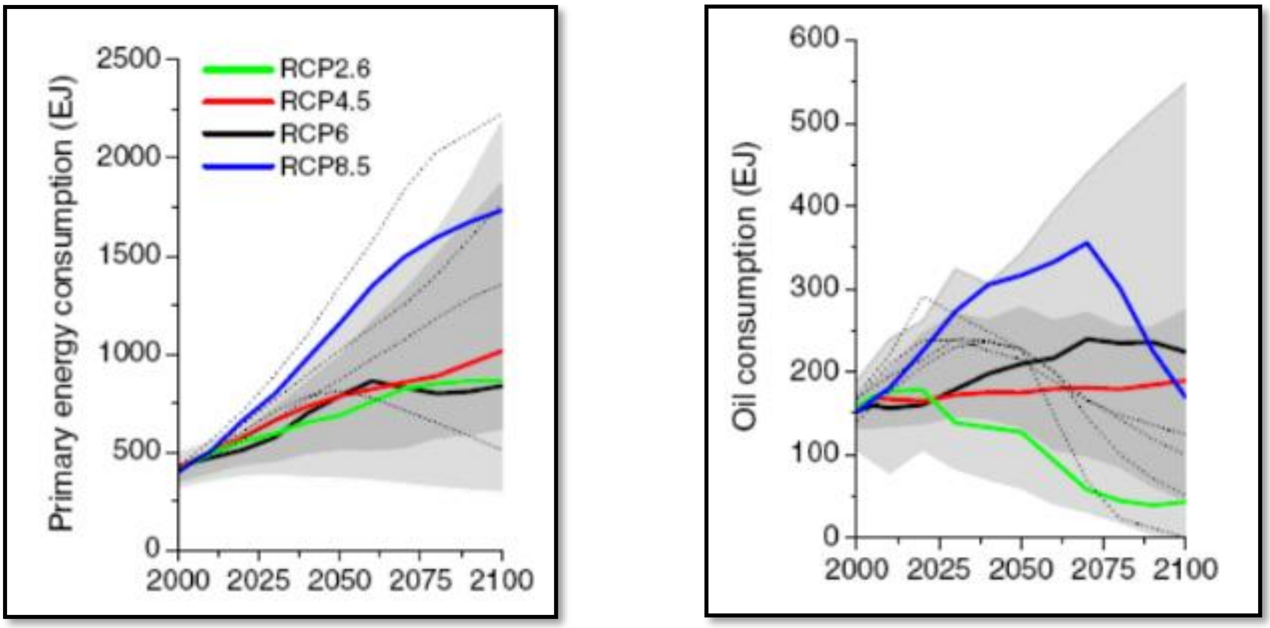


Figure 7: Development of primary energy consumption (direct equivalent) and oil consumption for the different RCPs .

Source: (Hanaoka and al.2006) and more recent literature (Clarke and al. 2010; Edenhofer and al. 2010).

2.4. Climate change Modelling

Climate simulations in West Africa have been a challenge for climate models due to the complexity and the diversity of processes to be represented. No coherent trend for either decreasing or increasing precipitation emerges from the Coupled Model Inter comparison Project Phase 3 (CMIP3) Global Climate Model (GCM) products.

Mohammed Zodi Saddam (2018) has combined GCMs and RCMs to know the future climate in Niger. An inter-annual evolution of shortwave downward direct irradiance for the historical period (1979-2005) to the near future (2019-2050) over Niamey and

Agadez under RCP4.5 Scenario was established as well. For the climate change scenarios, the author used the RCP 4.5 because of limited computational resources and on the basis of the fact this scenario seems more reasonable one in the light of Paris' COP21 climate agreement in December 2015.

Ensembles of models, both of GCMs and RCMs, were reported by Ganiyu Titilope Oyerinde (2018) as better predictor than individual models. Spatial pattern of ensemble median of changes of eight GCMs relative to the present-day reference period of 1970–1999 were evaluated in two future 30 years periods: the near term (2030–2059) and far term (2070-2099). Annual and seasonal climate trends from 2010 to 2100 relative to 1970-1999 were presented in line graphs.

In their study on forecasting changes in west Africa (including Niger) PV Energy Output by 2045, Dimitri and al (2016) took the climate projections (table 2) from the COordinated Regional climate Downscaling EXperiment for Africa (CORDEX). The authors primarily, used two kinds of data: surface downwelling solar radiation (rsds), which has a wavelength range from 0.2 to 4.0 µm, and near surface air temperature (tas). The used data range from 2006 to 2100 at daily time steps with a spatial of 0.44° which corresponds to approximately 50 km.

Table 2: Some Global Climate Models

Institute ID	Global Climate Model Name	Model Short Name
NOAA-GFDL	**GFDL-ESM2M**	**NOAA**
NCC	**NoerESM1-M**	**NCC**
MPI-M	**MPI-ESM-LR**	**MPI**
MIROC	**MIROC5**	**MIROC**
IPSL	**IPSL-CM5A-MR**	**IPSL**
ICHEC	**EC-EARTH**	**ICHEC**
CNRM-CERFACS	**CNRM-CM5**	**CNRM**
CCCma	**CanESM2**	**CCCMA**

Source: Adeline Bichet *et al* 2019

The Coordinated Regional Downscaling Experiment (CORDEX) is a program sponsored by World Climate Research Program (WCRP) to develop an improved framework for generating regional-scale climate projections for impact assessments using recent CMIP5 GCM projections. (Ganiyu Titilope Oyerinde 2018).

For Serge Dimitri and al (2016) only experiments performed with *RCP*8.5, which is the highest radiative forcing, were considered. The *RCP*8.5 is based on the *A*2*r* scenario which combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long-term to high energy demand and greenhouse gas emissions in the absence of climate change policies.

2.4.1. Expected Climate Change in Niger

Clearly, results are still uncertain and often mixed concerning the future potential of solar and wind energy over Africa under a warming climate, and more data and analyses are needed to provide more robust information toward the development of energy production strategies.
Anthropogenic climate change for the next several decades is very hard to estimate due to what can be expressed as noise in the climate change signal caused by inter-annual climate variability. There is however several robust trends already identified and on the basis of which future estimates can be drawn. These trends include the increases in temperatures in the lower atmosphere and sea surface, increases in sea level rise, reduction of wetness in top sol layers and others. However, there continue to be uncertainty about future pace of change and not all variables have the same degree of variability. Average temperatures are more robust than precipitation values, for example (Jane Ebinger and Walter Vergara 2011).

Even though the estimation is very hard, methods are becoming clearer than ever before. Past observations are no longer used alone to estimate potential future changes in surface solar radiation and related meteorological quantities relevant for solar power production. Instead, projections from comprehensive climate models have been used. Those climate models are the primary tools for the development of climate change scenarios for the 21 st century. But using them alone or one by one is not relevant for forecasting up-coming climate change.

(Olayinka et al., 2015) revealed that besides the fact many simulations are carried out using Global circulation models (GCMs), it is difficult for GCMs to reproduce various atmospheric variables of interest at a reasonable spatial resolution and thus cannot generate realistic outputs.

The expected climate change on Niger should also look at some parameters that will be useful in the PV potential model as well as in the future simulations. They are namely the solar radiation, the near surface air temperature and the wind speed.

A. Expected change in solar radiation

Mohammed Zodi Saddam (2018) found that for the period of 2019-2050 compared to the historical period of 1979-2005, a decrease in rsds is observed for most of the months of the year, except for the months of July, August and October for Niamey and April, July and August for Agadez where an increase is observed. The decrease could be due to the rainy season and hence more cloud cover during these months. The increase in April in Agadez is due to particles in the environment caused by harmattan winds. It also appears that peaks are observed in the months of May, June and September for Niamey and in April, July and September in Agadez. However, increase in direct irradiation is higher in Agadez, Niamey and other regions in Niger. The value, up to +6W/m², observed in August for the localities compared to the reference years. The minimum is observed in the month of August for both Niamey and Agadez. Compared to the reference years, a decrease of up to -4W/m² is observed in September. This could be due to increased cloud cover as August and September are within the rainy season.

The same author also discovered that a continuous increase in surface temperature is clearly observed for the near and far future over both Niamey and Agadez. The peaks over both localities are observed in May, June, and September. A high augmentation is observed during the month of February for both near and far future. The augmentation is up to 2°C for the near future for both cities and more than 3°C for Niamey and 2.6 °C for Agadez in the far future.

Meanwhile, Serge Dimitri and al (2016) stated that for the whole West Africa, the results show that the trends of solar irradiation are negative except for the Irish Centre for High-End Computing model which predicts a positive trend with a maximum value of 0.17 W/m²/year for Cape Verde and the minimum of −0.06 W/m²/year for Liberia.

The minimum of the negative trend is −0.18 W/m²/year predicted by the Model for Interdisciplinary Research on Climate (MIROC), developed at the University Of Tokyo Center for Climate System Research for Cape Verde. However, temperature trends are positive with a maximum of 0.08 K/year predicted by MIROC for Niger.

B. Expected change in Temperature

For temperature, according to Ganiyu Titilope Oyerinde (2018) a consistent but increasing trend with lower standard deviation across the GCMs was projected in two scenarios (RCP 4.5 and RCP 8.5). In the RCP 4.5 scenario, temperature will rise from about 0.05% to 0.1 % from the beginning to the end of the century, while under RCP 8.5 the Niger basin will experience an increase of about 0.05% to 0.2% towards the end of the century. There will be about 2°C increase in monthly temperature at the near future under the two scenarios presented. While the far future will experience about 2-5°C monthly increase under the two scenarios.

Geographical patterns of projected warming of surface temperatures are scenario-independent, with the greatest temperature increases over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic Ocean, consistent with the observed changes during the latter part of 20th century and over mountain regions. As the western part of Europe and Central Asia, West Africa including Niger is projected to experience increasing levels of temperature variability

Table 3 : Mean of ambient air temperature (tas) trends by country (K/year)

Countries	NOAA	NCC	MPI	MIROC	IPSL	ICHEC	CNRM	CCCMA
Benin	0.06	0.04	0.05	0.07	0.04	0.06	0.04	0.04
Cape Verde	0.04	0.03	0.03	0.04	0.04	0.04	0.03	0.03
Gambia	0.05	0.04	0.05	0.06	0.04	0.05	0.04	0.04
Ghana	0.05	0.04	0.05	0.07	0.04	0.05	0.04	0.04
Guinea	0.05	0.04	0.05	0.07	0.04	0.05	0.04	0.04
Cote d'Ivoire	0.05	0.04	0.05	0.07	0.04	0.05	0.04	0.04
Liberia	0.05	0.04	0.04	0.06	0.04	0.05	0.03	0.04
Mali	0.06	0.05	0.05	0.08	0.05	0.06	0.05	0.05
Niger	0.06	0.05	0.06	0.08	0.05	0.06	0.05	0.05
Nigeria	0.06	0.04	0.05	0.07	0.04	0.06	0.04	0.05
Guinea-Bissau	0.05	0.04	0.05	0.06	0.04	0.05	0.04	0.04
Senegal	0.06	0.04	0.05	0.06	0.05	0.05	0.04	0.05
Sierra Leone	0.05	0.04	0.04	0.06	0.04	0.05	0.03	0.04
Togo	0.06	0.04	0.05	0.07	0.04	0.05	0.04	0.04
Burkina Faso	0.06	0.05	0.05	0.07	0.05	0.06	0.04	0.05

C. Expected change in Wind Speed

Rising temperatures will also reduce the thermal difference between Polar Regions and the tropics and mean mid-latitude wind speeds will decrease; wind trend studies in selected areas indicate that this may indeed be happening. While changes in high-end extreme values need to be accompanied by other statistical measures (e.g., changes in mean values), they can provide an indication of how Peak solar energy production could vary. An overall reduction is projected over sub-Saharan Africa. (Jane Ebinger and Walter Vergara 2011).

2.4.2. Effect of climate change on Niger's renewable energy

In Africa, West Africa is particularly one of the most vulnerable to the effect of climate change (Tchotchou and Kamga, 2010). A study conducted by Li et al., (2012) demonstrates that climate changes can cause variabilities in weather patterns (wind speed, solar radiation, precipitation, temperature). This changes in resource potentials resulting from the impact or consequences of climate change may affect power generation from RE sources and can affect future electricity output. Also, changes in magnitude of several weather parameters (global solar radiation, relative humidity, precipitation, and wind speeds) are also to be expected (Ohunakin et al., 2015).

The International Energy Agency (IEA) report of 2011 projected that renewables based electricity generation would triple between 2008 and 2035 under the increasing-use-of-renewables scenario (Byman Hamududu and Aanund Killingtveit 2012). Hydropower, Solar power and wind power generation are the major renewable energies that make a substantial contribution to meeting today's increasing world electricity demands.

Meanwhile, climate change impacts are expected to exacerbate poverty in most developing countries, thereby creating new poverty pockets in countries with increasing inequality (Ganiyu Titilope Oyerinde 2018).

Effect of climate change on solar energy in Niger

The impacts of climate change on solar energy are also well-acknowledged in the literature (e.g. Tobin et al. 2018; Wild et al. 2015; Jerez et al. 2015; Burnett et al. 2014; Crook et al. 2011). For instance, a reduction of direct normal irradiation over Africa (up to 10%) and an increase over Europe (up to 10%) were projected by Huber et al. (2016). Bazyomo et al. (2016) also projected a general decrease of PV power generation over West African countries, except for Sierra Leone. Using an ensemble of regional climate models (RCMs) from the Coordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi et al. 2009), Sawadogo et al. (2019b) projected a general decrease of photovoltaic power potential (PVP) over West Africa under RCP8.5, with a maximum decrease reaching 3.8%. Likewise, Bichet et al. (2019) projected an average decrease of PVP of about 4% over most of Africa by the end of the century (Windmanagda Sawadogo and al, 2020).

2.5. Climate mitigation and adaptation relevant to the energy sector

The impacts of climate change, including changes in temperature, rainfall patterns and droughts, was assessed for the following sectors; agriculture, livestock, forestry, health and water resources. There is a need to strengthen climate observation and monitoring systems in all sectors, to reduce uncertainties and provide more robust information to decision-makers.

According to UNDP report of 2018 on the National Adaptation Plan process of Niger, the adaptation goals of Niger as defined in NDC (2016) are

- Ensuring food security
- Combating poverty
- Promoting rational management of natural resources
- Enhancing the resilience of population and ecosystems

To strengthen its people's resilience to climate change, Niger sees adaptation as paramount, through actions with strong co-benefits that strengthen the resilience of ecosystems and populations and reduce GHG emissions.

Climate change mitigation actions in Niger have improved access to electricity, with the goal of reaching 60% by 2030 (against 10% in 2010), thanks to rural electrification and the promotion of renewable energy. Eventually, energy efficiency will be improved by this and the Kandadji hydropower station will be developed to supply 130 MW, in addition to a 100 MW solar project (AfDB 2016).

The NDC provides a sense of direction by outlining long term adaptation goals linked to development priorities. There is a high level of awareness of climate change risks in Niger at the national level. Various initiatives and interventions have already supported substantial adaptation actions, contributing to laying the groundwork for the NAP process. Niger is preparing a medium-term development strategy, the Sustainable Development and Inclusive Growth Strategy (2035) or ‘2035 Vision’. Building on this strategy, the NAP process will facilitate adaptation planning in the country by supporting the integration of climate risk and opportunities in national and sector strategies and programmes. There are many stakeholders involved in climate change adaptation planning in Niger. This is due to the expected impact on food security, as well as overall economic development. Building synergies, improving coordination and mainstreaming climate change are considered crucial, and different initiatives have begun to lay the groundwork for a successful NAP process (UNDP, report of 2018).

3. PHOTOVOLTAIC SYSTEMS IN NIGER

Solar Radiation in Niger

To have a better understanding of the Photovoltaic system in Niger, we will need to quantify the available solar energy. Therefore, it is very important to locally know the solar radiation. Solar radiation (kW/m^2) is the energy from the sun that reaches the earth. The earth receives a nearly constant of solar radiation at its outer atmosphere. The intensity of solar radiation varies either with geographic location or with the season and time of the day. As for Niger, the most productive hours of sunlight are from 9:00 a.m. to 5:00 p.m (Madougou SaiÌdou and al, 2013).

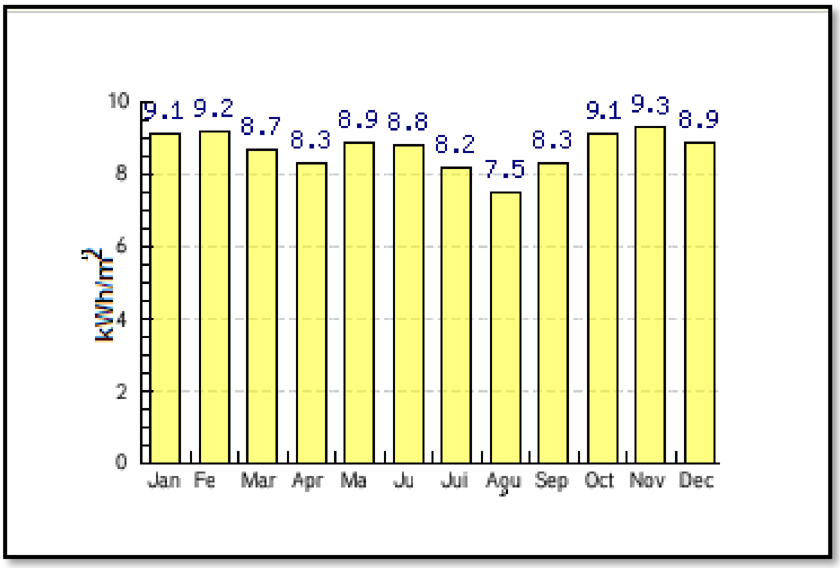


Figure 8: Monthly solar radiation in Niger for the year 2013

Source: Madougou SaiÌdou and al, 2013

CHAPTER THREE. METHODOLOGY AND DATA PROCESSING

1. SCOPE

Our goal in this study is to provide an overall picture of the direct effects of climate change on solar PV production at the scale of the Niger's Dosso Region considering future scenarios. In order to achieve the assigned objectives, from the main to the specific ones, in this study, we are analyzing the climate change effect on the PV systems by simulating some climate variables up to 2100 for different time periods. Thoses climate variables will also be used as parameters in looking at the PV cell temperature and how the potential production of solar power (PVpot) for any given site is expected to evolve as a result of climate change.

The PVpot which is an equation will represent a model where its parameters are variables that come from simulated meteorological data and the solar radiation. It must be noticed that this potential production is not directly related to the real production as the latter depends on the installed capacity.

For that, we use the most up-to-date ensemble of high-resolution regional climate model (RCM) projections as used by (Sonia Jerez and all, 2015) and that is Africa-Cordex.

2. DATA COLLECTION

In this field, simulation is the instrument to predict the key parameters as well as the different scenarios for the evolution of possible climatic phenomena. It is generally based on past and current data. The data that we will use in this study are from different sources. We will be using Meteorological data, remote sensing data and climate models.These data are useful in reaching the results of the climate projections that were drawn from the coordinated regional climate downscaling experience for Africa. (CORDEX).

2.1. Meteorological data

The meteorological data that we are going to use in this study are primary data taken from INERA. They cover the period from 1979 to 2014 with a minimu of 40 stations for Dosso region. They include near surface air temperature, the solar radiation and wind speed data as well.

As arlready stated, these meteorological data will mainly be used for analyzing the historical pathway of climate change from 1979 to 2014 regarding the availability of data. Firstly, the climate models will take the period from 2006 to the end of the century. For the period before 2005, we rely on historical pattern. Secondly, the meteorological data will also be used for cross-checking the variables with the ones of climate models that will be used during the work.

2.2. Climate models

A climate model can perform well in retrospective simulation tests to predict future climate with great accuracy. To achieve this, the climate forcing would have to change based on a feasible future scenario. The models that are used in this study are from Cordex as mentioned above. Here is a quick presentation:

Project : ***CORDEX***
Frequency : ***DAILY***
Experiement : ***RCP 2.6 and RCP 8.5***
Domain : ***AFR 44***
Date : ***2006-2100***
Rcm Name : ***RCA 4 for tas and RACMO22T for rsds***
Driving model : ***MIROC 5 for tas and ICHEC-EC-EARTH for rsds***

The example below (file rsds1.nc) shows the details of the netcdf file containing the rsds projections from 2006-01-01 to 2010-12-31 for the whole Africa including Niger.

```
File rsds1.nc (NC_FORMAT_NETCDF4_CLASSIC):

   5 variables (excluding dimension variables):
     char rotated_pole []
        Grid_mapping_name: rotated_latitude_longitude
        Grid_north_pole_latitude: 90
        Grid_north_pole_longitude: 0
     Double lon [rlon, rlat]
        Standard_name: longitude
        Long_name: longitude
        Units: degrees_east
     Double lat [rlon, rlat]
        Standard_name: latitude
        Long_name: latitude
```

Units: degrees_north
Double time_bnds [bnds, time]
Long_name: time bounds
Float rsds [rlon, rlat, time]
Standard_name: surface_downwelling_shortwave_flux_in_air
Long_name: Surface Downwelling Shortwave Radiation
Units: W m-2
Positive: down
Cell_methods: time: mean
Coordinates: lon lat
Grid_mapping: rotated_pole
Missing_value: 1.00000002004088e+20
_FillValue: 1.00000002004088e+20

4 dimensions:
Bnds Size: 2
[1] "vobjtovarid4: **** WARNING **** I was asked to get a varid for dimension named bnds BUT this dimension HAS NO DIMVAR! Code will probably fail at this point"
rlon Size:194
Axis: X
Standard_name: grid_longitude
Long_name: longitude in rotated pole grid
Units: degrees
rlat Size:201
axis: Y
Standard_name: grid_latitude
Long_name: latitude in rotated pole grid
units: degrees
time Size:1826 *** is unlimited ***
Units: days since 1949-12-01 00:00:00
Standard_name: time
Long_name: time
Calendar: standard
Bounds: time_bnds

24 global attributes:
Conventions: CF-1.4
Contact: Erik van Meijgaard, KNMI, Regional Climate division (vanmeijg@knmi.nl)
Experiment: RCP2.6 run
Experiment_id: rcp26
Realization: 1
Driving_experiment: ICHEC-EC-EARTH, rcp26, r12i1p1
Driving_model_id: ICHEC-EC-EARTH
Driving_model_ensemble_member: r12i1p1
Driving_experiment_name: rcp26
Institution: Royal Netherlands Meteorological Institute, De Bilt, The Netherlands
Institute_id: KNMI
Model_id: KNMI-RACMO22T
Rcm_version_id: v1
References: http://www.knmi.nl/research/regional_climate
Project_id: CORDEX

CORDEX_domain: AFR-44
Product: output
Frequency: day
Knmi_global_comment:
Knmi_model_comment: RACMO22T: baseline physics from ECMWF CY31r1; modifications include HTESSEL CY33r1, patch K-diffusion CY32r3, Modis surface albedo
Knmi_version_comment: v1: reference version for Africa and other (sub)tropical regions
Knmi_grib_path: mos.knmi.nl:/climreg/CXAFR50/yCS6-v441-fECEARTH-r12i1p1+rcp26/GRIB_data
Creation_date: 2017-02-09T03:45:13Z
Tracking_id: 6c7d944a-1ff5-41b3-9ba4-33678beae7fd

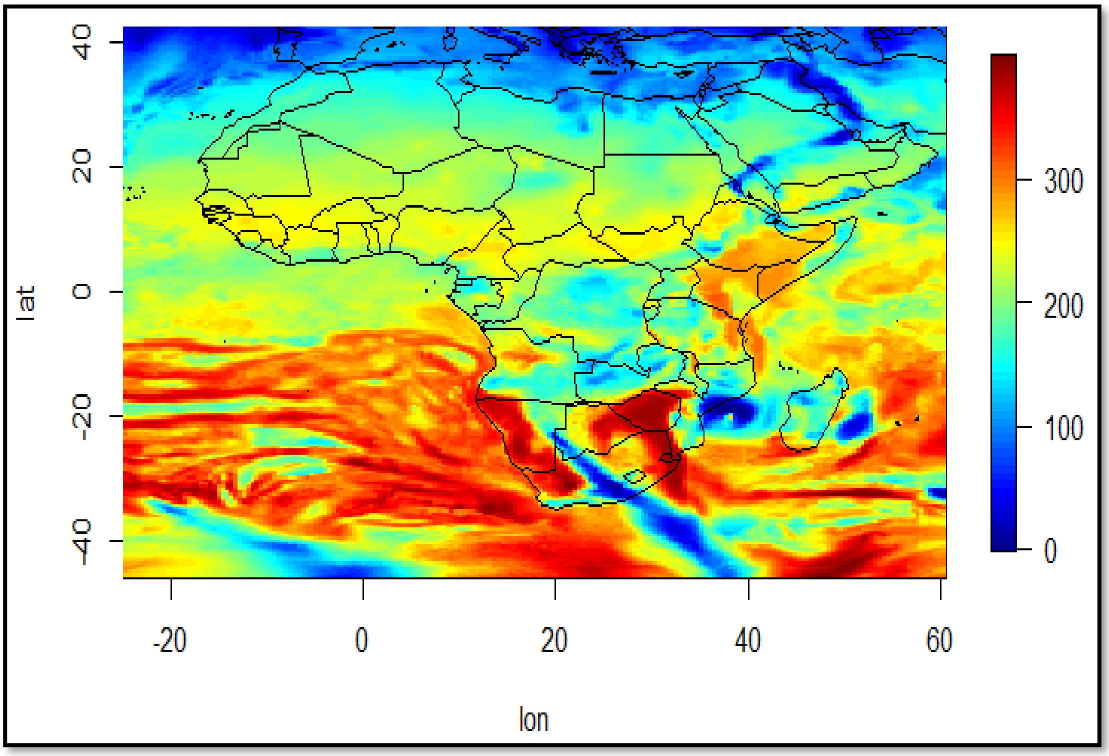


Figure 9: Image illustrating TAS value of the whole Africa

2.3. Satellite Data

As an important prerequisite for this work, we evaluated the simulated TAS for the period 2010-2015, by comparison with extracted Temperature index taken from the high-resolution satellite LANDSAT 8 ETM+.

There are several types and kinds of sensors, but for this work we will use the images taken by the LANDSAT 8 sensor.

The current literature present 8 different LANDSAT missions. The first Landsat 1 satellite was launched in 1972 and followed by 4 others (Landsat 2 to 5). The first three are the first generation, equipped with two acquisition systems: the RBV (Return Beam Vidicom) digital camera and the MSS (Multi Spectral Scanner) multispectral sensor. In 1982, the Landsat 4 satellite was the first of the second generation, with as a major modification: a change from an acquisition system from 4 to 7 channels and a resolution of 30 m against 80 previously, and the last generation with Landsat 6, launched on October 5, 1993 and crashed at sea during launch, and Landsat 7 successfully launched on April 15, 1999. Both equipped with new sensors: the Thematic Mapper (TM) and the Enhanced Thematic Mapper Plus (ETM +). The improved version of this generation is the Landsat 8 or LDCM (Landsat Data Continuity Mission) launched on February 11, 2013, with its new OLI sensor.

The Landsat 8 OLI instrument has 11 spectral bands, the characteristics of which are shown in the following table.

Table 3: Landsat 8 bands description

Bands	Spectral Bands	Wavelength	Spatial Resolution
Band 1	Coastal	0,435-0,451 µm	30 m
Band 2	Blue (visible)	0,452-0,512 µm	30 m
Band 3	Green (visible)	0,533-0,590 µm	30 m
Bande 4	Red (visible)	0,636-0,673 µm	30 m
Band 5	PIR	0,851-0,859 µm	30 m
Bande 6	NIR	1,566-1,651 µm	30 m
Bande 10	Thermal IR	10,60-11,19 µm	100 m
Bande 11	Thermal IR	11,50-12,51 µm	100 m
Bande 7	IR moyen	2,107-2,294 µm	30 m
Bande 8	Panchromatic	0,503-0,676 µm	15 m
Bande 9	Cirrus	1,363-1,384 µm	30 m

Source: OSFAC 2017

In this work, we will focus on using only the bands that record information in thermal infrared. These are bands 10 and 11 which record temperature information.

Thanks to them, we will be able to calculate the temperature indices for a certain determined period.

3. PARAMETERS TO BE CONSIDERED

Most renewable resources are dependent on weather and climate, a dependency (and vulnerability) that could affect the feasibility of future low-carbon energy supply systems. Photovoltaic (PV) electricity generation depends on solar irradiance, named surface-downwelling shortwave (that is, wavelength interval 0.2–4.0 μm) radiation (RSDS) and other atmospheric variables affecting panel efficiency, namely surface air temperature (TAS) and surface wind velocity (VWS).

Primarily, two variables are used: surface downwelling solar radiation (rsds), which has a wavelength range from 0.2 to 4.0 µm, and near surface air temperature (TAS).

The Cordex data range from 2006 to 2100 at daily time steps with a spatial of 0.44° which corresponds to approximately 50 km (Serge Dimitri Bazyomo, 2016) will be able to give produce such variables.

Climate change may therefore affect PV power generation and its temporal stability for a given panel fleet (Sonia Jerez and al, 2015).

Sonia Jerez and al. used five RCMs to downscale five global climate models (GCMs) under two climate scenarios (RCP4.5 and RCP8.5). RSDS, TAS and VWS time series retrieved from each ensemble member were used to estimate the corresponding PVpot time series for each grid cell of the domain (Sonia Jerez and all, 2015). TAS and VWS are used to compute the solar potential, as they affect the temperature of the PV cells (Adeline Bichet *and al*, 2019).

CORDEX: requested variables

output variable name	units	Tier 2 frq [1/day]	Core frq [1/mon]	ag	frq [1/sem]	ag	long_name
tas	K	8	1	m*8	1	s*8	Near-Surface Air Temperature
tasmax	K		1	m	1	s	Daily Maximum Near-Surface Air Temperature
tasmin	K		1	m	1	s	Daily Minimum Near-Surface Air Temperature
pr	kg m^{-2} s^{-1}	8	1		1		Precipitation
ps	Pa	8					Surface Air Pressure
psl	Pa	8	1	m*8	1	s*8	Sea Level Pressure
huss	1	8	1	m*8	1	s*8	Near-Surface Specific Humidity
hurs	%	8	1	m*8	1	s*8	Near-Surface Relative Humidity
sfcWind	m s^{-1}	8	1	m*8	1	s*8	Near-Surface Wind Speed
sfcWindmax	m s^{-1}		1	m	1	s	Daily Maximum Near-Surface Wind Speed
clt	%	8	1		1		Total Cloud Fraction
sund	s	8	1		1		Duration of Sunshine
rsds	W m^{-2}	8	1		1		Surface Downwelling Shortwave Radiation
rlds	W m^{-2}	8	1		1		Surface Downwelling Longwave Radiation
hfls	W m^{-2}	8	1		1		Surface Upward Latent Heat Flux
hfss	W m^{-2}	8	1		1		Surface Upward Sensible Heat Flux
rsus	W m^{-2}	8	1		1		Surface Upwelling Shortwave Radiation
rlus	W m^{-2}	8	1		1		Surface Upwelling Longwave Radiation
evspsbl	kg m^{-2} s^{-1}	4	1		1		Evaporation
evspsblpot	kg m^{-2} s^{-1}	4					Potential Evapotranspiration
mrfso	kg m-2	4	1	m*4	1	s*4	Soil Frozen Water Content
mrros	kg m^{-2} s^{-1}	4	1		1		Surface Runoff
mrro	kg m^{-2} s^{-1}	4	1		1		Total Runoff
mrso	kg m^{-2}	4	1	m*4	1	s*4	Total Soil Moisture Content
snw	kg m^{-2}	4	1	m*4	1	s*4	Surface Snow Amount
snm	kg m^{-2} s^{-1}	4	1		1		Surface Snow Melt
prhmax	kg m^{-2} s^{-1}						Daily Maximum Hourly Precipitation Rate
prc	kg m^{-2} s^{-1}	8					Convective Precipitation
rlut	W m^{-2}	4	1		1		TOA Outgoing Longwave Radiation
rsdt	W m^{-2}	4	1		1		TOA Incident Shortwave Radiation
rsut	W m^{-2}	4	1		1		TOA Outgoing Shortwave Radiation
uas	m s^{-1}	4	1	m*4	1	s*4	Eastward Near-Surface Wind
vas	m s^{-1}	4	1	m*4	1	s*4	Northward Near-Surface Wind

4. PROCESSING CLIMATE DATA

4.1. Scope

The climate is a long-term average of daily weather conditions. The analysis of climate data helps to understand the climate behavior at the Earth level, down to a specific location. Local climatic conditions are the result of complex interactions between the atmosphere and all the elements on the Earth's surface. Scientists use general circulation models (GCMs) that represent this complexity when they model potential climates. These GCMs include data and algorithms to simulate the physical processes, geochemical processes and the composition of different systems on the Earth's surface. A critical part of GCMs are decades of detailed historical weather measurements, ensuring that the modeled climates are based on actual climatic conditions.

At the turn of the 20th century, scientists began to assume that the introduction of greenhouse gases (GHGs) into the atmosphere would lead to climate change. This was confirmed in the 1970s, when the first models of baseline climate conditions corresponding to the recent past showed changes. Over time, the outputs of these models were found to correlate with the amount of GHGs introduced by natural and human processes.

The impact of greenhouse gases is measured as the ratio of energy (heat) absorbed by the Earth's atmosphere to the energy back reflected to space. Scientists call this balance radiative forcing and measure it in watts per square meter (W / m^2). As greenhouse gas levels increase or decrease in the atmosphere, radiative forcing values increase or decrease accordingly. In other words, the more the radiative forcing values increase, the more the atmosphere warms due to the retention of more energy in the atmosphere.

The climate processing is going to be under climate scenarios. Scenarios are possible stories about how quickly human population will grow, how land will be used, how economies will evolve, and the atmospheric conditions (and therefore, climate forcing) that would result for each storyline. https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-models

4.2.Climate scenarios

For analyzing historical changes of climate in Niger based on solar irrandiance, wind speed and temperature, we rely on the historicall available data collected from INERA. Normally we are trying to see what have been means values of all the tested parameters during the past years and how they have changed for a time period of 20 years starting from 1979. The historical data will be considered as a whole scenario during the results presentation and discussions.

For analyzing future changes of climate in Dosso and predicting the short and long-term effects on solar PV systems, we are going to select the most optimist RCP and the most pessimist RCP, namely RCP 2.6 and RCP8.5 under two different regional climate models (RCMs).

In the first scenario, we will use the RCA4 RCM to downscale the MIROC-MIROC GCM for TAS and RSDS wariables. The MECOT22O is the chosen RCM to downscale ICHEC-EE-EARTH GCM. The models are the same in the second scenario.

The emission trends for air pollutants are determined by three factors: the change in driving forces (fossil fuel use, fertilizer use), the assumed air pollution control policy, and the assumed climate policy.
Knowing that All RCPs include the assumption that air pollution control becomes more stringent, over time, as a result of rising income levels, this would cause emissions to decrease, over time—although trends can be different for specific regions or at particular moments in time (that is why we are looking at the Niger's Dosso region trend) —we are more focusing on concentrations of greenhouse gases and one of the Driving forces which is the climate policy. (Detlef P, 2011) agreed that the combination of trends in greenhouse gases and those in atmospheric pollutants translate to changes in concentrations affecting the overall development of radiative forcing. It has led to choose two different scenarios.

Therefore, our variables will be tested under the scenarios for precise periods that include March, June, September, and December. These periods are chosen because they refer to different seasons in the country and the meteorological data are likely to change during these periods. The simulation is then made based on the listed periods for 20 years time scale starting from 2006.

4.3.Preprocessing

The Cordex being the main source of models, the data are saved in 5 years for each file. This simply means that for a study that requires many years to be analyzed, we have to combine the individual files to make them one single file in order to have less data to manipulate. This is for this reason that we used the Netcdf extractor (a commercial software) to merge the individual files before extracting data for our area of study.

The Netcdf extractor allows to get data for each point in the area of study and also for all the time series. Since there is a big amount of dataset for all the period, the Netcdf extractor was also used to create the mean values for each variable using its sum and average functions.
Those means will be then used in all the analysis and calculations during the work.
Since it is the Cordex model that has been preprocessed, it simply means that all the variable are preprocessed.
The preprocessing is done using the data saved under the scenario RCP 26 then those saved under the scenario RCP 85, that is for each variable.

4.4.Data extraction and Climate data simulation

The extraction process will be the same for all the variables at some points.
Once different variables data are extracted (following the area of study) and merged for the wole period, the new files are now imported into R software for reading and screening (for TAS data) through some libraries and functions. It should be noted that the process is performed for each variable individually and not all the variables at the same time.
Primarily the rsds data are imported into R studio (which is a part of R software wherewe write scripts) and processed in order to get values for the up coming time series. Secondary, the VWS will be considered and perfomed in R studio in order toget the simulated values. Thirdly, the TAS value will be extracted and screened in different layers following the time series.

The RSDS data will be extracted and used as parameters in the PVpot model, before suggesting, if needed, the best range of the variables for the PV systems knowing that for any given time t, the potential production (PVpot (t)) is defined as the ratio between (1) the production that would be obtained for that time as a result of the current weather conditions (wind, temperature and solar radiation) and (2) the production that would have been obtained under standard test weather conditions. PVpot (t) is sometimes referred to as the 'capacity factor' of the PV cells for time t (IRENA 2018).

More especially for the TAS variable, being a fundamental descriptor of the conditions of the Earth's environment and one of the most widely used climatic variables in studies of global change. It will be mapped to show the difference between the various forecasted periods. Accurate estimation of TAS as well as mapping of its spatial distribution are useful in predicting the consequences of climate change on PV systems. For instance, global warming will lead to higher temperatures and an increase in extreme weather events, which are associated with changes in the performance of photovoltaic cells.

Generally, the near surface temperature is often measured in thermometric shelters 1.5m-2m above the ground at weather stations, and it is a commonly recorded form of weather observation data with precision and temporal resolution. However, those recorded data is limited by the poor distribution of meteorological stations. Therefore, the spatial resolution of the recorded air temperature data is coarse and sometimes random. Though various interpolation methods such as global interpolators and kriging are often implemented in order to overcome this shortcoming and have been found to be effective in estimating temperature near weather stations, but these methods could lead to considerable uncertainties caused by an inhomogeneous distribution of meteorological stations, especially in regions with complicated topography.

Thanks to remote sensing and satellite images, we can have in real time the exact TAS data recorded over the region. These remote sensing data being compared with those of the climate model used, allowed us to use the predictions of the model with a lot of confidence because the data of the same years have a lot of similarities. Which means, after exporting TAS data as raster layers, we process them in ArcGis for mapping them and extracting single data in such a way they can be used for making curves and graphs in Excel sheets time serie by time serie.

After the map for each date (month and year) has been created and the TAS variables plotted, and after extracting all the variables for different time series, the next step will be analyzing the changes over time, and discussing the results. By doing so, that is achieving the secong specific objective which is in line with the main objective of this study.

For the simulation, we are going to use some software including the statistical software R and ArcGis.

Thanks to some of its packages, the statistical software R will be very important for statistics and for visualizing (tables, graphs, etc.) a large amount of meteorological data in different time series and in different forms.

From the map and the charts, the read data will be used as inputs in the PV Potential formula.

4.5.PV Potential Modelling

The potential production PVpot characterizes the amount of solar energy that can be retrieved for a given site using PV cells. It depends on the local meteorological conditions, and it is thus linked to climate characteristics.

The results of historical analysis and climate change simulations will then be used to evaluate the PV Potential for past years and for future years in short-term and long-term period.

The PV power output at a site depends on two factors: the PV power generation potential (PVpot) and the installed capacity. As defined and used in this study, PVpot is a magnitude without dimension and reporting the performance of the PV cells with respect to their nominal power capacity under the actual ambient conditions. Therefore, PVpot multiplied by the nominal installed watts of PV power capacity gives instantaneous PV power production.

PVpot mainly involves the amount of the resource (RSDS) but also the influence that other atmospheric variables may have on the efficiency of the PV cells, which reduces as their temperature increases (Radziemska, E. 2003).

According to Mavromatakis, F. et al. (2010) it can be expressed as:

$$PV\ pot(t) = P_R(t)\ \frac{RSDS\ (t)}{RSDS_{STC}} \qquad \textbf{(1)}$$

Where STC refers to standard test conditions ($RSDS_{STC}$ = 1,000 W m^{-2}), those for which the nominal capacity of a PV device is determined as its measured power output, and P_R is the so-called performance ratio, formulated to account for changes of the PV cells efficiency due to changes in their temperature as:

$$P_R(t) = 1 + \gamma[T_{cell}(t) - T_{STC}] \quad \textbf{(2)}$$

Where T_{cell} is the PV cell temperature, T_{STC} = 25 °C and γ is taken here as -0.005 $°C^{-1}$, considering the typical response of monocrystalline silicon solar panels. Finally, T_{cell} is modelled considering the effects of TAS, RSDS and VWS on it as:

$$T_{cell}(t) = c_1 + c_2 TAS(t) + c_3 RSDS(t) + c_4 VWS(t) \quad \textbf{(3)}$$

With C_1= 4.3 °C, C_2 = 0.943, C_3 = 0.028 °C m^2W^{-1} and C_4 = -1.528 $°Csm^{-1}$ according to Chenni, R. and al, (2007).

Hence, if ambient conditions (RSDS, TAS and VWS) correspond to the STCs, PVpot equals 1 and PV power production reaches the rated value. If they are so that Tcell is higher (lower) than 25 °C and/or RSDS lower (higher) than 1,000W.$^{-2}$, PVpot will be lower (higher) than the unit and the PV power output will be lower (higher) than the nominal power of the module.

CHAPTER FOUR. RESULTS AND DISCUSSION

In this section of the work, we are going to present the results that we got from different simulations and some useful calculations. The results are presented under the two different scenarios.

4.1. HISTORICAL DATA

For historical data there was no prediction to make. The only thing was to analyse all the parameters that we are testing in this work and see how they have changed during the last years. This has also allowed us to evaluate the PV potential at the past time so that we can compare with the future PV potential based on climate change simulations under the other climate scenario.

4.1.1. TAS, VWS and RSDS VALUES

Since data were available from 1979 to 2014, we are presenting results for the 20 first years and those for the last 15 years.

4.1.2. PV Potential evaluation Vs Historical Data

Tas $_{(hist)}$ = 30.51 °C

Rsds $_{(hist)}$ = 255.67 W.m^{-2}

Vws $_{(hist)}$ = 2.502 m/s

From equation (3), we compute the PV Cell temperature

$$T_{cell}(t) = 4.3\ °C + 0.943 * 30.51\ °C + 0.028\ °Cm^2w^{-1} * 255.67W.m^{-2} + 1.528\ °Csm^{-1} * 2.502\ ms^{-1}$$

$$T_{cell}(2096) = 4.3\ °C + 28.77\ °C + 7.1587°C + 3.823\ °C$$

$$T_{cell}(hist) = 44.05\ °C$$

From equation (2), compute the Performance ratio

We have

$$P_R(hist) = 1 - 0.005\ °C^{-1}[44.05°C - 25\ °C]$$

$$P_R(hist) = 1 - 0.095$$

$$P_R(hist) = 0.905$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(hist) = P_R(hist)\ \frac{RSDS\ (hist)}{RSDS_{STC}}$$

$$PV\ pot(hist) = 0.905\ \frac{255.67}{1000}$$

$$PV\ pot(hist) = 0.231$$

4.2. FIRST CLIMATE SCENARIO (UNDER RCP 26)

The application of energy efficiency or use of renewables reduces both greenhouse gas emissions and air pollutants. The range of air pollution projections, generally, is smaller than that found in the literature. This is mostly due to the RCPs' shared assumption of stringent air pollution policies increasing proportionally with income (van Ruijven et al. 2008). In general, the lowest emissions are found for the scenario with the most stringent climate policy (RCP2.6) (Detlef P, 2011).
The results that will be presented under this first scenario were perfomed and processed based on the RCP26.

4.2.1. Simulated values of RSDS

For the RSDS, we generated graphs where curves will be showing the trend for the chosen time period.

Focusing on data from 2006 to 2010, the rsds data varied for the different periods assigned in this work but the mean value of the period is read as 253.8478 W/m².

The RACMO22T Regional Climate Model used to forecast rsds data up to 2100 revealed some changes even small in the solar irradiation trend.
For the period going from 2026 and 2030, or 20 years after the first time period, we can see that the solar irradiation has increased from 253.8478 W/m² to 254.2365 W/m².

The rsds_AFR-44_ICHEC-EC-EARTH_rcp26 data from the RACMO22T Rcm model suggests that for the 20 next year (2046-2050) Dosso will witness another increase in the solar irradiation data mean up to 257.0998 W/m².

Unlike the forecasted increase in solar irradiation during the two precedent 20 years time series, from 2066 to 2070, the trend shows the decrease up to 256.3270 W/m² before it get increase for the 20 next years (2086-2099) to the value of 257.6453 W/m².

Finally, the model predicts a mean value of 258.1788 W/m² for rsds within the next 10 years (2096-2100) in Dosso region.

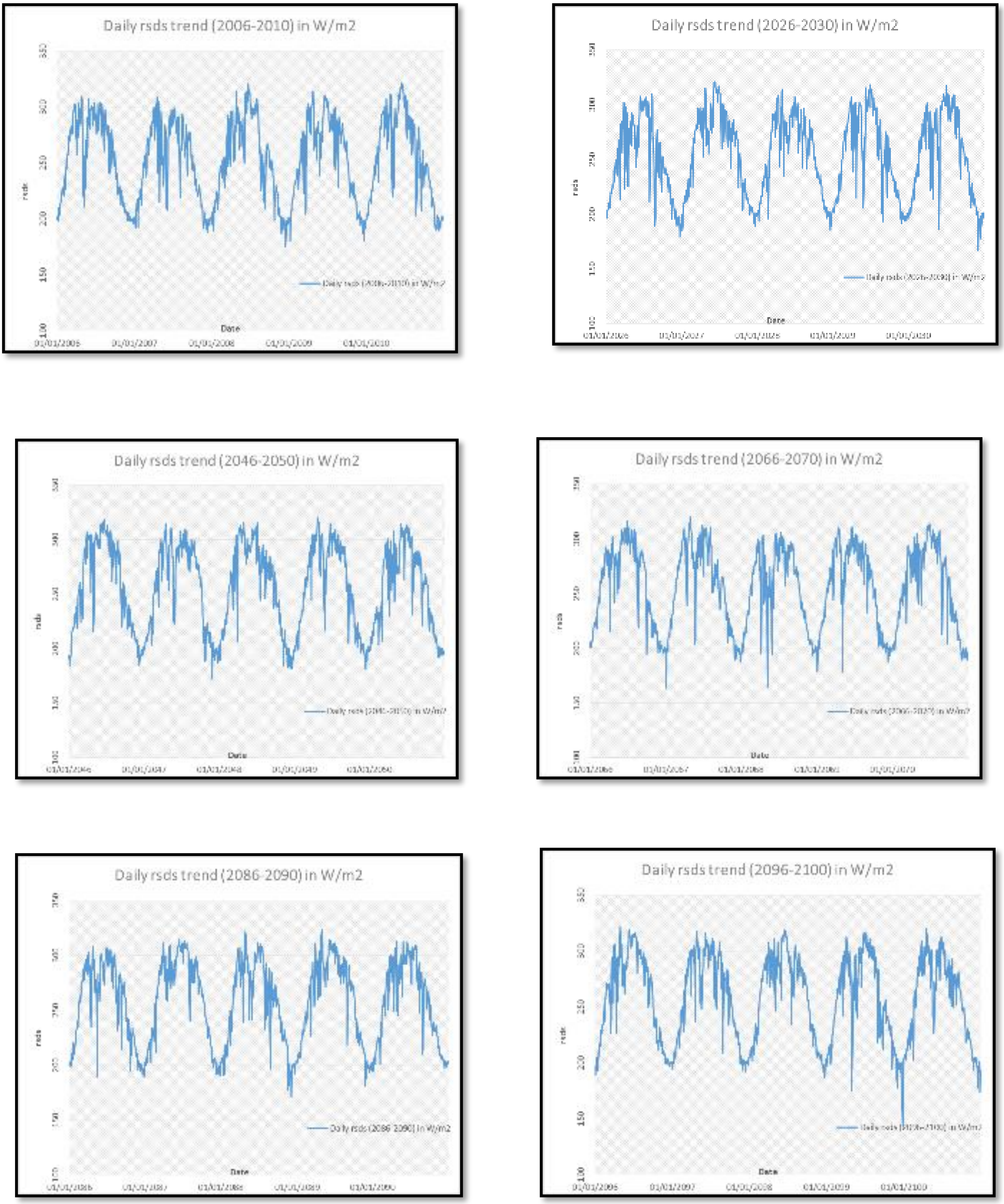


Figure 9: Daily solar radiation trend under RCP26 from 2006 to 2100

4.2.2. Simulated values of TAS

The maps presented below show the distribution of the Tas variable over time.
First, we compared the maps of 2006 with those of 2100 being the extreme years of our time series, then we compared the maps of 2026 and those of 2046 because they are in the middle of the time series of this study.

For the period of 2006-2010, the model shows a Tas mean value of 25.56 °C.

For the period from 2026 to 2030, the temperature increased slightly to 26.2 ° C.
The observation to be made for this RCP is that during the whole period of the study, the Tas does not really vary because from 2026 the RCA4 model simulates the future values of Tas and the data are around 26 °C. But we will be using each data for computing our model. Therefore, the mean value for 2006-2010 is 25.5 °C whilst the one for 2026 to 2030 has increased to 26.2 °C.
The resulsts shows that from 2046 to 2050, the Tas has mean of 26.71 °C being the highest value of Tas during the whole study period under this RCP.
Then after, the value is going to be 26.4 °C for the next 20 years and 26.12 °C for the other next 20 years. Finally, the model has predicted the Tas having a mean value of 26.12 °C from 2096 to 2100.

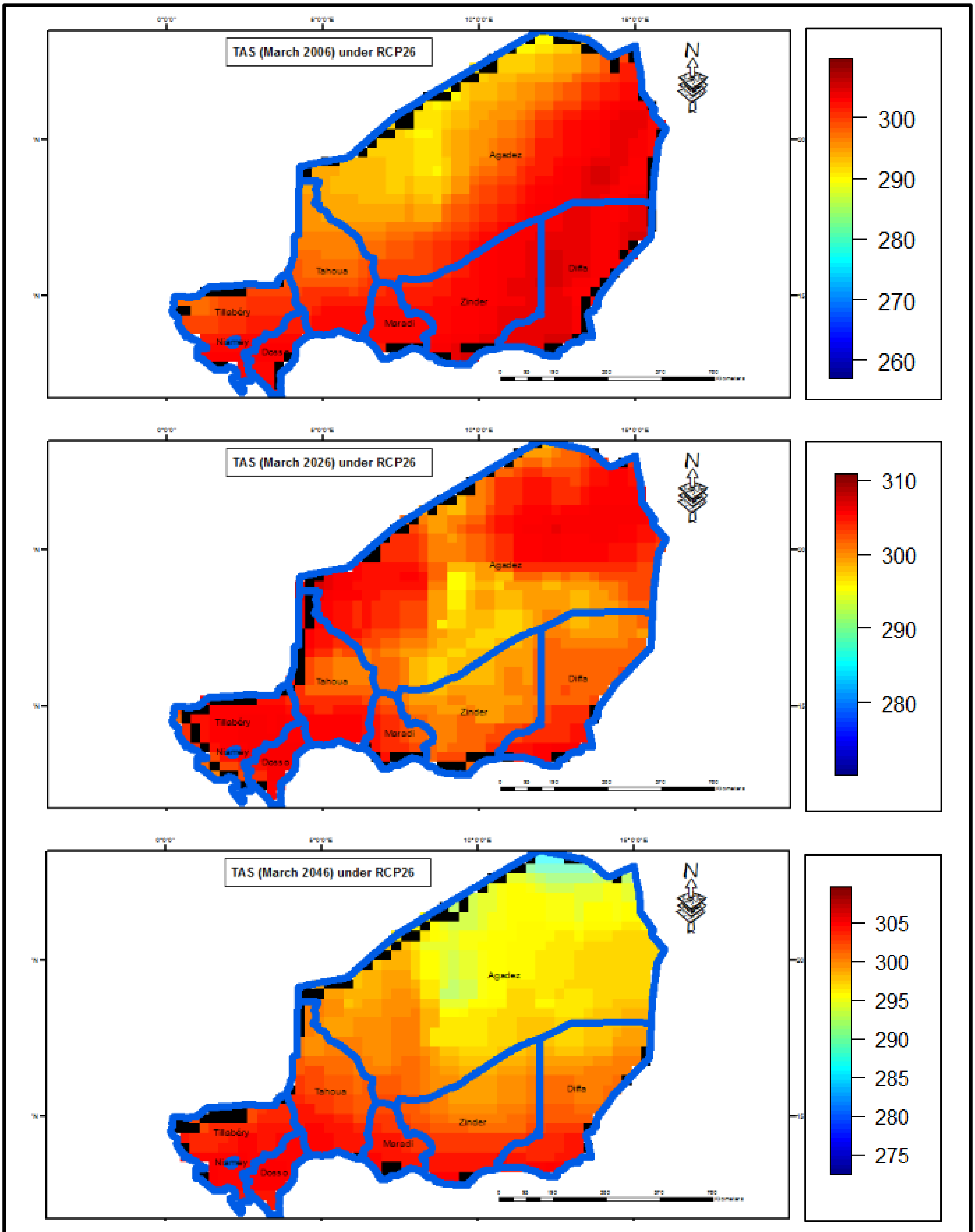


Figure 10: Near Surface Temperature change under RCP26 in Niger from 2006 to 2046

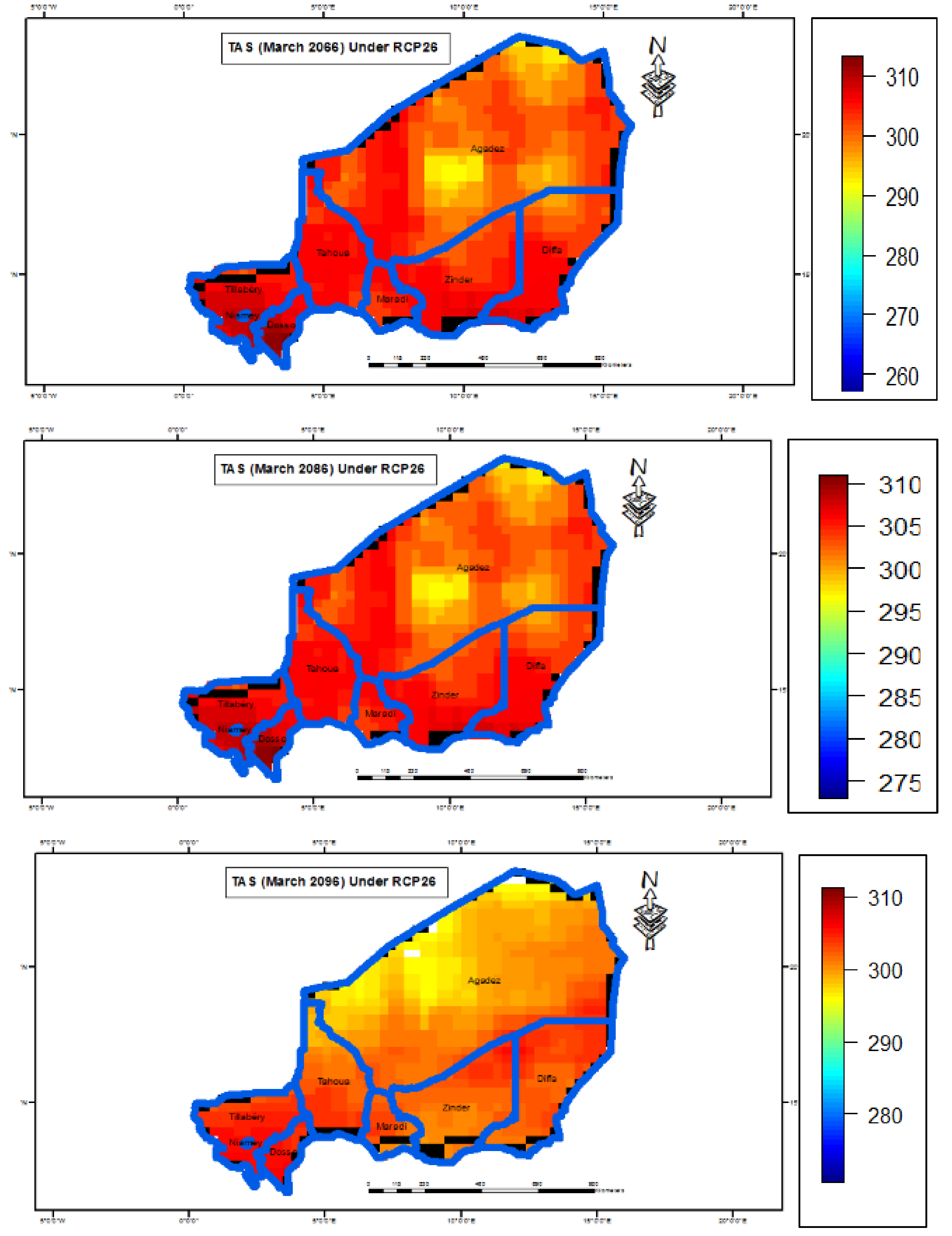


Figure 11: Near Surface Temperature change under RCP26in Niger from 2066 to 2100

4.2.3. Simulated values of VWS

The values of the wind speed during the period of our study are very important because they will be used for the calculation of our new PV Potential model.

The idea remains the same, the one of extracting data from 20 years time period.

The follwing table shows the different vws data versus the different time series.

Table 4: Simulated values of VWS under RCP26

N°	Period	Vws (m/s)
1	2006-2010	3.68
2	2026-2030	3.67
3	2046-2050	3.73
4	2066-2070	3.69
5	2086-2090	3.75
6	2096-2100	3.74

4.2.4. PV Potential Vs Scenario 1 (RCP26)

Given the above extracted data, we can compute the PVpot for each time serie under the scenario RCP 26.

- **For 2006**

Tas (2006) = 25. 56 °C

Rsds (2006) = 253.8474 W.m-2

Vws (2006) = 3.68 m/s

From equation (3), we have

$$T_{cell}(t) = 4.3\,°C + 0.943 * 25.56\,°C + 0.028\,°Cm^2w^{-1} * 253.8478\,W.m^{-2} + 1.528\,°Csm^{-1} * 3.68\,ms^{-1}$$

$$T_{cell}(2006) = 4.3\,°C + 24.103\,°C + 7.1077\,°C + 5.623\,°C$$

$$T_{cell}(2006) = 41.126\,°C$$

From equation (2), we have

$$P_R(2006) = 1 - 0.005\,°C^{-1}[41.126\,°C - 25\,°C]$$

$$P_R(2006) = 1 - 0.08063$$

$$P_R(2006) = 0.9193$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2006) = P_R(2006)\ \frac{RSDS\ (2006)}{RSDS_{STC}}$$

$$PV\ pot(2006) = 0.9193\ \frac{253.8478}{1000}$$

$$PV\ pot(2006) = 0.2333$$

- **For 2026**

Tas(2026) = 26.21 °C

Rsds(2026) = 254.2365 $W.m^{-2}$

Vws(2026) = 3.67 m/s

From equation (3), we have

$$T_{cell}(t) = 4.3\,°C + 0.943 * 26.21\,°C + 0.028\,°Cm^2w^{-1} * 254.2365W.m^{-2} + 1.528\,°Csm^{-1} * 3.67\,ms^{-1}$$

$$T_{cell}(2026) = 4.3\,°C + 24.71\,°C + 7.1186\,°C + 5.6077\,°C$$

$$T_{cell}(2026) = 41.73\,°C$$

From equation (2), we have

$$P_R(2026) = 1 - 0.005\,°C^{-1}[41.73\,°C - 25\,°C]$$

$$P_R(2026) = 1 - 0.08365$$

$$P_R(2026) = 0.9163$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2026) = P_R(2026)\ \frac{RSDS\ (2026)}{RSDS_{STC}}$$

$$PV\ pot(2026) = 0.9163\ \frac{254.2365}{1000}$$

$$\boldsymbol{PV\ pot(2026) = 0.2329}$$

- **For 2046**

Tas $_{(2046)}$ = 26.71 °C

Rsds $_{(2046)}$ = 257.0998 W.m^{-2}

Vws $_{(2046)}$ = 3.73 m/s

From equation (3), we have

$$T_{cell}(t) = 4.3\,°C + 0.943 * 26.71\,°C + 0.028\,°Cm^2w^{-1} * 257.0998W.m^{-2} + 1.528\,°Csm^{-1} * 3.73\,ms^{-1}$$

$$T_{cell}(2046) = 4.3\,°C + 25.18\,°C + 7.1987\,°C + 5.699\,°C$$

$$T_{cell}(2046) = 42.38\ °C$$

From equation (2), we have

$$P_R(2046) = 1 - 0.005\ °C^{-1}[42.38\ °C - 25\ °C]$$

$$P_R(2046) = 1 - 0.0869$$

$$P_R(2046) = 0.9131$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2046) = P_R(2046)\ \frac{RSDS\ (2046)}{RSDS_{STC}}$$

$$PV\ pot(2046) = 0.9131\ \frac{257.0998}{1000}$$

$$\boldsymbol{PV\ pot(2046) = 0.2347}$$

- **For 2066**

Tas $_{(2066)}$ = 26.43 °C

Rsds $_{(2066)}$ = 256.3270 W.m^{-2}

Vws $_{(2066)}$ = 3.69 m/s

From equation (3), we have

$$T_{cell}(t) = 4.3\ °C + 0.943 * 26.43\ °C + 0.028\ °Cm^2w^{-1} * 256.3270W.m^{-2} + 1.528\ °Csm^{-1} * 3.69\ ms^{-1}$$

$$T_{cell}(2066) = 4.3\ °C + 24.92\ °C + 7.1771\ °C + 5.6383\ °C$$

$$T_{cell}(2066) = 42.03\ °C$$

From equation (2), we have

$$P_R(2066) = 1 - 0.005\ °C^{-1}[42.03\ °C - 25\ °C]$$

$$P_R(2066) = 1 - 0.0851$$

$$P_R(2066) = 0.9149$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2066) = P_R(2066)\ \frac{RSDS\ (2066)}{RSDS_{STC}}$$

$$PV\ pot(2066) = 0.9149\ \frac{256.3270}{1000}$$

$$\boldsymbol{PV\ pot(2066) = 0.2345}$$

- **For 2086**

Tas $_{(2086)}$ = 26.02 °C

Rsds $_{(2086)}$ = 257.6453 W.m^{-2}

Vws $_{(2086)}$ = 3.74 m/s

From equation (3), we have

$$T_{cell}(t) = 4.3\ °C + 0.943 * 26.02\ °C + 0.028\ °Cm^2w^{-1} * 257.6453\ W.m^{-2} + 1.528\ °Csm^{-1} * 3.74\ ms^{-1}$$

$$T_{cell}(2086) = 4.3\ °C + 24.54\ °C + 7.2140\ °C + 5.7147\ °C$$

$$T_{cell}(2086) = 41.77\ °C$$

From equation (2), we have

$$P_R(2086) = 1 - 0.005\ °C^{-1}[41.77\ °C - 25\ °C]$$

$$P_R(2086) = 1 - 0.0838$$

$$P_R(2086) = 0.9162$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2086) = P_R(2086)\ \frac{RSDS\ (2086)}{RSDS_{STC}}$$

$$PV\ pot(2086) = 0.9162\ \frac{257.6453}{1000}$$

$$\boldsymbol{PV\ pot(2086) = 0.2360}$$

- **For 2096**

Tas $_{(2096)}$ = 26.12 °C

Rsds $_{(2096)}$ = 258.1788 W.m^{-2}

Vws $_{(2096)}$ = 3.74 m/s

From equation (3), we have

$$T_{cell}(t) = 4.3\ °C + 0.943 * 26.12\ °C + 0.028\ °Cm^2w^{-1} * 258.1788\ W.m^{-2} + 1.528\ °Csm^{-1} * 3.74\ ms^{-1}$$

$$T_{cell}(2096) = 4.3\ °C + 24.63\ °C + 7.2290\ °C + 5.7147\ °C$$

$$T_{cell}(2096) = 41.87\ °C$$

From equation (2), we have

$$P_R(2096) = 1 - 0.005\ °C^{-1}[41.87\ °C - 25\ °C]$$

$$P_R(2096) = 1 - 0.0844$$

$$P_R(2096) = 0.9156$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2096) = P_R(2096)\ \frac{RSDS\ (2096)}{RSDS_{STC}}$$

$$PV\ pot(2096) = 0.9156\ \frac{258.1788}{1000}$$

$$\boldsymbol{PV\ pot(2096) = 0.2363}$$

4.3. SECOND CLIMATE SCENARIO

The overall correlation implies that climate policy induces systemic changes in the energy system away from technologies with high greenhouse gas emission levels, which also have high emissions of air pollutants.

The highest emissions are found for the scenario without climate policy (RCP8.5) (Detlef P, 2011). That is the reason why for the first climate scenario, we rely on the RCP 8.5.

As for the first scenario, our three variables are tested under this second one for fixed periods that include March, June, September, and December and the simulation are made based on the listed periods for 20 years time scale starting from 2006.
For the TAS variable, the purpose is to map them and get data points for different time series and use them to compute the temperature of PV cells under different weather conditions knowing the standard, in order to see if it is going to decrease or increase.
After the mapping for each date (month and year) has been created and the TAS variables plotted, the next step will be analyzing the changes over time, and discussing the results.
Then, the RSDS data will be extracted and used as parameters in the PVpot model, knowing that for any given time t, the potential production (PVpot (t)) is defined as the ratio between (1) the production that would be obtained for that time because of the current weather conditions (wind, temperature and solar radiation) and (2) the production that would have been obtained under standard test weather conditions.

4.3.1. Simulated values of RSDS

Since data used are daily data, making daily plot from 2006 to 2100 will be unnecessary and very painfull. That is why we are focusing on the mean data variability in this section as suggested earlier in this work.
It has come that the rsds data varied for the different periods assigned in this work producing a mean value 253.3307 W/m² for the first time series (2006-2010).

The same model used for the RCP 2.6 was still used in thisnew scenario and that was the RACMO22T Regional Climate Model that revealed a very small change in the solar irradiation trend from 2026 to 2030 with similar value of 253.75 W/m².

The forecast of rsds under the RCP 8.5 for the 20 next year (2046-2050) shows that Dosso will witness an increase in the solar irration data mean up to 256.0868 W/m².

After witnessing an increase in solar irradiation during the two precedent 20 years time series, from 2066 to 2070 the trend will start decreasing up to 253.9515 W/m².

The Model shows that the decrease will still continue for the next 20 years (2086-290). This could be due to the amount of air polluants and solid particles in the atmosphere, preventing the sunlight to get properly the earth surface. This scenario being the most pessimist in terms of air polluants releasing and Green House Gas Emissions, the rsds is supposed to decrease to a mean value of 249.8774 W/m².
That is what also explains the decrease in the next 10 years where the rsds mean value is of 248.3098 W/m².

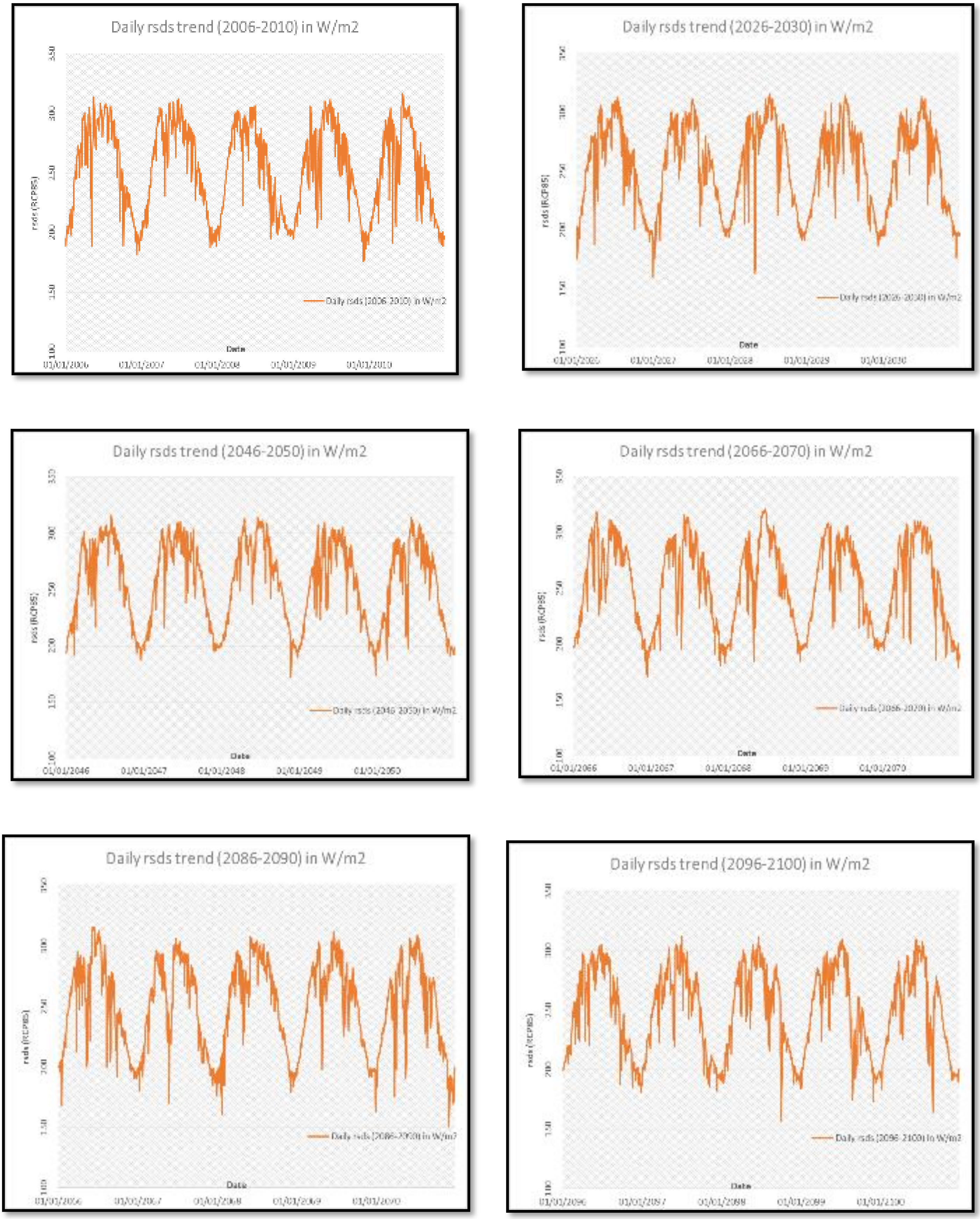


Figure 12: Daily solar radiation trend under RCP85 from 2006 to 2100

4.3.2. Simulated values of TAS

Knowing that the Tas value is going to be used to evaluate the temperature of PV cells, we are looking at it for the different time series because whenever TCell > 25 °C which is the standard, then PVpot (t) <1 and the PV production is lower than the rated value. Likewise, the Tas change will also have an impact on the T_{Cell}. More the temperature increases, more the Pv plot decreases.

For the period of 2006-2010, the model shows a Tas mean value of 25.87 °C.

For the period from 2026 to 2030, the temperature increased to 26.66 ° C.
Unlike the observation to be made for the previous scenario under RCP26, for the scenario under RCP85, the Tas has experienced considerable variations during the whole period of the study, because from 2006 the RCA4 model simulates the future values from 25.87 °C to 30.47 ° C in 2100.
The resulsts shows that from 2046 to 2050, the Tas has mean of 27.16 °C.
Then after, the value is going to be 28.38 °C for the next 20 years and 29.80 °C for the other next 20 years. Finally the model has predicted the Tas having a mean value of 30.47 °C from 2096 to 2100 being the highest value of Tas during the whole study period under this RCP.

The maps presented below show the distribution of the Tas variable over time.
First, we compared the maps of 2006 with those of 2100 being the extreme years of our time series, then we compared the maps of 2026 and those of 2046 because they are in the middle of the time series of this study.

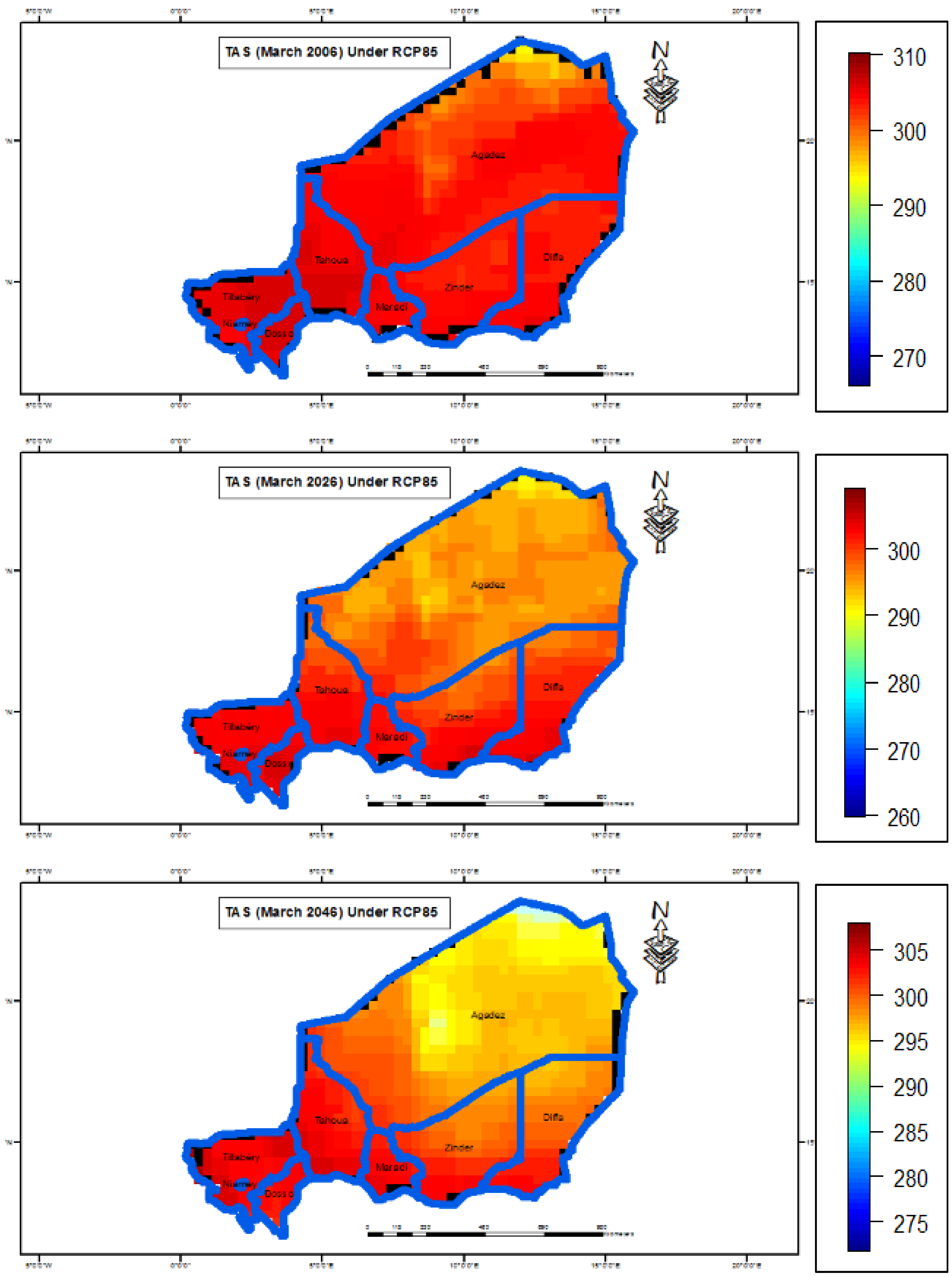


Figure 13: Near Surface Temperature change under RCP85 in Niger from 2006 to 2046

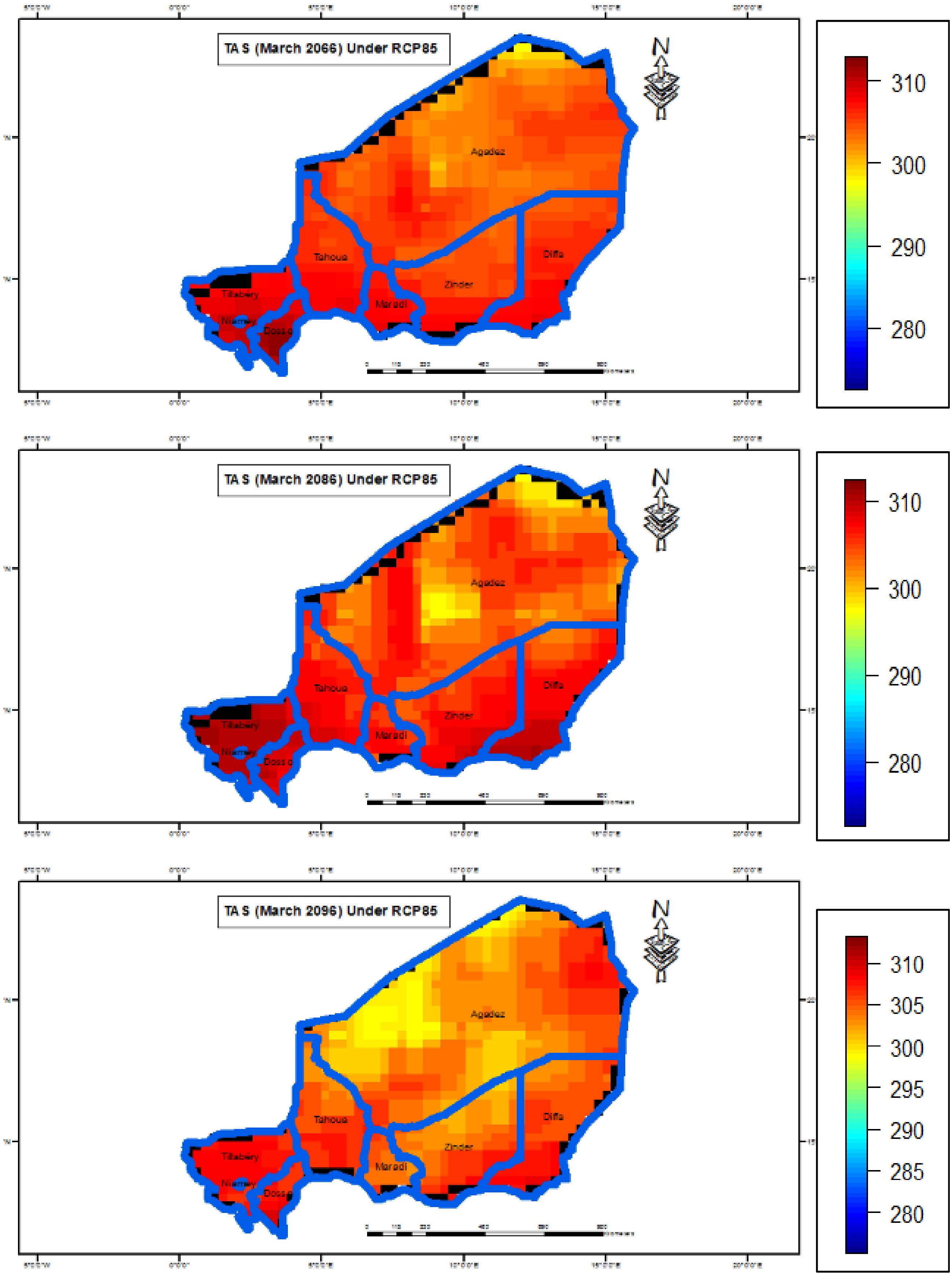


Figure 14: Near Surface Temperature change under RCP85 in Niger from 2066 to 2100

4.3.3. Simulated values of VWS

The follwing table shows the different vws data versus the different time series.

Table 5: Simulated values of VWS under RCP85

N°	Period	Vws (m/s)
1	2006-2010	3.69
2	2026-2030	3.70
3	2046-2050	3.74
4	2066-2070	3.77
5	2086-2090	3.74
6	2096-2100	3.77

4.3.4. PV Potential Vs Scenario 2 (RCP85)

Given the above extracted data, and the standard ones, we can compute the PV pot for each time serie under the scenario RCP 85.

From (Chenni, R. and al, (2007), we got standard data as followed:

T_{STC} = 25 °C
RSDS =1,000W.$^{m-2}$
γ = 0.005 °C^{-1},
C_1= 4.3 °C,
C_2 = 0.943,
C_3 = 0.028 °C m²W^{-1}
C_4 = -1.528 °Csm^{-1}

- **For 2006**

Tas (2006) = 25. 87 °C

Rsds (2006) = 253.3307 W.m^{-2}

Vws (2006) = 3.69 m/s

From equation (3), we compute the PV Cell temperature

$$T_{cell}(t) = 4.3\,°C + 0.943 * 25.87\,°C + 0.028\,°Cm^2w^{-1} * 253.3307\,W.m^{-2} + 1.528\,°Csm^{-1} * 3.69\,ms^{-1}$$

$$T_{cell}(2006) = 4.3\,°C + 24.40\,°C + 7.0932\,°C + 5.638\,°C$$

$$T_{cell}(2006) = 41.43\ °C$$

From equation (2), compute the Performance ratio

We have

$$P_R(2006) = 1 - 0.005\ °C^{-1}[41.43\ °C - 25\ °C]$$

$$P_R(2006) = 1 - 0.082$$

$$P_R(2006) = 0.918$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2006) = P_R(2006)\ \frac{RSDS\ (2006)}{RSDS_{STC}}$$

$$PV\ pot(2006) = 0.918\ \frac{253.3307}{1000}$$

$$PV\ pot(2006) = 0.2325$$

- **For 2026**

Tas (2026) = 26.66 °C

Rsds (2026) = 253.7508 W.m^{-2}

Vws (2026) = 3.70 m/s

From equation (3), we compute the PV Cell temperature

$$T_{cell}(t) = 4.3\ °C + 0.943 * 26.66\ °C + 0.028\ °Cm^2w^{-1} * 253.7508\ \ W.m^{-2} + 1.528\ °Csm^{-1} * 3.70\ ms^{-1}$$

$$T_{cell}(2026) = 4.3\ °C + 25.14\ °C + 7.1050\ °C + 5.6536\ °C$$

$$T_{cell}(2026) = 42.20\ °C$$

From equation (2), compute the Performance ratio

We have

$$P_R(2026) = 1 - 0.005\ °C^{-1}[42.20\ °C - 25\ °C]$$

$$P_R(2026) = 1 - 0.086$$

$$P_R(2026) = 0.914$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2026) = P_R(2026)\ \frac{RSDS\ (2026)}{RSDS_{STC}}$$

$$PV\ pot(2026) = 0.914\ \frac{253.7508}{1000}$$

$$PV\ pot(2026) = 0.2319$$

- **For 2046**

Tas (2046) = 27.16 °C

Rsds (2046) = 256.0868 W.m^{-2}

Vws (2046) = 3.74 m/s

From equation (3), we compute the PV Cell temperature

$$T_{cell}(t) = 4.3\ °C + 0.943 * 27.16\ °C + 0.028\ °Cm^2w^{-1} * 256.0868\ \ W.m^{-2} + 1.528\ °Csm^{-1} * 3.74\ ms^{-1}$$

$$T_{cell}(2046) = 4.3\ °C + 25.61\ °C + 7.1704\ °C + 5.7147\ °C$$

$$T_{cell}(2046) = 42.80\ °C$$

From equation (2), compute the Performance ratio

We have

$$P_R(2046) = 1 - 0.005\ °C^{-1}[42.80\ °C - 25\ °C]$$

$$P_R(2046) = 1 - 0.089$$

$$P_R(2046) = 0.911$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2046) = P_R(2046)\ \frac{RSDS\ (2046)}{RSDS_{STC}}$$

$$PV\ pot(2046) = 0.911\ \frac{256.0868}{1000}$$

$$PV\ pot(2046) = 0.2332$$

- **For 2066**

Tas (2066) = 28.38 °C

Rsds (2066) = 253.9515 W.m^{-2}

Vws (2066) = 3.77 m/s

From equation (3), we compute the PV Cell temperature

$$T_{cell}(t) = 4.3\,°C + 0.943 * 28.38\,°C + 0.028\,°Cm^2w^{-1} * 253.9515\ \ W.m^{-2} + 1.528\,°Csm^{-1} * 3.77\,ms^{-1}$$

$$T_{cell}(2066) = 4.3\,°C + 26.76\,°C + 7.1106°C + 5.7605\,°C$$

$$T_{cell}(2066) = 43.93\,°C$$

From equation (2), compute the Performance ratio

We have

$$P_R(2066) = 1 - 0.005\,°C^{-1}[43.93°C - 25\,°C]$$

$$P_R(2066) = 1 - 0.095$$

$$P_R(2066) = 0.905$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2066) = P_R(2066)\ \frac{RSDS\ (2066)}{RSDS_{STC}}$$

$$PV\ pot(2066) = 0.905\ \frac{253.9515}{1000}$$

$$PV\ pot(2066) = 0.229$$

- **For 2086**

Tas (2086) = 29.80 °C

Rsds (2086) = 249.8774 W.m^{-2}

Vws (2086) = 3.74 m/s

From equation (3), we compute the PV Cell temperature

$$T_{cell}(t) = 4.3\,°C + 0.943 * 29.80\,°C + 0.028\,°Cm^2w^{-1} * 249.8774 \quad W.m^{-2} + 1.528\,°Csm^{-1} * 3.74\,ms^{-1}$$

$$T_{cell}(2086) = 4.3\,°C + 28.10\,°C + 6.9965°C + 5.7147\,°C$$

$$T_{cell}(2086) = 45.11\,°C$$

From equation (2), compute the Performance ratio

We have

$$P_R(2086) = 1 - 0.005\,°C^{-1}[45.11°C - 25\,°C]$$

$$P_R(2086) = 1 - 0.100$$

$$P_R(2086) = 0.9$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2086) = P_R(2086)\ \frac{RSDS\ (2086)}{RSDS_{STC}}$$

$$PV\ pot(2086) = 0.9\ \frac{249.8774}{1000}$$

$$PV\ pot(2086) = 0.224$$

- **For 2096**

Tas (2096) = 30.5 °C

Rsds (2096) = 248.3098 W.m^{-2}

Vws (2096) = 3.77 m/s

From equation (3), we compute the PV Cell temperature

$$T_{cell}(t) = 4.3\,°C + 0.943 * 30.5\,°C + 0.028\,°Cm^2w^{-1} * 248.3098 \quad W.m^{-2} + 1.528\,°Csm^{-1} * 3.77\,ms^{-1}$$

$$T_{cell}(2096) = 4.3\,°C + 28.76\,°C + 6.9526°C + 5.7605\,°C$$

$$T_{cell}(2096) = 45.77\ °C$$

From equation (2), compute the Performance ratio

We have

$$P_R(2096) = 1 - 0.005\ °C^{-1}[45.77°C - 25\ °C]$$

$$P_R(2096) = 1 - 0.103$$

$$P_R(2096) = 0.89$$

And from equation (1), by replacing all the values, we have

$$PV\ pot(2096) = P_R(2096)\ \frac{RSDS\ (2096)}{RSDS_{STC}}$$

$$PV\ pot(2096) = 0.89\ \frac{248.3098}{1000}$$

$$PV\ pot(2096) = 0.220$$

The simplest way to discuss the result based on what we have done so far is to use histograms. The following histograms are designed to show short-term and long-term meteorological data for all the scenario as well as short-term and long-term climate change effects on PV systems.

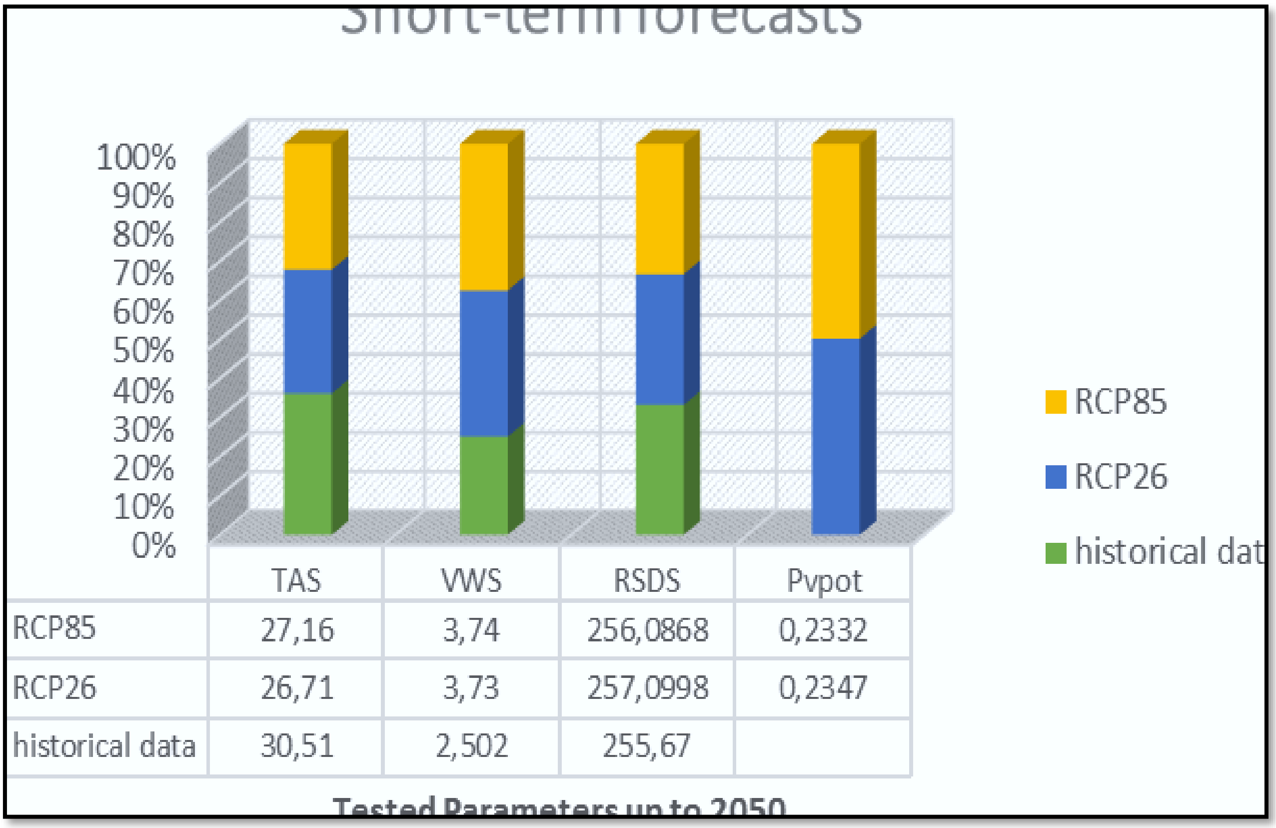


Figure 15a. Short-term prediction of climate data and PV pot

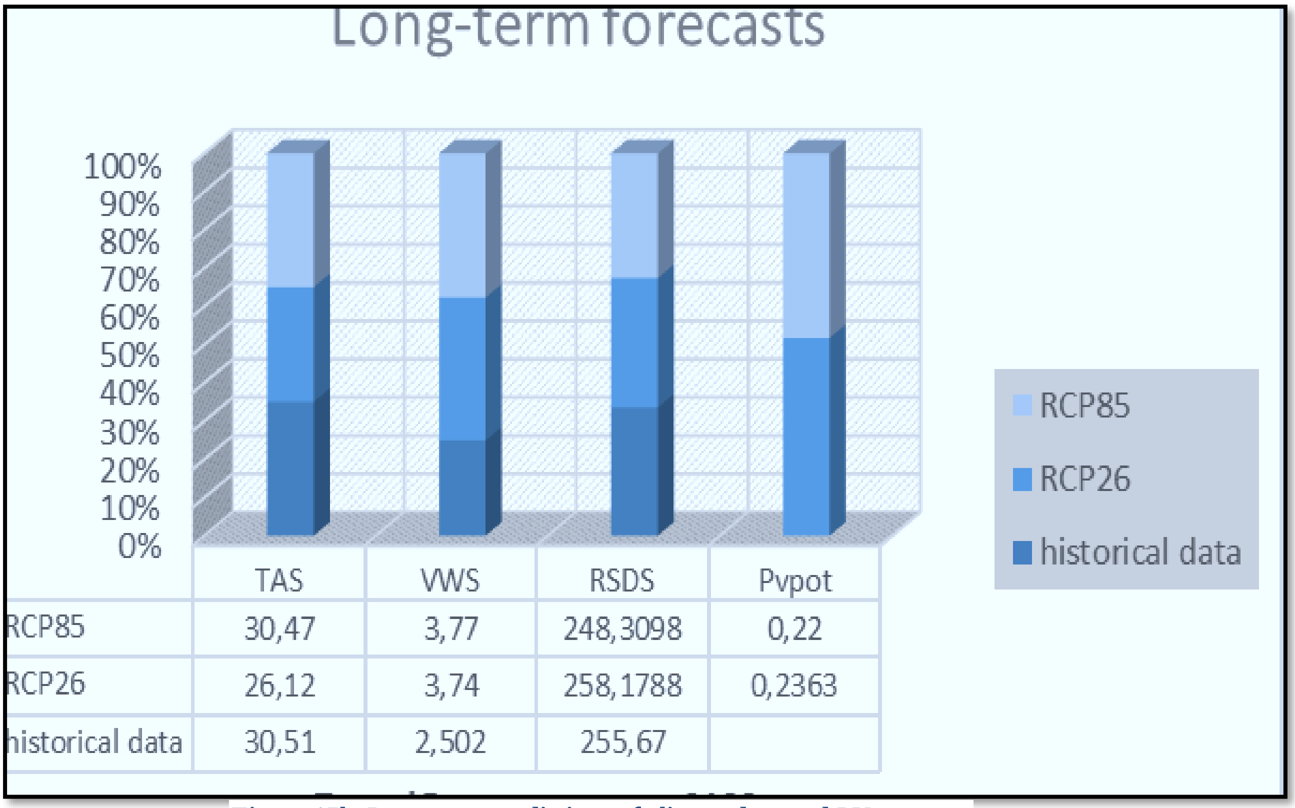


Figure 15b. Long-term predictions of climate data and PVpot

4.4. DISCUSSION

After getting results from various climate modelling and caluculations, we are going to discuss the results gotten so far and try to explain what they implie.

We recall here that the simulations were carried out according to two scenarios and the two scenarios were compared to the historical trends of climate and meteorological data.

From the results, the first observation is that for the first scenario (RCP26) which is an optimistic scenario, the values of solar radiations which are currently estimated around 254.2 $W.m^{-2}$ vary from the range of 253.8 $W.m^{-2}$ in 2006 until reaching the peak of 258.2 $W.m^{-2}$ in 2100. We can clearly see an increase of near 2% showing that the quantity of energy which arrives on the surface of Dosso increases as the years pass.

While the RAC4 model shows an increase in solar radiation values over time, it shows that surface temperature does not vary widely and the RACMO22T shows that the wind speed values do not vary widely as well. They are around 26 ° C for temperature and 3.7 m / s for wind speed.

The simulated values which served as input data for the calculation of the photovoltaic potential, and it emerges that for all the years, following the RCP 26 scenario, the incease of the rsds values lead to a small increase of the PV potential, being the most important parameter to consider in the PV cpot calculation. We can see that the combination of the RAC4 and RACMO22T models from which we produced the inputs of the PV pot equation shows difference in PV pot, the value going from 0.2333 in 2006 to 0.2363 in 2100 or about 1.3%.

This simply means according to Radziemska, E. (2003), the PVpot multiplied by the nominal installed watts of PV power capacity gives instantaneous PV power production. The PV power production in Dosso was less in 2006 than the one projected in 2100 under RCP26.

Therefore, the simulated values under RCP26 do not have a negative impact on the photovoltaic system of the region but it is going to be a positive impact if implemented.

Referring to past work, we can say that the optimistic scenario does not visibly lead to a great climate change that would negatively affect the Dosso photovoltaic system, given that the values of the current years (for all variables in general apart from solar radiations) are close to the simulated values.

Regarding the second scenario under RCP85, the results of the ICHEC-EE-EARTH model downscalled by the RACMO22T model show that solar radiation will significantly reduce over the Dosso region from 253.3307 $W.m^{-2}$ in 2006 to 248.3098 $W.m^{-2}$ in 2100 or 2.2%.
The rsds being a very important variable in the photovoltaic system, it appears that its reduction revealing a climate change will necessarily have a negative impact on the photovoltaic system.

As we have underlined above in this work, the decrease of the solar radiation value is not necessarily due to the fact that the sun is not reaching DOSSO, but it can be due to the presence of aerosols and solid particles in the atmosphere trapping the light. It's obvious, the presence of these aerosols and these solid particles would be justified by the fact that the scenario under RCP 85 foresees the consumption of fossils fuels that cause air pollution and contribute significantly to greenhouse gases (GHGs) emission and to climate change.

The regional model RAC4 with the scenario under RCP85 predict a sharp increase of around 5 ° C in the mean surface temperature between 2006 and 2100, i.e. an increase of 18.2%. This increase in temperature will have a negative impact on the photovoltaic system in rising the demand of energy for cooling devices as predicted by (Alycia Gordan, 2018) in USA.

The decrease in solar radiation as well as the increase in temperature simulated by the combination of the RAC4 and RACMO22T models negatively influence the photovoltaic potential which shows a decrease in the Dosso region of about 4.4 % for the period from 2006 to 2100, in agreement with past works where for instance,using an ensemble of regional climate models (RCMs) from the Coordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi et al. 2009), Sawadogo et al. (2019b) projected a general decrease of photovoltaic power potential (PVP) over West

Africa under RCP8.5, with a maximum decrease reaching 3.8%. Likewise, Bichet et al. (2019) projected an average decrease of PVP of about 4% over most of Africa by the end of the century.

CHAPTER FIVE. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

After the whole research in this work has been conducted, we can conclude that the level of present and future radiative forcing is determinant in the behavior of the climate. The higher the radiative forcing, the more negative impact there will be on the photovoltaic system.

The proof is that shown by the scenarios that we have presented throughout this work. We see that the scenario based on RCP 26 presents less negative impacts than the scenario based on RCP85 which has a large radiative forcing.

This evidence leads us directly to the conclusion that human behavior in the use of energy resources, especially those emitting carbon dioxide and other greenhouse gases, must be done in a very careful manner based on mitigation plans proposed by various structures.

Regarding the BAU scenario which is nothing more than historical data, we can say that the results showed an increase in temperature associated with the increase in solar radiation. This association has played on the photovoltaic potential, which has not really fallen over these years.

Regarding climate projections, the different models we used showed effects directly related to the scenarios presented.

In fact it is shown in this work that the climate will have negative impacts on the photovoltaic system in general in the Dosso region, and on the production of solar energy in particular in the same area.

This is in principle due to certain changes in the parameters playing a big role in the quantification of solar energies.

There is an increase over time in the surface temperature which is a very important element in determining the temperature of photovoltaic cells.

There is also a sharp decrease in solar radiation over time. Being a very determining element in the quantification of solar potential, when solar radiation decreases in the

Dosso region, the solar potential present will also decrease, negatively impacting the production of solar energy.

It is also important to point out that these impacts noted in this work are not limited simply to the production of energy, but extend throughout the solar system, also impacting other sectors directly dependent on the solar system: Seasonal demand profiles will alter responding to user needs for energy for heating and cooling in buildings, for industrial processes and for agriculture (e.g. irrigation). Temperature tolerances of energy sector infrastructure may be tested more regularly, as may those of cultivated biofuels. Infrastructure on permafrost will be affected.

Sea level rise appears inevitable and could be accompanied by increased risk of coastal storm damage even should storms not intensify. Potential issues include risks to offshore infrastructure, including production platforms and wave and tidal generators.

5.2. SOME RECOMMENDATIONS

Based on the conclusions drawn during this study and based on the related results, we make some recommendations.

The recommendation is to implement as soon as possible the mitigation plans proposed by different structures in the country in general and in the Dosso region in particular.

The second recommendation is made for the attention of the RETO DOSSO project: after the results of simulations of climatic values over time, the project is recommended to base the estimates on the most pessimistic scenario. In the event that the implementation of the mitigation plans proposed by PANER is delayed, the project will not suffice for any damage because in reality the solar system will be sized according to the most extreme conditions even if this may have a negative economic impact on its budgeting.

But in case the country manages to implement the mitigation action plans, then the project can fully build on the optimistic scenario for the solar system.

In connection with the sizing and specifications of the solar system to be set up in the Dosso region, it is desirable that the materials be purchased have specifications whose ranges of values for each parameter correspond to the values estimated in this work according to each scenario.

The third recommendation is made to the Cordex project which does not have many regional models on Africa while such studies are supposed to be done in detail for all regions in order to make the right decisions.

APPENDIX

1. **Some Rstudio Scripts used**

```
library(ncdf4)

library(spam)

library(maps)

library(fields)

setwd("C:/Users/lenovo/Documents/Data/tas")

fn <- "tas1.nc"

ncfile <- nc_open(fn)

lat <- ncvar_get(ncfile, "rlat")

lon <- ncvar_get(ncfile, "rlon")

tm <- ncvar_get(ncfile, "time")

tim <- as.Date(tm, origin= "1949-12-01", tz= "UTC")

temparray <- ncvar_get(ncfile, "tas")


tempsurf <- ncvar_get(ncfile, "tas", start= c(1, 1, 74), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf)

map(add=T)


tempsurf <- ncvar_get(ncfile, "tas", start= c(1, 1, 166), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf)

map(add=T)


tempsurf <- ncvar_get(ncfile, "tas", start= c(1, 1, 258), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf)

map(add=T)
```

```
tempsurf <- ncvar_get(ncfile, "tas", start= c(1, 1, 349), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf)
map(add=T)

### The first step was only for 2006-2010.
### We are going tp perform the same thing the other 20 next years.


setwd("C:/Users/lenovo/Documents/Data/tas")
fn <- "tas2.nc"
ncfile2 <- nc_open(fn)
lat2 <- ncvar_get(ncfile2, "rlat")
lon2 <- ncvar_get(ncfile2, "rlon")
tm2 <- ncvar_get(ncfile2, "time")
tim2 <- as.Date(tm2, origin= "1949-12-01", tz= "UTC")
temparray2 <- ncvar_get(ncfile2, "tas")

## we can start mapping the data for each year

tempsurf2 <- ncvar_get(ncfile2, "tas", start= c(1, 1, 79), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf2)
map(add=T)

tempsurf2 <- ncvar_get(ncfile2, "tas", start= c(1, 1, 171), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf2)
map(add=T)
```

```
tempsurf2 <- ncvar_get(ncfile2, "tas", start= c(1, 1, 263), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf2)

map(add=T)


tempsurf2 <- ncvar_get(ncfile2, "tas", start= c(1, 1, 354), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf2)

map(add=T)


### We perform the same thing for the period from 2046 to 2050.

###But we are only getting data for 2046.



setwd("C:/Users/lenovo/Documents/Data/tas")

fn <- "tas3.nc"

ncfile3 <- nc_open(fn)

lat3 <- ncvar_get(ncfile3, "rlat")

lon3 <- ncvar_get(ncfile3, "rlon")

tm3 <- ncvar_get(ncfile3, "time")

tim3 <- as.Date(tm3, origin= "1949-12-01", tz= "UTC")

temparray3 <- ncvar_get(ncfile3, "tas")


## we can start mapping the data for each year


tempsurf3 <- ncvar_get(ncfile3, "tas", start= c(1, 1, 84), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf3)

map(add=T)
```

```
tempsurf3 <- ncvar_get(ncfile3, "tas", start= c(1, 1, 176), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf3)
map(add=T)

tempsurf3 <- ncvar_get(ncfile3, "tas", start= c(1, 1, 268), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf3)
map(add=T)

tempsurf3 <- ncvar_get(ncfile3, "tas", start= c(1, 1, 359), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf3)
map(add=T)

## we perform the same thing for 2066-2070

fn <- "tas4.nc"
ncfile4 <- nc_open(fn)
lat4 <- ncvar_get(ncfile4, "rlat")
lon4 <- ncvar_get(ncfile4, "rlon")
tm4 <- ncvar_get(ncfile4, "time")
tim4 <- as.Date(tm4, origin= "1949-12-01", tz= "UTC")
temparray4 <- ncvar_get(ncfile4, "tas")

## we can start mapping the data. this time we only use March of each first year

tempsurf4 <- ncvar_get(ncfile4, "tas", start= c(1, 1, 89), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf4)
```

map(add=T)

we do the same for 2086

fn <- "tas5.nc"

ncfile5 <- nc_open(fn)

lat5 <- ncvar_get(ncfile5, "rlat")

lon5 <- ncvar_get(ncfile5, "rlon")

tm5 <- ncvar_get(ncfile5, "time")

tim5 <- as.Date(tm5, origin= "1949-12-01", tz= "UTC")

temparray5 <- ncvar_get(ncfile5, "tas")

we can start mapping the data. this time we only use March of each first year

tempsurf5 <- ncvar_get(ncfile5, "tas", start= c(1, 1, 94), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf5)

map(add=T)

same thing for 2096

fn <- "tas6.nc"

ncfile6 <- nc_open(fn)

lat6 <- ncvar_get(ncfile6, "rlat")

lon6 <- ncvar_get(ncfile6, "rlon")

tm6 <- ncvar_get(ncfile6, "time")

tim6 <- as.Date(tm6, origin= "1949-12-01", tz= "UTC")

temparray6 <- ncvar_get(ncfile6, "tas")

```
## we can start mapping the data. this time we only use March of each first year

tempsurf6 <- ncvar_get(ncfile6, "tas", start= c(1, 1, 97), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf6)
map(add=T)

### AFTER HAVING DONE THIS FOR THE RCP26
### WE ARE GOING TO EXTRACT TAS DATA FOR RCP85 FOLLOWING THE SAME IDEA
### WE AREGOING TO SET ANOTHER DIRECTORY AND WE RUN THE SCRIPT

setwd("C:/Users/lenovo/Documents/Data/tas85")
fn <- "tasa.nc"
ncfile <- nc_open(fn)
lat <- ncvar_get(ncfile, "rlat")
lon <- ncvar_get(ncfile, "rlon")
tm <- ncvar_get(ncfile, "time")
tim <- as.Date(tm, origin= "1949-12-01", tz= "UTC")
temparray <- ncvar_get(ncfile, "tas")

tempsurf <- ncvar_get(ncfile, "tas", start= c(1, 1, 74), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf)
map(add=T)
```

```
### for 2026

fn <- "tasb.nc"
ncfile2 <- nc_open(fn)
lat2 <- ncvar_get(ncfile2, "rlat")
lon2 <- ncvar_get(ncfile2, "rlon")
tm2 <- ncvar_get(ncfile2, "time")
tim2 <- as.Date(tm2, origin= "1949-12-01", tz= "UTC")
temparray2 <- ncvar_get(ncfile2, "tas")

tempsurf2 <- ncvar_get(ncfile2, "tas", start= c(1, 1, 79), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf2)
map(add=T)

### for 2046

fn <- "tasc.nc"
ncfile3 <- nc_open(fn)
lat3 <- ncvar_get(ncfile3, "rlat")
lon3 <- ncvar_get(ncfile3, "rlon")
tm3 <- ncvar_get(ncfile3, "time")
tim3 <- as.Date(tm3, origin= "1949-12-01", tz= "UTC")
temparray3 <- ncvar_get(ncfile3, "tas")

tempsurf3 <- ncvar_get(ncfile3, "tas", start= c(1, 1, 84), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf3)
```

```
map(add=T)

### we do for 2066



fn <- "tasd.nc"
ncfile4 <- nc_open(fn)
lat4 <- ncvar_get(ncfile4, "rlat")
lon4 <- ncvar_get(ncfile4, "rlon")
tm4 <- ncvar_get(ncfile4, "time")
tim4 <- as.Date(tm4, origin= "1949-12-01", tz= "UTC")
temparray4 <- ncvar_get(ncfile4, "tas")

tempsurf4 <- ncvar_get(ncfile4, "tas", start= c(1, 1, 89), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf4)
map(add=T)
### for 2086
fn <- "tase.nc"
ncfile5 <- nc_open(fn)
lat5 <- ncvar_get(ncfile5, "rlat")
lon5 <- ncvar_get(ncfile5, "rlon")
tm5 <- ncvar_get(ncfile5, "time")
tim5 <- as.Date(tm5, origin= "1949-12-01", tz= "UTC")
temparray5 <- ncvar_get(ncfile5, "tas")

tempsurf5 <- ncvar_get(ncfile5, "tas", start= c(1, 1, 94), count= c(194, 201, 1))
image.plot(lon, lat, tempsurf5)
```

```
map(add=T)


### for 2096


fn <- "tasf.nc"

ncfile6 <- nc_open(fn)

lat6 <- ncvar_get(ncfile6, "rlat")

lon6 <- ncvar_get(ncfile6, "rlon")

tm6 <- ncvar_get(ncfile6, "time")

tim6 <- as.Date(tm6, origin= "1949-12-01", tz= "UTC")

temparray6 <- ncvar_get(ncfile6, "tas")


tempsurf6 <- ncvar_get(ncfile6, "tas", start= c(1, 1, 97), count= c(194, 201, 1))

image.plot(lon, lat, tempsurf6)

map(add=T)
```

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Other Links

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