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Topic:

IMPACT OF CLIMATE CHANGE ON ELECTRICITY CONSUMPTION IN WEST AFRICA.

(A CASE STUDY OF CÔTE D'IVOIRE)

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ABSTRACT

Nowadays, the economy sector is affected by the weather vagaries. Electricity is one of the most sensitive sectors, due to the fact that electricity consumption is connected to the numerous climatic variables, especially the atmospheric temperature. This study focus on the impact of temperature change on electricity consumption in the different climate zones of Côte d'Ivoire. It analyzes the trend of electricity consumption and extreme temperatures (maximum, minimum and mean) on the period from 1973 up to 2016; it determines the link between electricity consumption and extreme temperatures by using the linear regression. And finally, it determines the future electricity demand using the Model for Analysis of Energy Demand (MAED).

The result reveals a clear evidence change in each parameter of temperature for each climate zone during the period of record. It shows an increase in the trend of the annual evolution of maximum, minimum and mean temperature. Besides, the trend of annual electricity consumption shows also an increase from 1990 to 2015.The monthly behavior of electricity consumption and temperature, shows that the electricity consumption is more important during the hot months, and low during the cool months. In addition, this work shows a positive significant correlation between the annual increase of the maximum temperature and the annual electricity consumption in the three climate zone. Projection of future electricity consumption from 2013 to 2045 with MAED model shows an increase of consumption in each scenario, which goes up to 8% of the growth rate during the period from 2013-2045.

Keys Words: Climate change, temperature, electricity consumption, correlation, MAED model.

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ACRONYMS

ANARE	Autorité Nationale de Régulation du Secteur de l'Electricité
CEB	Communauté Electrique du Benin
CIE	Compagnie Ivoirienne d'Electricité
CI-ENERGIES	Société des Energies de Côte d'Ivoire
CIPREL	Côte d'Ivoire Electricity Generation Company
DRABO	Direction Regional of Abobo
DRAN	Direction Regional of Abidjan Nord
DRAS	Direction Regional of Abidjan Sud
DRBC.	Direction Regional of Base Cote,
DRC	Direction Regional of Centre
DRCO	Direction Regional of Centre Ouest
DRCS	Direction Regional of Centre Sud
DRE	Direction Regional of Est
DRN	Direction Regional of Nord
DRO	Direction Regional of Ouest
DRSE	Direction Regional of Sud Est
DRSO	Direction Regional of Sud Ouest
DRYO	Direction Regional of Yopougon
ECOWAS	Economic Community Of West African States
EDF	Électricité De France
EDM	Énergie du Mali
EECI	Energie Electrique de Côte d'Ivoire
GDP	Gross Domestic Product
GWh	GigaWatt hour
HS	High economic Scenario
IAEA	International Atomic Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPs	Independent Power Producers
LEC	Liberia Electricity Corporation
LS	Low economy Scenario
MAED	Model for Analysis of Energy Demand
NCDC	National Climatic Data Center

NOAA	National Oceanic and Atmospheric Administration
OS	Optimistic Scenario
RS	Reference Scenario
SODEXAM	Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique
SONABEL	Société Nationale Burkinabè d'Electricité
Tmax	Maximum temperature
Tmean	Mean temperature
Tmin	Minimum temperature
VRA	Volta River Authority
WAGS	West African Grid System

GENERAL INTRODUCTION

Problem statement

Climate change is an extremely complex phenomenon and a global issue as well as a major challenge for scientists. It defines as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer, according to the fourth assessment report of IPCC (intergovernmental panel on climate change). The main driven of this phenomenon is the exponential increase over recent decades of greenhouse gas concentrations emitted into the atmosphere of which human activity, with the growing use of fossil fuels (coal, gas and oil).In fact, the most emissions of greenhouse gases are due to the consumption of fossil fuels for energy production. According to the (IPCC, 2007 a) around 70 % and 26% of global emissions of greenhouse gases in 2004 is due to the energy use, power generation and heat supply respectively.

Moreover, the main characteristics of climate change are increases in average global temperature (global warming); precipitation particularly over land, change in distribution of rainfall, melting of glaciers and an increase in the frequency and severity of extreme events such as drought, flood and so one.

In this context of climate change, Sub-Saharan Africa is unfortunately the most vulnerable to the effects of climate change (Boko et al., 2007), despite its less contribution to the greenhouse gases emissions in the atmosphere. This situation is due to its high dependence on agriculture and natural resources, warmer baseline climates, low precipitation, and limited ability to adapt (Hassan et al., 2008).

Côte d'Ivoire, located in West Africa is no exception to this situation because its economy is based on rain-fed agriculture and it has a strong dependence on river flow for the power generation and fisheries. In this country, the impacts of climate change have led to recurrent droughts, increase in temperature, change in rain amount distribution, coastal erosion, and flooding (Goula et al.,2006, 2009). This situation of climate change can modified not only the behavior of the populations but also the social and economic development of a country by affecting agriculture sector, river flow and energy system including the electricity system at generation, transmission, interconnection line, exportation and consumption levels.

Electricity plays a critical role in economic growth, technological development and planning of a country. It is essential to nearly all of the critical functions and infrastructures, from emergency services and banking, commerce, healthcare, water supply and so on.

However, Electricity reliability is increasingly put at risk by climate change and extreme weather events. Indeed climate change can pose many challenges in electricity sector through the demand, and supply. In fact, Colombo et al., 1999 and Hekkenberg et al., 2009, show that climate is one of the key factors influencing the energy consumption. Amongst various climatic factors, which may affect the energy consumption, temperature is the most dominant one (Yan, 1998;Cline, 1992) .

Changes in temperature are likely to alter the level, timing, and geographic distribution of electricity demand. In particular, higher temperatures are expected to raise electricity demand for cooling in summer, decrease demand for heating in winter (Mideksa et al., 2010; Pardo et al., 2002).It is also known that electricity load demand increase on hot days leading to an increase in power generation and transmission loss. But, there is very little information on how much linear or nonlinear is the relationship between electricity consumption and temperature.

Beside, Changes in both temperature and precipitation are likely to affect the magnitude, efficiency, and reliability of electricity supply. In fact, increase in ambient air and water temperatures will likely reduce cooling efficiency and available generation capacity of thermal power plants. And, Change in precipitation patterns, and occurrence of drought may also impact hydropower generation by affecting inflow of water (Hamlet et al., 2010; Madani and Lund, 2010).

The impact of climate change on electricity supply has more affected the West Africa countries, especially Côte d'Ivoire, in which hydropower and thermal plant are the main dominant source for supply of electricity for industrial, commercial and domestic use and to some neighboring countries. Indeed, from 1983 to 1984 and 2009 to 2010, Côte d'Ivoire recorded series of droughts which led to drastic and gross reduction in the water level and flow rate of the nation's dam. It's shutting down all hydropower plants, unable to turn and operate turbines. It has caused blackout in the capital Abidjan and productivity losses amounting to 35 percent in the industrial sector in 1984. In 2010, the reduction of power production oblige Côte d'Ivoire, to reduce its amount of electricity exported to 2.6% in 2010 compare to 2009 (Annual rapport CIE, 2014).

The study of Dell et al., 2014, has showed that the extreme climate change event like heat waves, change in temperature could indirectly affect the electricity exchange (export/ import) through the disruption of infrastructure, and electricity supply and interconnection line.

Despite the vulnerability of electricity system to climate change impacts in Côte d'Ivoire, the study on the impact of climate change on electricity system is limited. Moreover, it has been noted that climate change is happening and is going with increase in temperature, generating more warm days and hot temperatures in the future. Thus, this study aims to investigate how climate change will affect the climate zone and their impact on electricity consumptionin Côte d'Ivoire, in order to reduce the risk of shortage in power generation and hence the possible power system collapse.

Research objectives

The principal objective of the study is to evaluate the influence of extreme temperature on electricity consumption in Côte d'Ivoire.

The specific objectives are:

- ✓ To analyze the trend of maximum, minimum and mean temperature in each climate zone.
- ✓ To analyze the evolution of electricity consumption in each climate zone.
- ✓ To determine the link between extreme temperature and electricity consumption in each climate zone.
- ✓ To forecast the future electricity consumption from 2013 to 2045.

Research questions

The central question of this research is to identify how temperature will affect electricity consumption in Côte d'Ivoire.

This question will be answered by further examining the following secondary questions.

- ✓ What is the monthly and annual evolution of the extreme temperature for each climate zone?
- ✓ What is the monthly and annual evolution of the electricity consumption for each climate zone?

- ✓ What is the relationship between the extreme temperature and electricity consumption for each climate zone?
- ✓ How will be the future electricity consumption without climate change effect?

General hypothesis

Main Hypothesis is: atmospheric parameters affect the electricity consumption in Côte d'Ivoire.

Secondary hypotheses are:

High temperature will increase the electrical consumption.

Mean and maximum temperature will influence more electricity consumption.

Organization of the thesis

For a good understanding of this study, its outline is articulated around six mains chapters:

Chapter one will present the study area: we will present the demography, economy and climate. After we will look at in the chapter two, the overview of current electricity situation evolution. The chapter three will be left for the evolution of extreme temperature. In the chapter four, we will look at the evolution of electricity generation and electricity demand: how does the electricity generation and demand evolve? In the chapter five, we will determine the relationship between electricity consumption and extreme temperature. Afterward, we will forecast the future electricity demand using the MAED model in the chapter six: what will be the electricity demand in the near future 2013- 2045?

This present study will close with a general conclusion and perspectives.

CHAPTER I: PRESENTATION OF THE STUDY AREA

I-1 Location and overview

Côte d'Ivoire is a country of West Africa located along the Gulf of Guinea between 2°30 and 8°30 west longitudes and between 4°30 and 10°30 north latitudes (figure I-1). The country is approximately square in shape and its southern border is 515 km coastline on the Gulf of Guinea on the North Atlantic Ocean. It borders five others African nations for a total of 3,458 km : Liberia to the southwest for 778 km, Guinea to the northwest for 816 km, Mali to the north-northwest for 599 km, Burkina Faso to the north-northeast for 545 km , and Ghana to the east for 720 km. Côte d'Ivoire covers 318,003 square kilometers of land and 4,460 square kilometers of water, making it the sixty ninth (69th) largest nation in the world with a total area of 322,463 square kilometers. The political capital is Yamoussoukro and the administrative and economic capital is Abidjan. Four large rivers (Bandama, Comoé, Sassandra and Cavally), on which hydroelectric dams have been built, supply the entire country with electricity.

For administrative purposes, the country is divided into 12 regional districts since 2012, including two autonomous districts (Abidjan and Yamoussoukro).

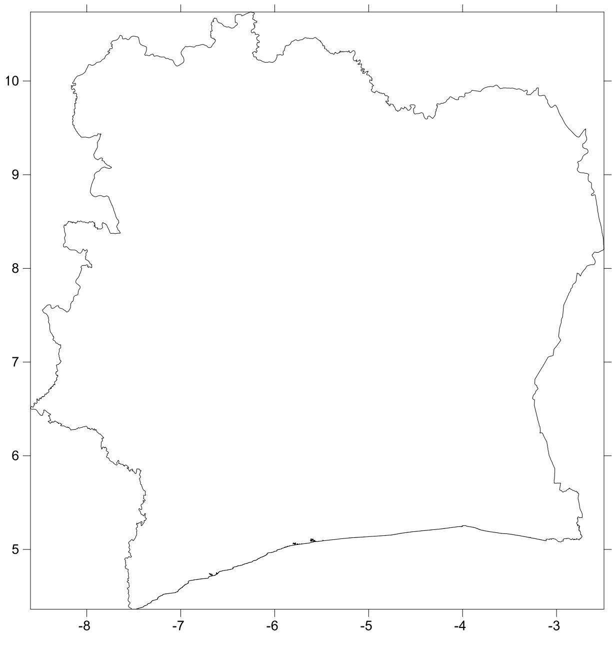

Figure I-1: Geographical location of Cote d'Ivoire.

I-2 Climate

Côte d'Ivoire is located in the transition zone between the humid equatorial climate and the dry tropical climate. The climate of Côte d'Ivoire is controlled by the movement of the Inter Tropical Convergent Zone (ITCZ) (Saley, 2003). It is defined as the convergence zone of two air masses: the moist equatorial air masses originating over the Atlantic Ocean called monsoon and the Hot, dry continental air masses originating from the high pressure system above the Sahara Desert commonly called harmattan. According to the latitude, three main climate zones can be distinguished, as we can see in figure I-1 (Kouadio et al., 2011 and Kouadio et al., 2007).

- In the north, there is a dry sub-tropical climate, it is drier and characterized by two seasons, one wet (rainy) season from April/May to October, with a peak in August, and one dry season from November to Mars which is accentuate by the Harmattan (Ardoin, 2004). The months of August and September are the heavy rain months.
- In the central part of Côte d'Ivoire, the climate is equatorial climate. One have four seasons: one long wet season from March to June, one long dry season start from November to February, one short dry season from July to August, which is hot and wet and one short wet season from September to October.
- The southern part or littoral zone (humid equatorial climate) is humid and has four seasons: a long dry season from December to March drived by the Harmattan, a long wet season from April to July with a peak in June, a short dry season from August to September during this period there are not rain but the sky is covered by cloud, and a short wet season from October to November.

The northern region is drier than the rest of the country, because of the elevation somewhat it is cool. In the equatorial climate, the annual rainfall is greater than 1500 mm. The amount of rainfall is higher in the humid equatorial climate, with a yearly mean of 1800 mm.

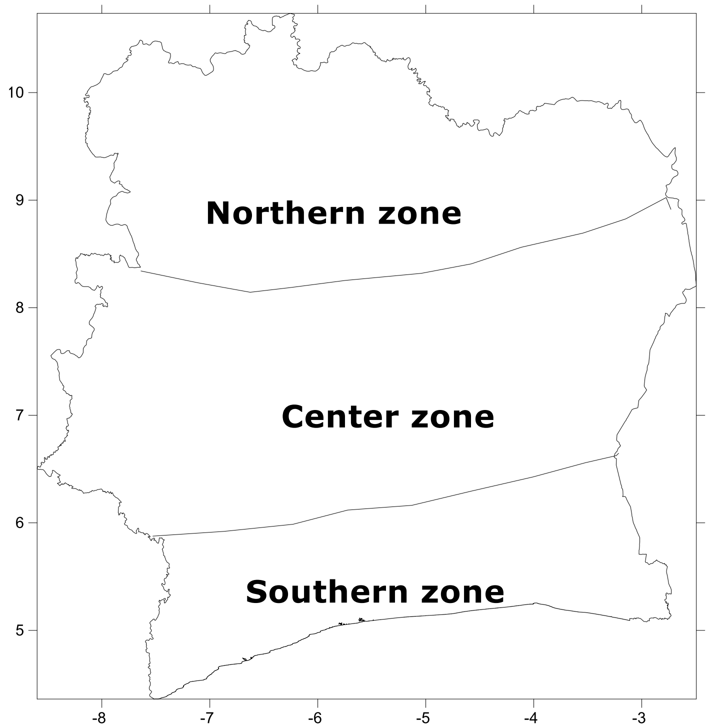

Figure I-2: Côte d'Ivoire's climatic zones (up to down, sub-tropical, equatorial and Humid Equatorial).

I-3 Vegetation

The northern part is covered with savannas, characterized by large areas of grassland and sparse trees. Only areas near streams have dense forests and rich vegetation. In the center, vast coffee and cocoa plantations have largely taken the place of the forest. The forest extends over the entire southern part of the country. Its surface has declined sharply in recent decades, partly due to excessive exploitation. Primary forest has virtually disappeared, outside some protected areas, such as the Tai National Park in the southwest and Banco in the Abidjan area. According to the work of Parrenet De Graaf, 1995, the area of forest reduce was estimated to 11.9 million of hectare from 1900 to 1991. In 2000, the forest was estimate to 4 million of hectare (Brou, 2005) and today, it is estimated at about 2.5 million of hectare. This situation is attributable to extensive agriculture based on the technique of shifting cultivation, the overexploitation of the forest with timber and wood energy and bush fires.

I-4 Demography and economy

I-4.1 Demography

According to the General Census of Population and Housing in 1998 the population of Côte d'Ivoire was estimated at 15,336,672 inhabitants (RGPH, 1998). The 1st May 2014, it rose to 22.671031 inhabitants (RGPH, 2014), and estimated at nearly 23.67 million in 2016 (figureI-4). This strong demographic expansion is driven by a relatively high fertility rate (5.4 children per woman in 2014) and also by a large foreign population that accounts for more than 24.2% of the total population. The population living in urban areas was 50.3% and the remaining live in rural areas. The average annual growth rate of the population was 2.6% from 1998 to 2014.The population of Côte d'Ivoire is unequally distributed in the climate zone, as we can see in the figure I-5, the density of the population in the southern and center zone is high than the northern zone during the period of 1998 and 2000 (Schwartz, 1993; Ruf, 1994). The zone the most populated is the southern zone. Currently, one observe the same repartition of the population in these zones.

The evolution of population has ploted by using the population data from Word Bank data from 1960 to 2016.

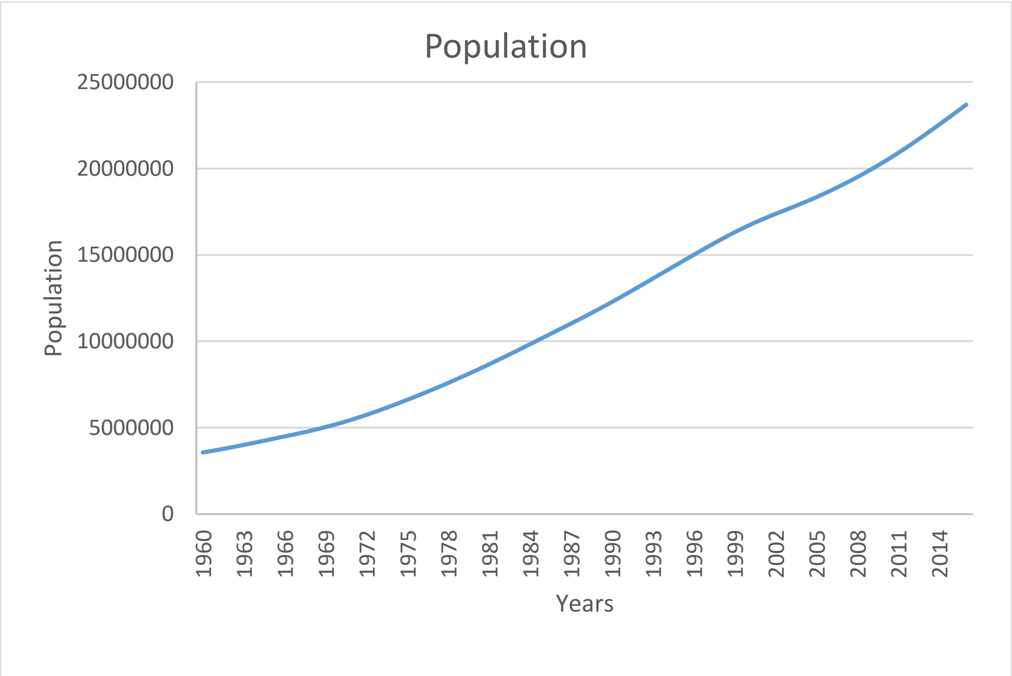

Figure I-3: Evolution of Côte d'Ivoire's population from 1960 to 2016 (data source from Word bank data).

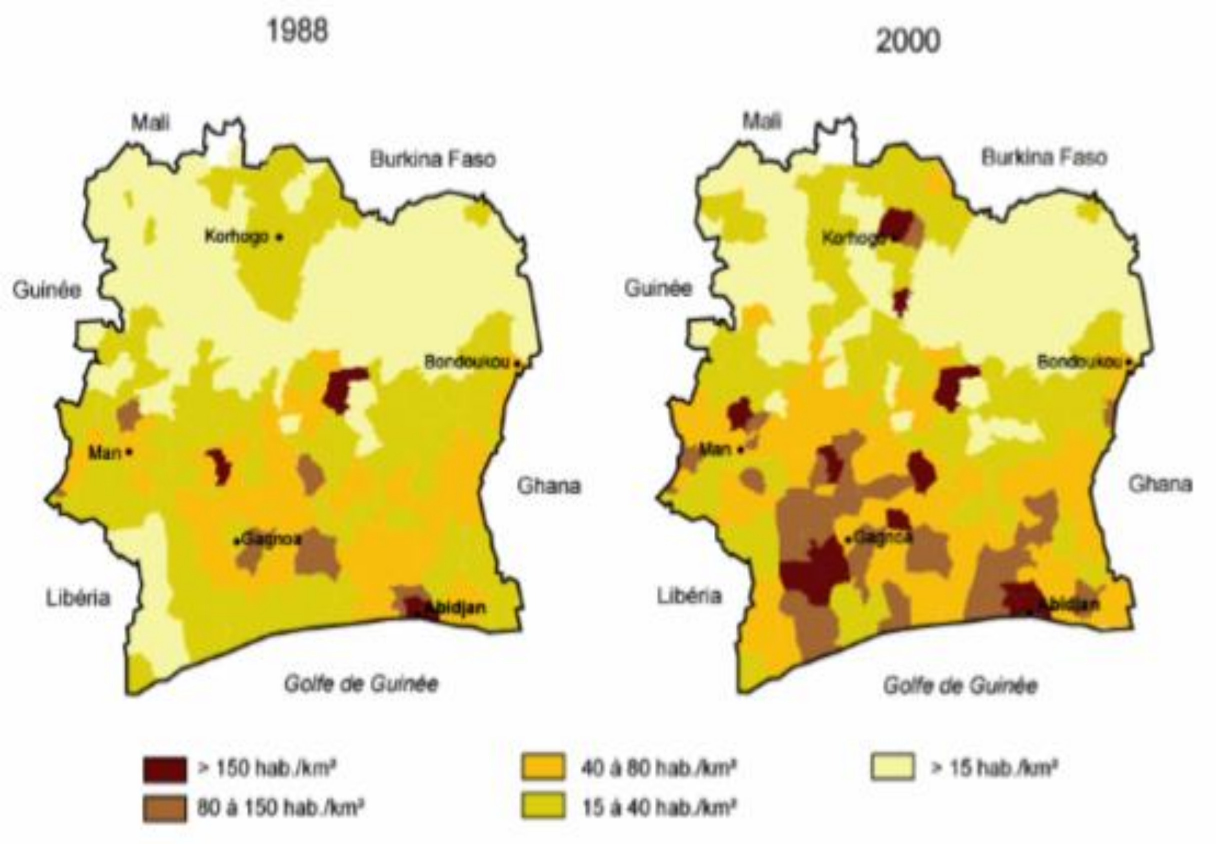

Figure I-4: Density of the population in 1988 and 2000 (source: Oszwald, 2005).

I-4.2 Economic

The economy of Cote d'Ivoire is stable and currently growing since 2012. Its gross domestic product (GDP) growth reach 10.7% in 2012, 8.89% in 2013, 8.80% in 2014, 8.84% in 2015 and 8.33% in 2016 (Figure I-7). So, Côte d'Ivoire's gross domestic product (GDP) has been growing at a rate of 9 % annually from 2012 to 2016 (COTE D'IVOIRE: Rapport économique, 2017). Côte d'Ivoire is the second largest economy in West Africa after Nigeria, and the largest economy in the West African Economic and Monetary Union (WAEMU).Approximately 85 percent of all economic activity is concentrated in the southern part of the country. The Côte d'Ivoire's economic depend on the agriculture. Moreover, the national economy is considered to be fairly well diversified. The primary sector, which makes direct use of natural resources through agriculture, forestry, and fishing or hunting, comprises roughly 30 percent of the country's GDP. The secondary sector, covering industrial and manufacturing activities that produce finished goods, comprises 21 percent of GDP. The tertiary, or service, sector represents 49 percent of the economy.

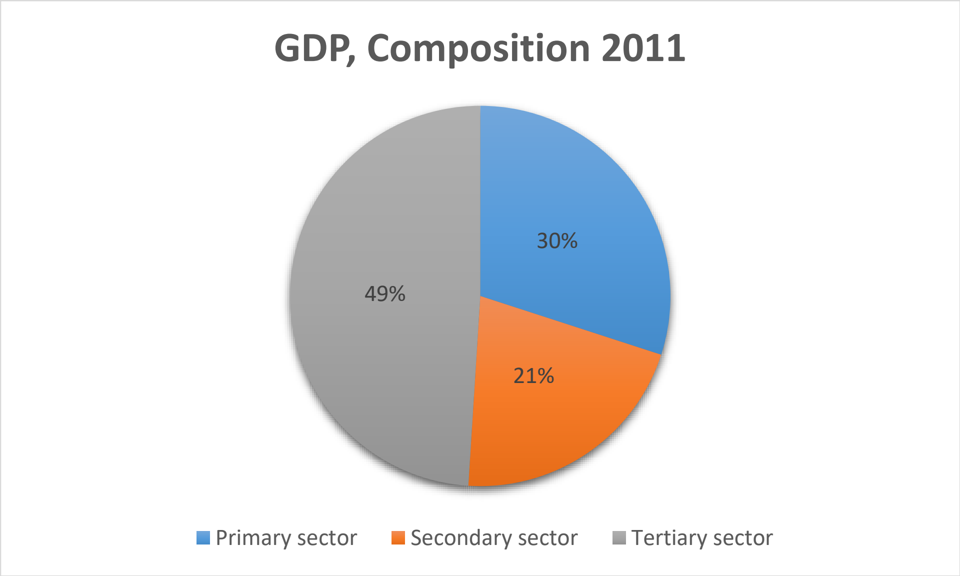

Figure I-5: Distribution of Gross domestic product (GDP) per sector (Source: UNEP, 2015).

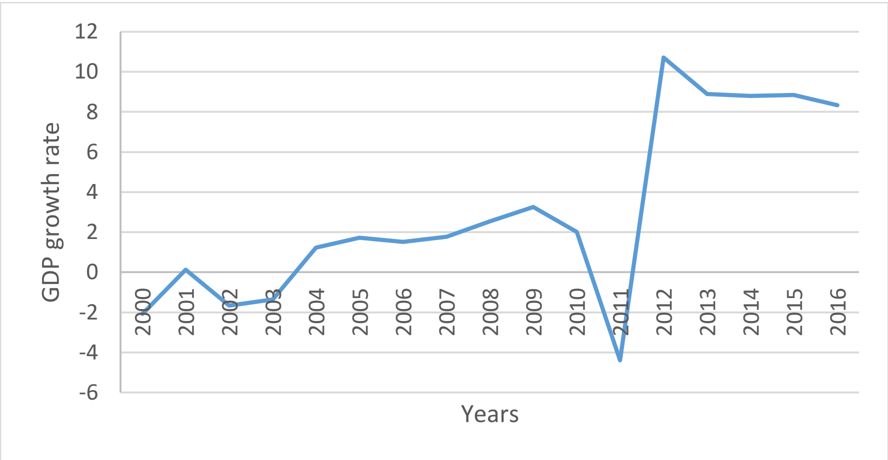

Figure I-6: Evolution of the growth rate of the real Gross Domestic Product (GDP) from 2000 to 2016 (Source: Data from World Bank).

CHAPITRE II: PRESENTATION OF CÔTE D'IVOIRE'S ELECTRICITY SECTOR

II-1 Legal and institutional framework of the electricity sector

From 1985 to 2014, electricity sector is governed by the law n° 85-585 of 29 July 1985. Under this law, the production of power was open to the private sector, but the transmission, distribution, import and export activities of electricity remained a State monopoly. However, in accordance with articles 5 and 6 of the Electricity Law of 1985, the State of Côte d'Ivoire granted to a private operator namely "Companie Ivoirienne d'Electricité" (CIE), a concession over the production, transmission, distribution, import and export of electricity. The CIE replaced the former national company "Energie Electrique de Côte d'Ivoire" (EECI) who retained its role in the management of assets and projects, the development of technical studies as well as the technical control of the concession holder (ANARE, 2012).

In 2014, electricity sector activities in Côte d'Ivoire undergo major changes. They are governed by the 2013 National Energy Policy and a new Electricity Code adopted by the National Assembly in March 2014. The revised National Energy Policy adopted in 2013 sets an objective for the country to become an energy hub in West Africa. The policy has three main axes: (i) restore financial viability of the energy sector, including through tariff adjustments and loss reduction; (ii) generation of sufficient electricity and demand side management; and (iii) improvement of the sector institutional framework. . Following this, the 2014 Electricity Code adopted the liberalization of power sector by ending the State monopoly on transport, distribution, commercialization, importation and exportation of electricity, keeping only the dispatching activity under state monopoly and providing third party access to the transmission grid (ANARE, 2012).

II-2 Actor of electricity sector

The different actor of the electricity sector in Côte d'Ivoire is seen in the figure II-1. The electricity sector is institutionally placed under the dual supervision of the ministry of petroleum and energy and the ministry in charge of the economy and finance, representing the

State of Côte d'Ivoire sets policy and plays an overarching surveillance role of the electricity sector. In addition, the ministries in charge of electricity, there are the following actors:

- ✓ The national electricity company "Société des Energies de Côte d'Ivoire" ("CI-ENERGIES") having as main activities the management of the electricity supply as well as the management of projects on behalf of the State as grantor of the concession agreements. The electricity code of 2014 gives greater independence and authority to the body by specifically providing that it is an independent legal entity with financial autonomy (ANARE, 2015).
- ✓ The Autorité Nationale de Régulation du Secteur de l'Electricité (ANARE) is the National authority for the regulation of the electricity sector. The agency was established in 1998. It is in charge of overseeing the compliance by the operators with the legislation, arbitrating disputes between operators or between operators and the State as well as ensuring the protection of the interests of the consumers of electricity.
- ✓ The Independent power producers (IPPs) are Côte d'Ivoire Electricity Generation Company (CIPREL), Azito-Énergie and Aggreko, dominate thermal power production, based on local natural gas production from majority private players (Petroci CI 11, AFREN, Foxtrot, and Canadian Natural Resources).
- ✓ Producers of natural gas: Petroci CI 11, AFREN, Foxtrot and Canadian Natural Resources (CNR).
- ✓ The national company "Compagnie Ivoirienne d'Électricité" (CIE) is a vertically integrated monopoly, handling most generation, management and distribution of electricity in the country. Created in 24 August 1990 by the French group Bouygues and the electricity company, Électricité De France (EDF).CIE is a mainly private Ivorian company. It holds a public service concession for the production, transportation, distribution, importation and exportation of electricity power for service to customers and marketing of electricity, under a 15-year renewable, "affermage" (concession) contract. The IPPs in the generation sector sign Power Purchasing Agreements with CIE in its role as the sole transmission and distribution operator. (ANARE, 2015)
- ✓ Customers (customers at national rate and export customers).

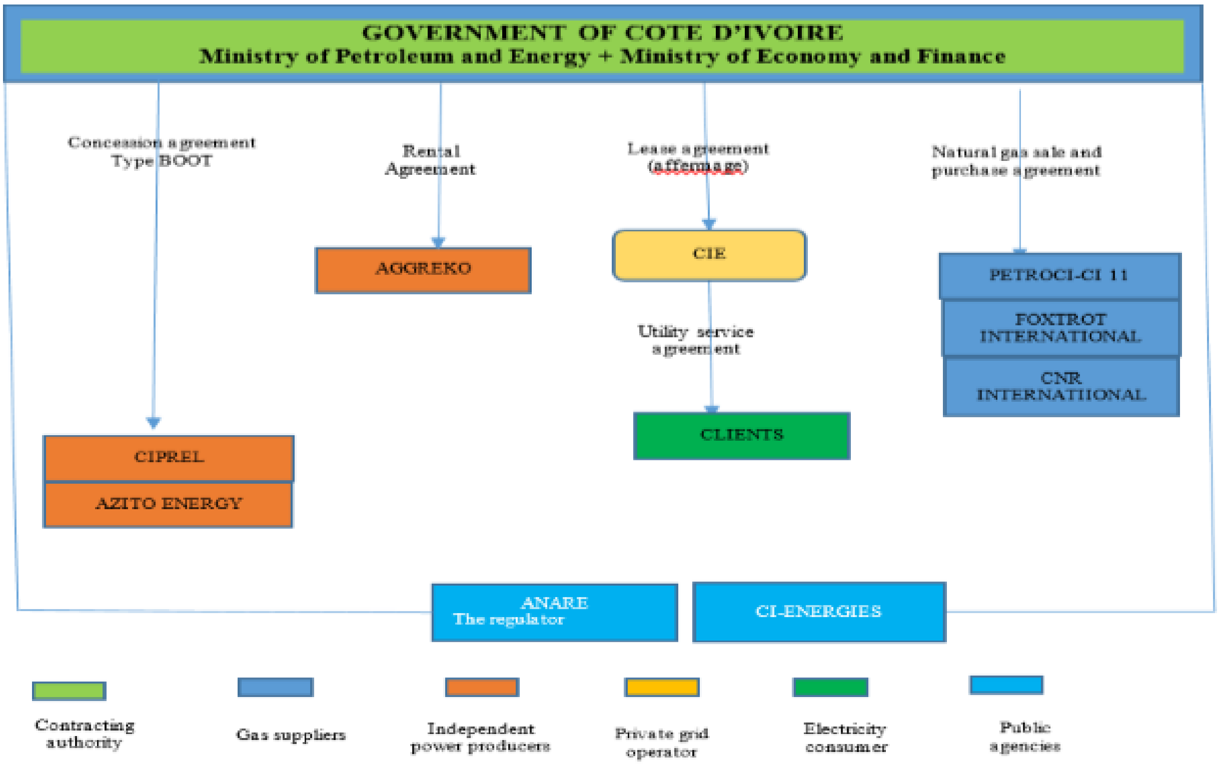

Figure II-1: Power Sector Institutional Arrangement in Côte d'Ivoire (Source: World Bank, 2017).

II-3 Presentation of Côte d'Ivoire's interconnection network

Within the framework of Economic Community Of West African States (ECOWAS) co-operation in the energy sector, Côte d'Ivoire has actively been involved in the establishment of the West African Grid System (WAGS) by spearheading interconnections with five clients: Énergie du Mali (EDM) in Mali, Volta River Authority (VRA) in Ghana, Communauté Electrique du Bénin (CEB) for Benin-Togo, the Société Nationale d'électricité (SONABEL) in Burkina Faso, and the Liberia Electricity Corporation (LEC) in Liberia. Its interconnection with Liberia is already complete since 2015. It has also played a key role in making this co-operation in the electricity business a major success. Interconnecting these countries with the Côte d'Ivoire would allow mutually beneficial power exchanges and a reliable electricity supply necessary for economic growth and consolidation of peace. All member countries of the interconnection Côte d'Ivoire, Ghana, Togo, Benin, Burkina Faso, Mali and Liberia are also founding members of ECOWAS. Côte d'Ivoire exchange electricity with these countries through an interconnection line (Figure II-2). The different interconnection line with Côte d'Ivoire are:

- Côte d'Ivoire is interconnected to Ghana through by the line between Abobo substation (north of Abidjan) in Côte d'Ivoire and the Prestea substation in the western part of the Ghana, with 225KV of operating voltage(Guide to Electric Power in Ghana,2005).
- Côte d'Ivoire and Burkina Faso are interconnected through the line between Ferkéssedougou substation (Côte d'Ivoire) and Bobo Dioulasso (Burkina Faso) – Ouagadougou (Burkina Faso) substations, with 225KV of operating voltage.
- Côte d'Ivoire and Mali are interconnected with the transmission line Ferkéssedougou (Côte d'Ivoire) – Sikasso (Mali) – Ségou (Mali).
- Côte d'Ivoire is interconnected to Liberia through the transmission line Man (Côte d'Ivoire)-Yepeka (Liberia).
- Côte d'Ivoire sale electricity to Togo/Benin through the Ghanain network.

Figure II-2: Map of Grid interconnection of Côte d'Ivoire (Source CIE: http://www.cie.ci).

II-4 Electricity exchange Agreement

The first cross-border electricity connection of the national electricity grids of Côte d'Ivoire, Compagnie Ivoirienne d'Electricité (CIE) was established in 1984 with its eastern neighbor Ghana, Volta River Authority (VRA). While exchanges between the two nations have been modest and it marked the start of regional exchanges with other countries such as Burkina Faso, Mali, Togo-Benin, and recently Liberia. The quantity of electricity exchange between these countries and Côte d'Ivoire depend on the agreement or bilateral contract that has been signed between Côte d'Ivoire and the others countries.

II-4.1 Electricity exchange agreements between Côte d'Ivoire and Ghana

Ghana's imports and exports of electricity are driven primarily by two factors: the need to meet growing peak demand and the variability of the Volta River flow rates. Côte d'Ivoire is one of the primary electricity trading partners of Ghana, with which electricity is traded via an interconnection line between the Abobo substation (north of Abidjan) in Côte d'Ivoire and the Prestea substation in the western part of the Ghana network. The operating voltage is 225KV on a single circuit line of about 220km in length. From 1984 to 1993, Côte d'Ivoire was the net electricity importer from Ghana. Since 1994, it became the net electricity exporter (as we can see in figure II-3).

This situation is attributed to an increase in its electricity production. In fact due to electric power sector reforms and authorization of independent power producers (IPPs) that took place in Côte d'Ivoire since October 1990, the country succeeded in attracting private investment for two IPP projects, which enabled it to have excess generating capacity, and became a net exporter of energy in the sub-region. Since 1994, CIE has been exporting electrical energy to VRA. Until, bilateral agreements between VRA and CIE, Ghana has an exchange agreement with the Côte d'Ivoire for up to 200-250MW of power import or export as the need arises on either side.

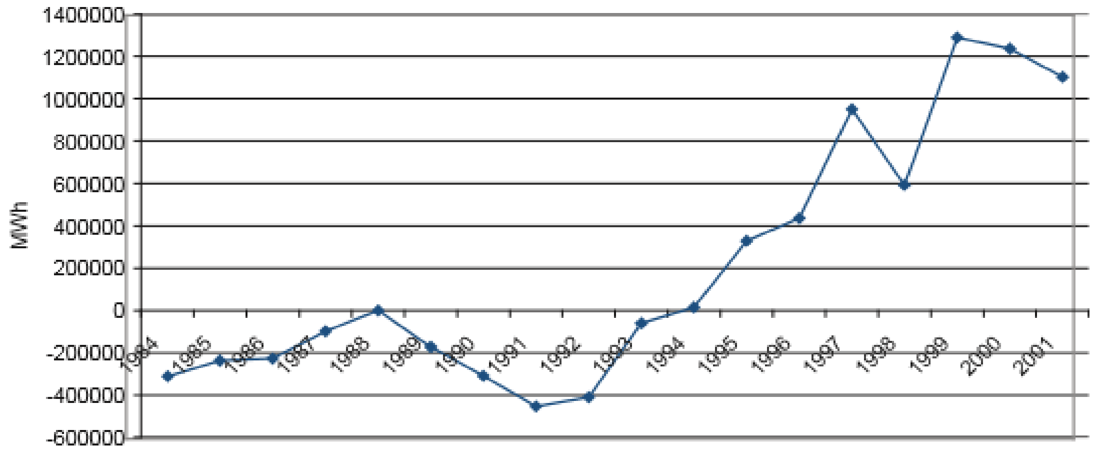

Figure II-3:Evolution of electricity exchange between EECI/CIE and Ghana's VRA (1984-2001) (source: Compagnie Ivoirienne d'Electricité (CIE) – Direction des mouvements d'énergie)

II-4.2 Côte d'Ivoire - Burkina Faso Interconnection

The bilateral agreement between CIE and electricity company of Bukina Faso "Société Nationale Burkinabè d'Electricité '' (SONABEL) was signed and came into effect in April 2001. Under the agreement of electricity exchange, electricity supply is guaranteed by one party to the other for a specific period. Guaranteed supplies are billed monthly according to negotiated tariffs as is the agreement between Côte d'Ivoire and Burkina Faso. Under this agreement, Côte d'Ivoire is obliged to supply a continuous power of 50MW to Burkina Faso, except under "force majeur" conditions for a period of 8000 hours/years.

II-4.3 Côte d'Ivoire -Togo/Benin Interconnection

The bilateral agreement signed between the Côte d'Ivoire's CIE and Communauté Electrique du Benin (CEB), the bi-national utility of Togo and Benin, came into effect in 1995. Under the terms of this Agreement, CIE has to supply electrical energy for a maximum amount of 200 GWh per year to CEB through Ghana's transmission network.

II-4.4 Côte d'Ivoire -Mali Interconnection

The agreement signed in 1996 between the Governments of Côte d'Ivoire and Mali, required (CIE) to initially supply guaranteed continuous power of 30MW to Mali. This value was reviewed and increased to 45MW in 2014.

II-5 Electricity generation and installed capacity

II-5.1 Electricity generation

Electricity power in Côte d'Ivoire come from a mix of thermal (mostly natural gas) and hydropower generating facilities. Its electricity production plant is composed of six hydroelectric dams (Ayamé 1, Ayamé 2, Kossou, Taabo, Buyo and Fayé) and four thermal plant (gas-powered stations) and isolated thermal power stations. The first power plant is Vridi power plant, was built in 1984 near Abidjan. Another power station at Azito Energie, located in Abidjan's suburbs, began to supply electricity to the grid in 1999, The CIPREL thermal power station was operated in 1995, is located in the Vridi industrial zone of Abidjan (Côte d'Ivoire), Aggreko power plant located at Vridi Canal in Abidjan and it was built in 2010).The thermal power plant are mainly supplied by local offshore natural gas and generate more than half of the country's annual production. As of 2016, the country's generating capacity was 1,886 MW. Although the thermal energy production still represents more than 84% of the energy electric against a little less than 16% for hydroelectric production in 2015. The Hydro and thermal generating plants are situated in the southern, central and western sides of the country as we can see in the figure II-3.

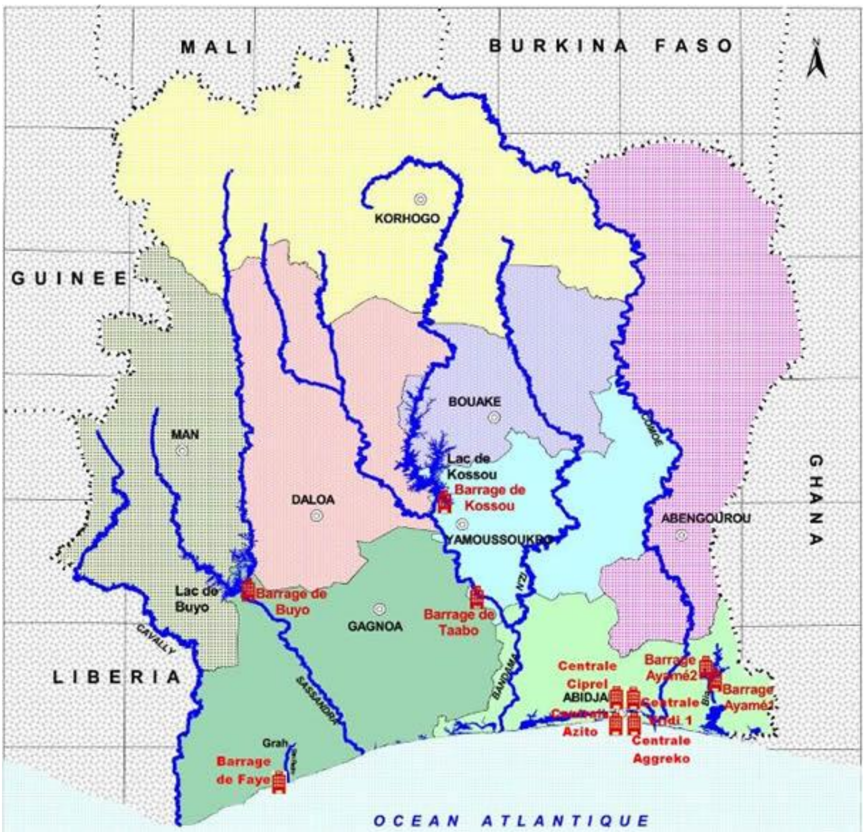

Figure II-4: Location of thermal and hydroelectric plant. (Source: www.anare.ci/index.php?id=28)

II-5.2 Installed capacity

Electricity generation is provided from hydroelectric dams and thermal power plants. Solar energy is very little developed in Côte d'Ivoire, despite the efforts undertaken by the IREN (Institute for Research on New Energies). The electricity generation capacity is based on a total installed capacity of 1886 MW, at the end of the years 2016, of which 604MW is generated from hydro plants and 1282 MW from Steam and Gas Turbine Generating (Thermal plant) (See table II-1).

Table II-1: Table of Installed capacity in 2016. Source: (www.anare.ci) and RECP

Power Station	Type	Installed Capacity (MW)	Year completed
Ayame 1	Hydro	20	1959
Ayame 2	Hydro	30	1965
Kossou	Hydro	174	1972
Taabo	Hydro	210	1979
Buyo	Hydro	165	1980
Faye	Hydro	5	1983
Total	**Hydro**	**604**	
Vridi 1	Thermal	100	1984
CIPREL	Thermal	543	1994-1997-2010
Azito Energie	Thermal	439	1999 - 2000
Aggreko	Thermal	200	2010-2012-2013
Total	**Thermal**	**1282**	
TOTAL	**Hydro + Thermal**	**1886**	

II-6 Transmission and distribution

The electricity transport is an essential intermediary between Production and Distribution, the electricity transmission network consists of lines, high stations and very high voltage that allow the energy produced from the power stations to be transferred to the consumption centers in optimal conditions. In Côte d'Ivoire, the transmission of electricity is channeled through an electricity grid consisting of 4402 km of high-voltage power line including 2088km of 225 KV line and 2645 km of 90 KV. The distribution grid consists of 30 kV and 15 kV (22,336 km) as well as 220 V and 380 V (19,599 km) lines. The transmission and distribution systems in Côte d'Ivoire are out-dated and overloaded with total energy losses at 22%.

II-7 Repartition of electricity consumption

The distribution of electricity on the Côte d'Ivoire area is organized in function of the direction regional of the Company of electricity of Côte d'Ivoire (CIE). (As we can see in the map below, Figure II-4).

- In the Southern zone, the distribution covers the direction regional of Basse Cote, (DRBC), the direction regional of Sud Ouest (DRSO), the direction regional of Sud Est (DRSE) and four others located at the capital city of Abidjan, one can cite the direction regional of Yopougon (DRYO), the direction regional of Abobo (DRABO), the direction regional of Abidjan Nord (DRAN) and the direction regional of Abidjan Sud (DRAS).
- in the center and northern zone, we have the direction regional of Centre (DRC), the direction regional of Centre Ouest (DRCO),), the direction regional of Ouest (DRO), the direction regional of Centre Sud (DRCS), the direction regional of Est (DRE).and , the direction regional of Nord (DRN)

Figure II-5: Map of the direction regional of the Company of electricity of Côte d'Ivoire (Source: CIE, 2016).

CHAPTER III: EVOLUTION OF EXTREME TEMPERATURES

III-1 Introduction

In this section, we will look for the evolution of the extreme temperature in the different climate zone of Côte d'Ivoire, based on the daily observation data (temperature) ranging from 1973 to 2016 for the center and northern zones and ranging from 1978 to 2016 for the southern zone. This part will help us to have a knowledge on the evolution of the maximum temperature (Tmax), the minimum temperature (Tmin) and the mean temperature (Tmean) over the study period.

III-2 Data and methods

III-2.1 Data

The daily maximal, minimal and mean temperature observations used to characterize the current climate change in Côte d'Ivoire come from the National Meteorology of Côte d'Ivoire named "Société d'Exploitation et de Developpement Aéroportuaire, Aéronautique et Météorologique" (SODEXAM) and also to the Global Summary of the Day Dataset published by the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC). Data available on the web site: (https://www7.ncdc.noaa.gov/CDO/cdoselect.cmd?datasetabbv=GSOD). The dataset contains daily observations from 14 weather stations in Côte d'Ivoire.

Figure III-1: Representation of sites of different weather stations (source SODEXAM).

III-2.2 Methods

The annual and monthly extreme temperature in each climatic zone have been compound by following two steps. First of all, we classify each station in different climatic zone, depending on its geographic location as we can see in table III-1 below. Five stations (Tabou, San pedro, Adiake, Abidjan, and Sassandra) are located along the southern zone. Seven stations (Bouake, Daloa, Yamoussoukro, Man, Dimbokro, Gagnoa, and Bondougou) are in the center zone and two stations (Korhogo, and Odienné) belong to the Norther zone.

Next, we calculate annual/monthly average for the extreme temperature observations across all weather stations in each climate zone. The difference of weather stations across climate zone is partially corrected by the fact that climate zones differ in size, and the zones that cover larger areas have more weather stations.

Table III-1: Repartition of meteorological stations by climate zone in Côte d'Ivoire

Climatic zone	Meteorological stations	Data availability
Northern (subtropical climate)	Odienné , Korogho	1973-2002 and 2013-2016
Center (Equatorial climate)	Bouake, Daloa, Yamoussoukro, Man, Dimbokro, Gagnoa, Bondougou	1978-2016
Southern (Humid Equatorial climate)	Tabou, San pedro, Adiake, Abidjan, Sassandra	1978-2016

III-3 Evolution of the extreme temperatures

III-3.1 Inter annual variability of the extreme temperatures

III-3.1.1 Inter annual variability of the extreme temperatures in the southern zone (Humid Equatorial)

The figure III-2 represents the evolution of the mean annual maximum temperature (Tmax), minimum temperature (Tmin), mean temperature (Tmean) in the southern zone over the period from 1978 to 2016 (i.e., 39 years). In general, these graphs show a continuous increase in the trend of the evolution of extreme temperatures over the considered period. For the graphs of temperature (Tmax), Tmean and Tmin, the coefficient of correlation (R^2) is around 0.7, 0.3 and 0.55 respectively for Tmax, Tmin and Tmean. All the coefficient of correlations are greater than 0.3 (given that the critical value of correlation at 5% is 0.3 for a set of 30 data). This means the increasing observed in the evolution of these extreme temperatures is statically significant and can affect the behavior of the population, use of energy and so one.

In the Tmax graph (Figure III-2), the highest value is seen in 2010 of 30.94ºC and the lowest is 28.82 ºC in 1978 making a difference of around 2.12 ºC during 32 years.

For the Tmin graph, the lowest is 22.82 ºC in 1986 and the highest is 24.36 ºC in 2003 making a difference of 1.54 ºC. The Tmean has exactly the same trend as Tmax and Tmin and varies from 21.71 ºC in 1978 to 27.07 ºC in 2016.

In addition, from 1978 to 2016, the graphs show a rise in the maximal temperature, minimum temperature and mean temperature of approximately 1.48°C, 0.74°C and 0.95 °C respectively.

The increase in the extreme temperatures observed during the 39 years (1978 – 2016) in the southern zone denote a change in the climate at local scale.

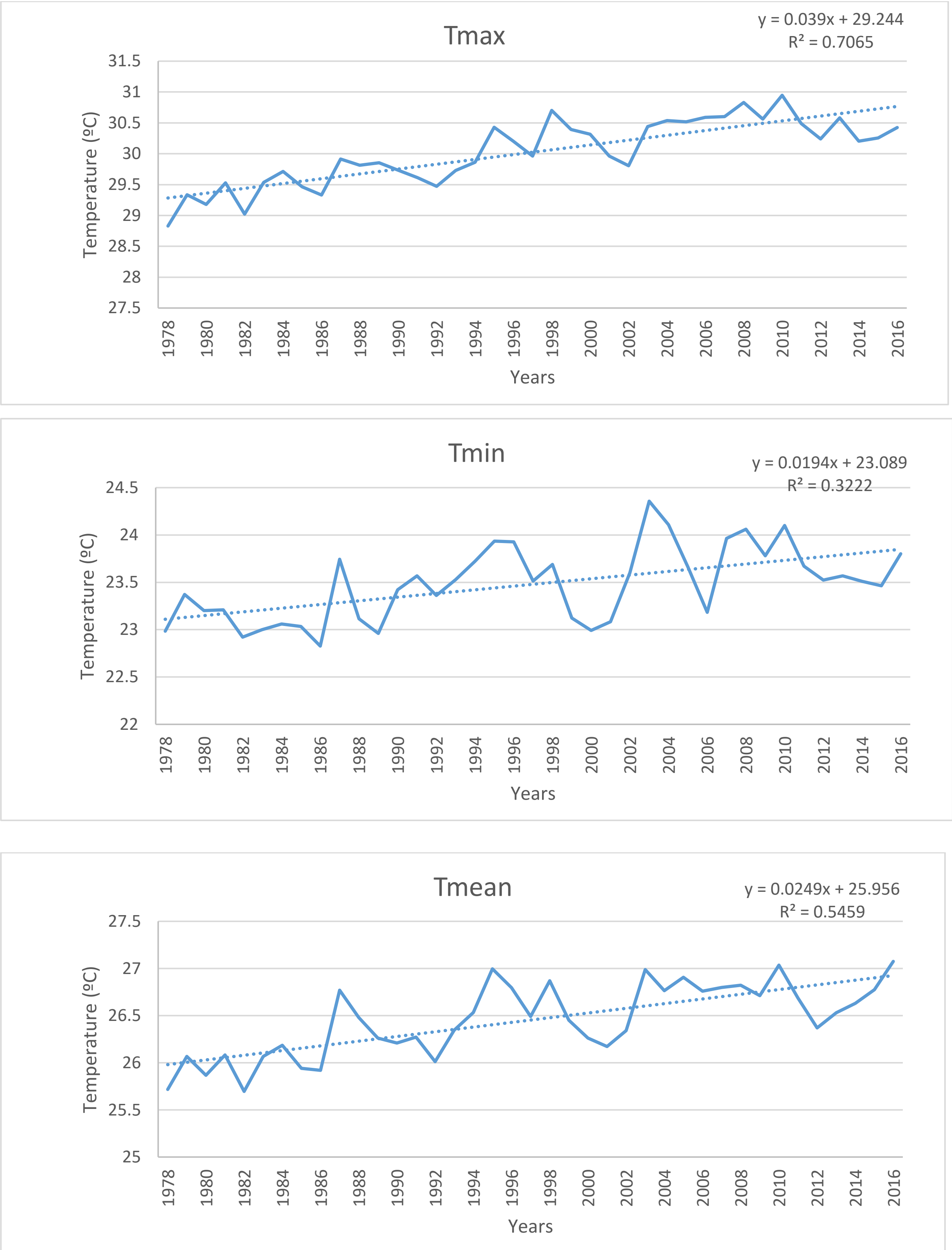

Figure III-2: Mean annual surface temperature of the southern zone of Côte d'Ivoire over the period 1978-2016 for the maximum temperature (Tmax), the minimum (Tmin), the mean (Tmean).

III-3.1.2 Inter annual variability of the extreme temperatures in the center zone

The inter annual variability of the extreme temperature in the center zone has been seen in the figure III-3. The graph of Tmax, Tmean and Tmin show also an increase in their trend. For the graphs of temperature (Tmax), Tmean and Tmin, the coefficient of correlation (R^2) is around 0.88, 0.49 and 0.81 respectively for Tmax, Tmin and Tmean. These coefficient of correlations are greater than 0.3. That result attests that the increase in the extreme temperature is significant. So, the change in the climate appears clearly in the zone.
We have a meaningful increase in the evolution of Tmax and Tmean from 1973 to 2016 compare to the evolution of Tmin, where we observe a slight increase from 1973 to 2016 marked by fluctuations.
Tmax varies from the low value 30.71 ºC in 1976 to 33.07 ºC in 2013 making a difference of around 2.36 ºC during the 37 Years. In general the value of Tmax in center zone is higher than the southern zone one.
For Tmean, the highest value is showed in 2016 with 27.26 ºC and the lowest is 25.52 ºC in 1975 making the difference of 1.74 ºC during the 41 years.
For Tmin, we have the highest value is 22.99 ºC in 2003 and the lowest is 2.09 ºC in 1973. The rise of maximum temperature, minimum and mean temperature is around 1.98ºC, 0.97ºC and 1.33ºC respectively, from 1973 to 2016. This result shows that the center zone experiences more increase in temperature compared to the southern zone, this can be explained by the overexploitation of the forest in the center zone (vegetal cover) due to the culture of cacao.

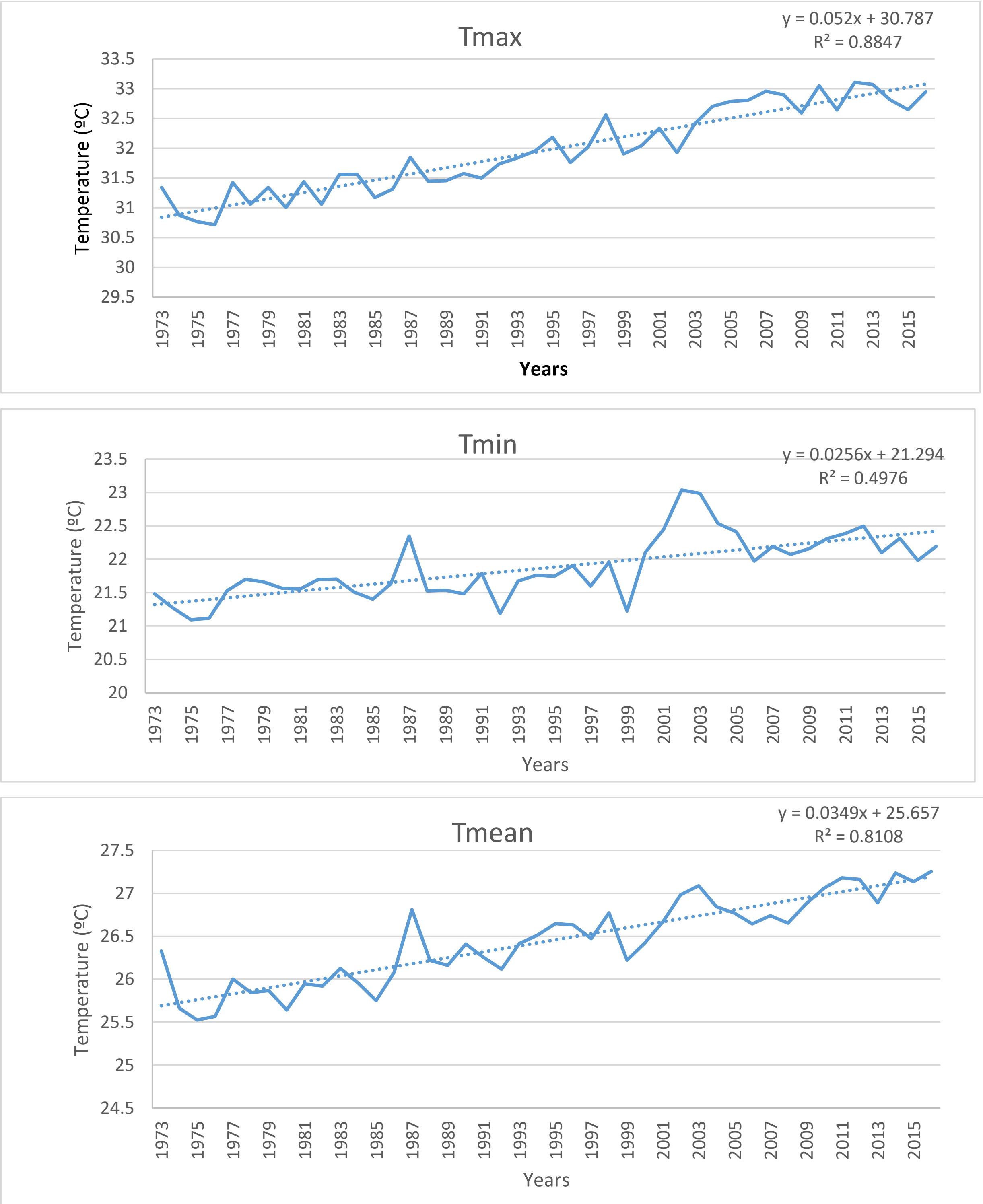

Figure III-3: Mean annual surface temperature of the center zone of Côte d'Ivoire over the period 1973-2016 for the maximum temperature (Tmax), the minimum (Tmin), the mean (Tmean).

III-3.1.3 Inter annual variability of the extreme temperatures in the northern zone

Figure III-4 represents the mean annual extreme temperatures of the northern zone of Côte d’Ivoire over the period 1973-2002 and 2015-2016 for the maximum temperature (Tmax), the minimum temperature (Tmin), the mean temperature (Tmean). The lack of data during the period from 2002 to 2014 is due to the political crisis.

In this figure, we have a lot of missing data but the increasing trend is clear in the graph of Tmax, Tmin and Tmean over the study period, as we have seen in the southern and center zone. Here, the correlation coefficient of maximum temperature (0.46) and mean temperature (0.32) is higher than 0.3, meaning that the increase in the both temperature is significant. While that of minimum temperature (0.15) is less than 0.3. So, the increase in minimum temperature (Tmin) is not statically significant. It is rather marked by the fluctuation and less increase.

Thus, one notice that the climate change is characterize by the increase in maximum and mean temperature in that northern zone, despite some lack of data.

The maximum temperature (Tmax) varies from the lowest value 31.78 ºC in 1976 to the highest value 33.38 ºC in 1998, making a difference of 1.6 ºC during the period of 22 years.

For the minimum temperature (Tmin) the values is comprise from the lowest value 19.81 ºC in 1989 to the highest value 21.82 in 1996, giving a difference of 2 ºC during 7 years.

For mean temperature (Tmean), the highest value is showed in 1996 with 27.50 ºC and the lowest is 25.92ºC in 1976 making the difference of 1.58 ºC during the 20 years.

The rise of maximum temperature, minimum and mean temperature is around 1.17ºC, 0.85ºC and 1.07ºC respectively from 1973 to 2016. This result is also affected by the lack of data during twelve (12) years due to the political crisis.

It appear clearly that the rise in the extreme temperatures seen in the center zone is more important than those in the northern zone, event through there are less forest in north compare to the center. Indeed, during the last decade, the forest in the center has considerable reduce due to the culture of hevea, cacoa and coffee which take place of the previous forest.

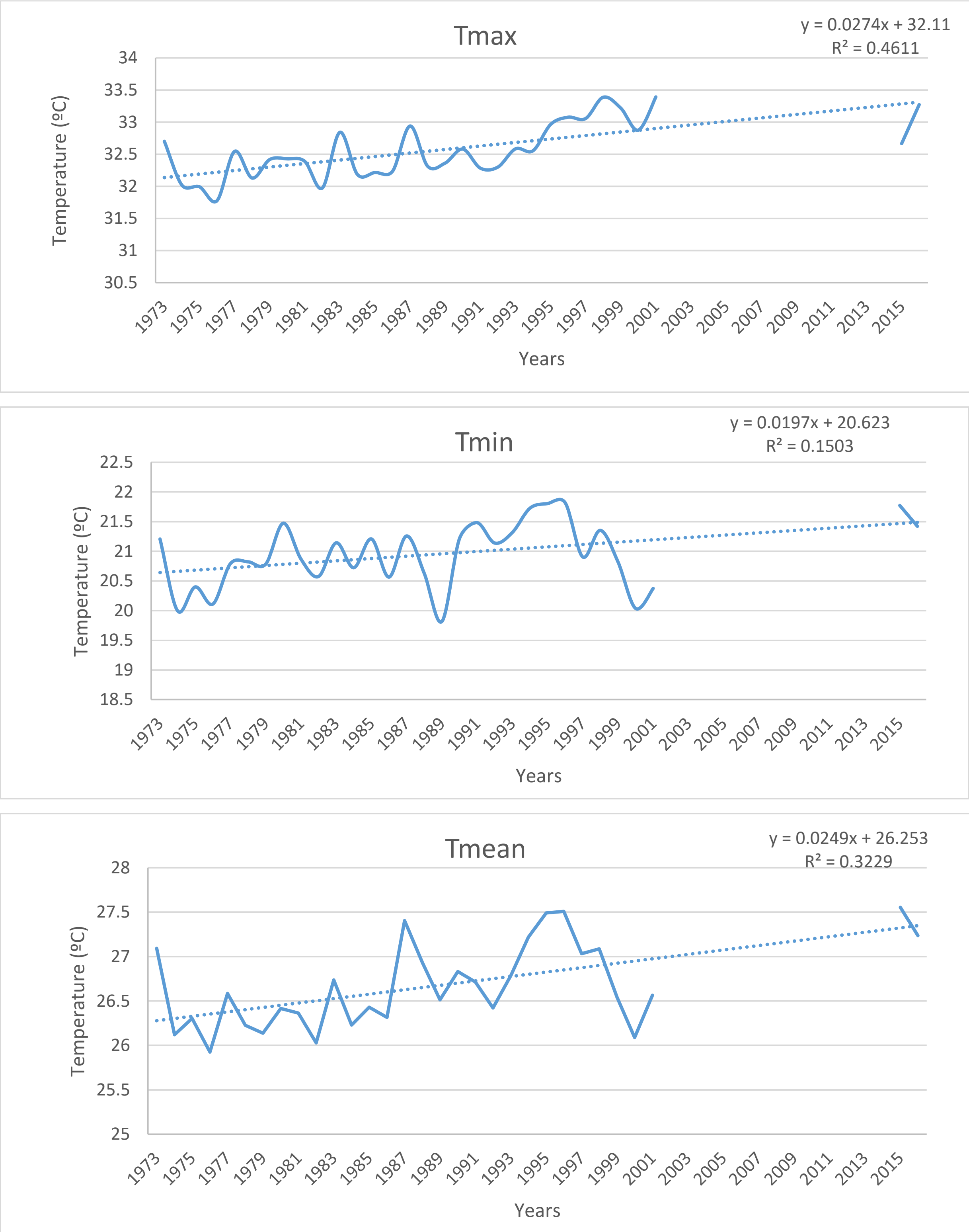

Figure III-4: Mean annual surface temperature of the northern zone of Côte d'Ivoire over the period 1973-2016 for the maximum temperature (Tmax), the minimum (Tmin).

III-3.2 Intra seasonal variability of the extreme temperatures

In this part, we determined the evolution of the intra seasonal variability of extreme temperature for all the climatic zone, in order to determine, the modification which could appear during the months in the extreme temperatures.

III-3.2.1 Intra seasonal variability of the extreme temperatures in the southern zone.

The evolution of the monthly average of maximal temperature, minimal temperature and mean temperature from 1978 to 2016 in the southern zone have been indicated in the figure III-5:

We observe the same trend in all the variables (maximum temperature, minimum temperature and mean temperature) during the year. They start increasing from January up to March for Tmax and April for Tmin and Tmean, where they reach the maximal value 32.2 ºC, 24.4 ºC and 27.9 ºC respectively for Tmax, Tmin and Tmean. Corresponding to the beginning of the first rainy season in the southern zone. Then, from March-April they decrease until August, before to restart a little bit an increase until December.

During the year, the average monthly of mean temperatures fluctuate between 24.6ºC and 27.9C, While maximal temperature varies between 27.5 ºC and 32.2 ºC , and minimal temperature fluctuate between 22.47ºC and 24.4 ºC.

The figure shows also, two seasons in the temperature during the year. We have the hot season and cool season, the hot season lasts from January to May and from October to December and the cool season from June to September. Among the two hot seasons, the hottest months are comprised between January and May with maximum average temperatures reaching 32.2 ºC, 24.4 ºC, 27.9 ºC respectively for Tmax Tmin and Tmean from (1978-2016) as we have already seen.

The coldest months comprise between July, August and September. It has been confined that this period from July to September is the period of cooling in Atlantic Ocean, namely (upwelling) in the Gulf of Guinea.

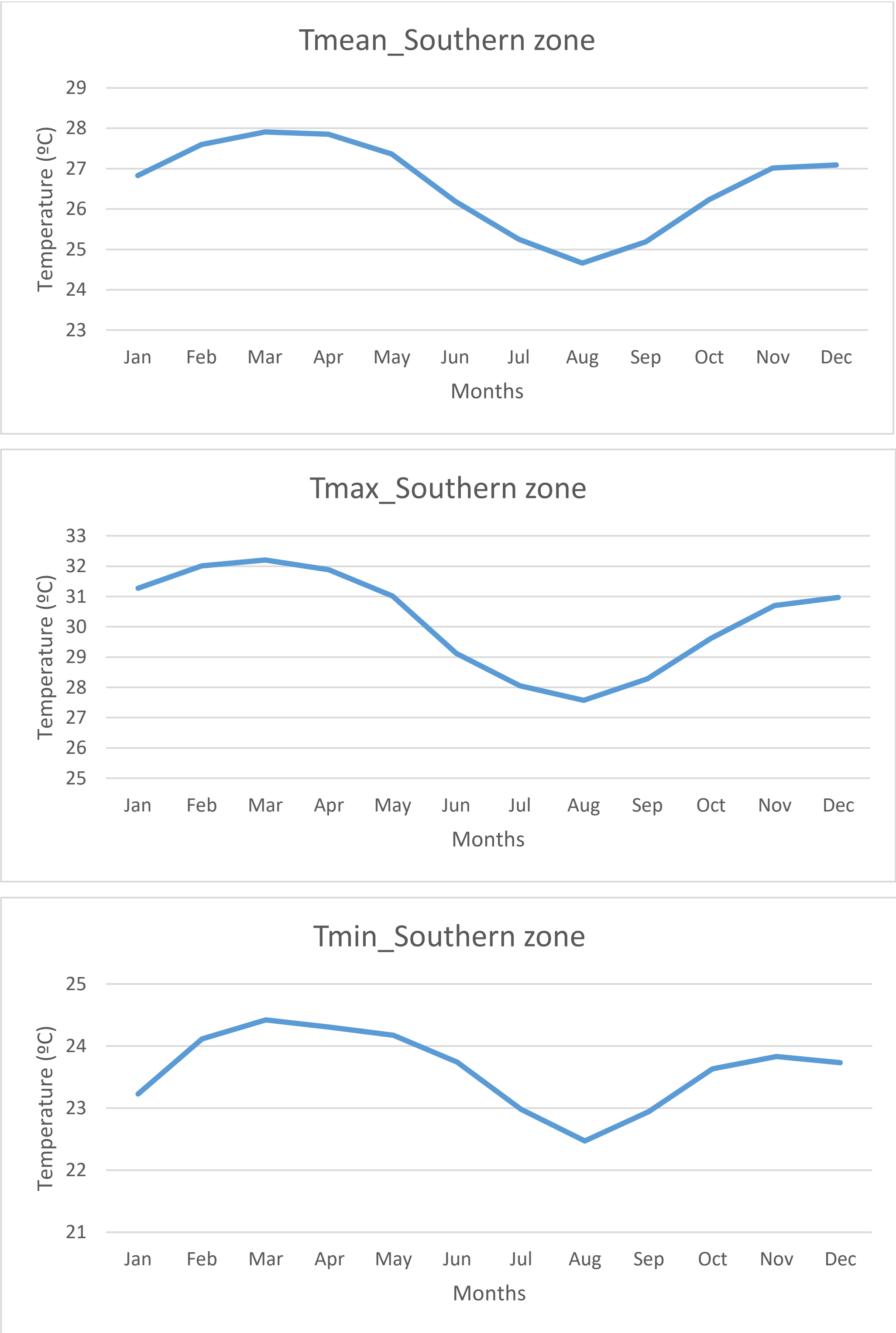

Figure III-5: Mean seasonal cycle of the extreme temperatures (Tmax, Tmin, Tmean) over the period 1978-2016 in the southern zone.

III-3.2.2 Intra seasonal variability of the extreme temperatures in the Center zone

The figure III-6 represents the evolution of the monthly average of maximum temperature, minimum temperature and mean temperature from 1973 to 2016 in the Center zone. In this climatic zone, the pace of the extreme temperature is mostly the same in the southern zone and they differ in their amplitudes.

Tmax and Tmean start increase from January to February/March where they reach their peak of 34.09 ºC for Tmax and 28.41 ºC for Tmean. Corresponding to the beginning of the first rainy season in the center zone. Then, they decrease from April to August, before to restart a little increase from September to November. The lowest value of Tmean and Tmax is in August, with 24.98 ºC for Tmean and 28.50 ºC for Tmax.

We have the same trend for Tmin, but it reach is peak only in March/April with a value of 23.11 ºC.

The lowest value of the maximum temperature and mean temperature are seen in August with 34.09 ºC for Tmax 24.98 ºC for Tmean. While the lowest value of minimum temperature (Tmin) is seen in January with a value of 20.48 ºC.

The average of monthly mean temperature varies from 24.98 ºC to 28.41 ºC. While maximal temperature fluctuate between 28.50 ºC to 34.09 ºC and minimal temperature varies from 20.48 ºC to 23.11 ºC. The maximum and mean temperature in this zone are higher than those in the southern zone.

We can also distinguish two hot seasons as in the southern zone, corresponding to the months from January to May and October to November. The period from January to May is hotter than from those of October to November. The coldest months are from July to September.

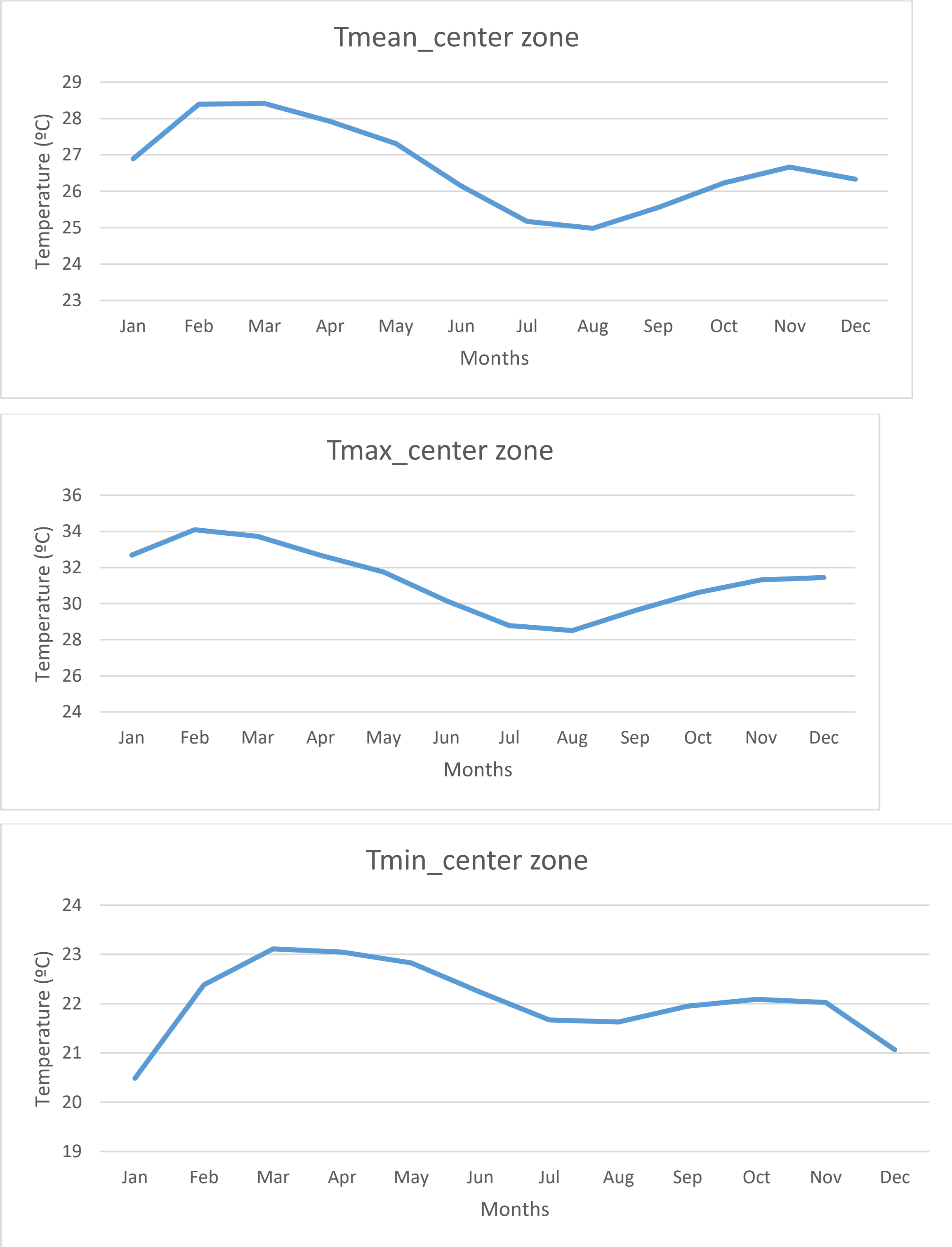

Figure III-6: Mean seasonal cycle of the extreme temperatures (Tmax, Tmin, Tmean) over the period 1973-2016 in the center zone.

III-3.2.3 Intra seasonal variability of the extreme temperatures in the Northern zone

The monthly mean, maximal and minimal temperatures have been represented in figure III-7. This figure shows that, the extreme temperatures vary differently according to the months of the years.

Here we observe the same trend in the variables of maximum temperature and mean temperature during the year. It is the same trend as those observed in the center and southern zones. While, we have a change in the evolution of minimum temperature (Tmin) during the year, in this zone compared to the two others zones.

The maximum temperature and mean temperature start increasing in the January and keep it until March-April where they reach their peak 29.72 ºC for Tmean and 36.32 ºC for Tmax. They decrease from June to September corresponding to the period of rainy season in this zone. Then they restart a little bit increase from October to November.

The lowest values of maximal temperature and mean temperature are in August with a lowest value of 29.56ºC for Tmax and 25.13 ºC for Tmean.

For the minimum temperature (Tmin), it starts increase from January to March where it reaches the peak of 23.68 ºC and it decreases from April up to December.

The lowest value of the maximum temperature and mean temperature are also seen in August with 29.55 ºC for Tmax 25.13 ºC for Tmean. While the lowest value of minimum temperature (Tmin) is seen in December with a value of 18.12 ºC.

The average of monthly maximum temperature varies from 29.56 ºC to 36.32 ºC, and monthly mean temperature is comprised between 25.13 ºC and 29.72 ºC. While minimal temperature varies from 18.12 ºC to 23.68 ºC.

The period from January to May corresponds to the hottest months and the coldest months are from July to September in that climatic zone.

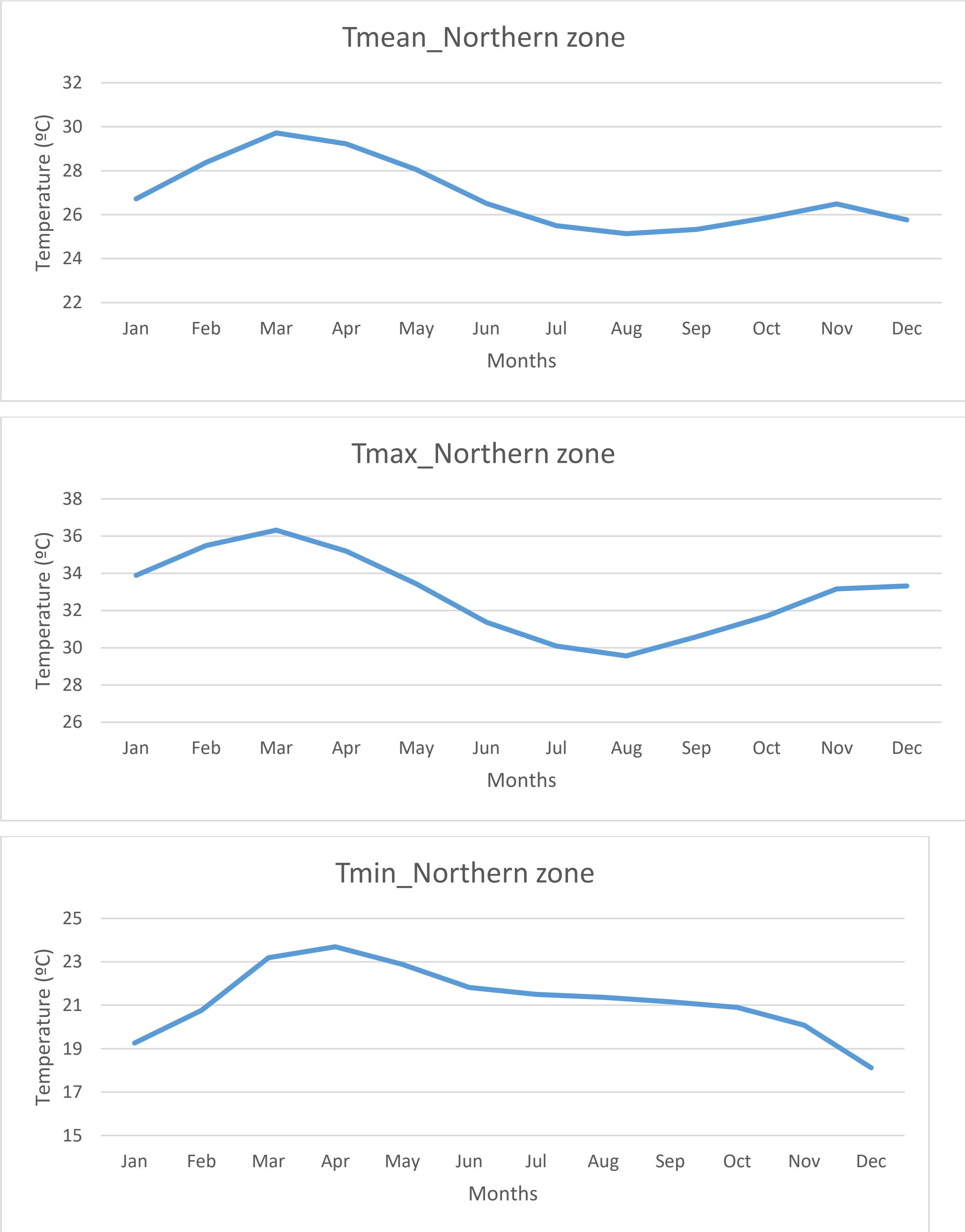

Figure III-7: Mean seasonal cycle of the extreme temperatures (Tmax, Tmin, Tmean) over the period 1973-2016 in the northern zone.

III-4 Conclusion

This chapter presents the evolution of the extreme temperature in all the climatic zone of Côte d'Ivoire (southern zone, center zone and northern zone). The annual extreme temperature observed in the three climatic zones, have shown a continuous increase between 1978 and 2016. Regarding to the elevation of maximum and mean temperature, it appears clearly that the air becomes increasingly hot in all the climatic zone of Côte d'Ivoire and this could affect the electricity consumption in that zones. Indeed, between 1978 to 2016 for southern zone, 1973 to 2016 for the center and northern zone, the maximum and mean temperature is approximately greater than 1 ºC in each zone. This situation could be caused by the agricultural policy. In fact, since the independence of Côte d'Ivoire, the government has promoted the sector of agriculture. Thus, the populations are rushing on the forests for the culture of coffee and cocoa. This agricultural policy reduced considerably the forests of 16 million hectares to 3 million hectares today. This situation exploited the reheating of the atmosphere since the forests constitute a significant carbon sink. So, the increase in the extreme temperatures observed in all the climatic zones could be due to the reduction in vegetable cover and also by the world emissions of greenhouse gases of anthropic origin.

The study on the intra seasonal variability of the extreme temperatures, has shown that, the extreme temperatures differ from one months to another months in all the zones. The Hot months is from January to May and from October to December. The hottest period is from January to May. One has one cold period from June to September witch coincide with the period of rainy season in the northern zone, and it also coincide with the period of Upwelling in the Gulf of Guinea (period of cooling in Atlantic ocean) in the center and southern zone.

CHAPTER IV: EVOLUTION OF ELECTRICITY GENERATION AND ELECTRICITY CONSUMPTION

IV-1 Introduction

In this chapter we will analyze the trend of the electricity generation and the electricity consumption in Côte d'Ivoire and in each of climatic zones as already defined in chapter I. Afterward, we will interest to the evolution of electricity exchange between Côte d'Ivoire and the countries with which it is interconnected.

IV-2 Annual Evolution of electricity generation

Annual data on electricity production have been collected from the Electricity Company of Côte d'Ivoire (CIE) and the national authority for the regulation of the electricity sector of Côte d'Ivoire (ANARE).

The figure IV-1 represents the annual evolution of electricity generation mix in Côte d'Ivoire from 2003 to 2015. The electricity mix in each year has been calculated by the summation of electricity generation from hydropower and thermal plant in the same year, they represent the main electricity generation in Côte d'Ivoire.

This figure shows a clear increase of the electricity production from 2003 to 2015. The production has increased from 5092 GWh in 2003 to around 8607 GWh in 2015. Côte d'Ivoire's electricity generation from 2003 to 2010 increase slightly compared to the period from 2012 to 2015. This situation can be linked to the reduction of private investments due to the political instability from 2000 to 2011. Since 2012 Côte d'Ivoire has recorded faster growth in electricity generation. During that period 2012- 2015, the electricity production varies from 6947.9Gwh to 8607 GWh. It can be due to the installation of new thermal plant (AGGREKO) in 2010 and also to the increase in electricity demand.

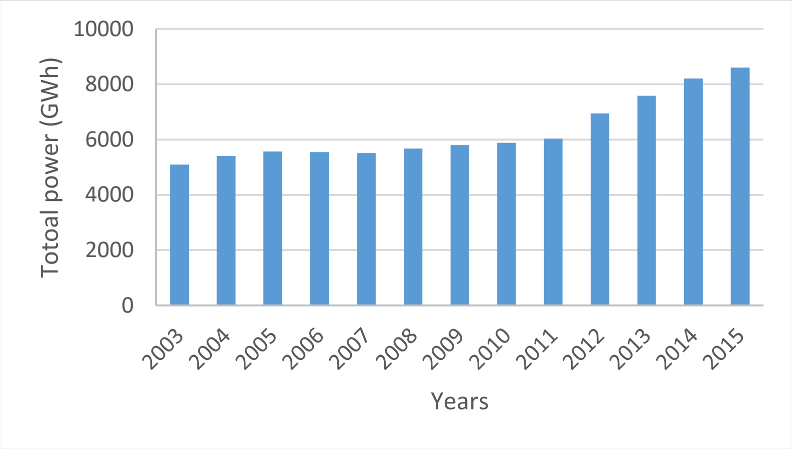

Figure IV-1: Annual evolution of electricity generation mix in Côte d'Ivoire from 2003 to 2015.

IV-3 Contribution of hydropower and thermoelectric power to total electricity generation

The figure IV-2 represents the evolution and the contribution of electricity production of thermal and hydro power plants in Côte d'Ivoire. That figure shows that the electricity production is mainly dominated by thermal plant. It contributes to about 78.8%, 76.7% and 84.3% to the electricity production in 2013, 2014 and 2015 respectively.

The electricity produces by thermal plants increase from 2003 to 2015. The power varies from 3260.7 GWh in 2003 to 7255 GWh in 2015. From 2003 to 2011 we observe a little bit increase of electricity produce from thermal. We have a highly increase in the produce from thermal from 2012 to 2015 compare to the period from 2012 to 2015, where the production has considerable increase. That can explained the increase in the national electricity production during that period (2012-2015). The reason on the pattern of the thermal electricity production can be linked either to the increase in national electricity capacity in thermal plant due to the increase in local demand or to the increase in electricity exported to its neighboring.

The contribution of hydropower in the electricity production in Côte d'Ivoire is mostly constant, due the no increase in the installing capacity of hydropower, even though we observe a decrease in electricity production from hydropower some years.

The weakness participation of hydropower can be explained by the oldness of production equipment and also by the fluctuation of rainfall distribution resulting from the climate change impact on precipitation (low precipitation).

All the electricity produce by the thermal plants and the hydropower is one hand transported and distributed in the national electricity network and other hand it is exported into the neighbors' countries through the interconnection line. In the next section, we will look at the evolution of the local electricity consumption and also the electricity export to the neighbors' countries.

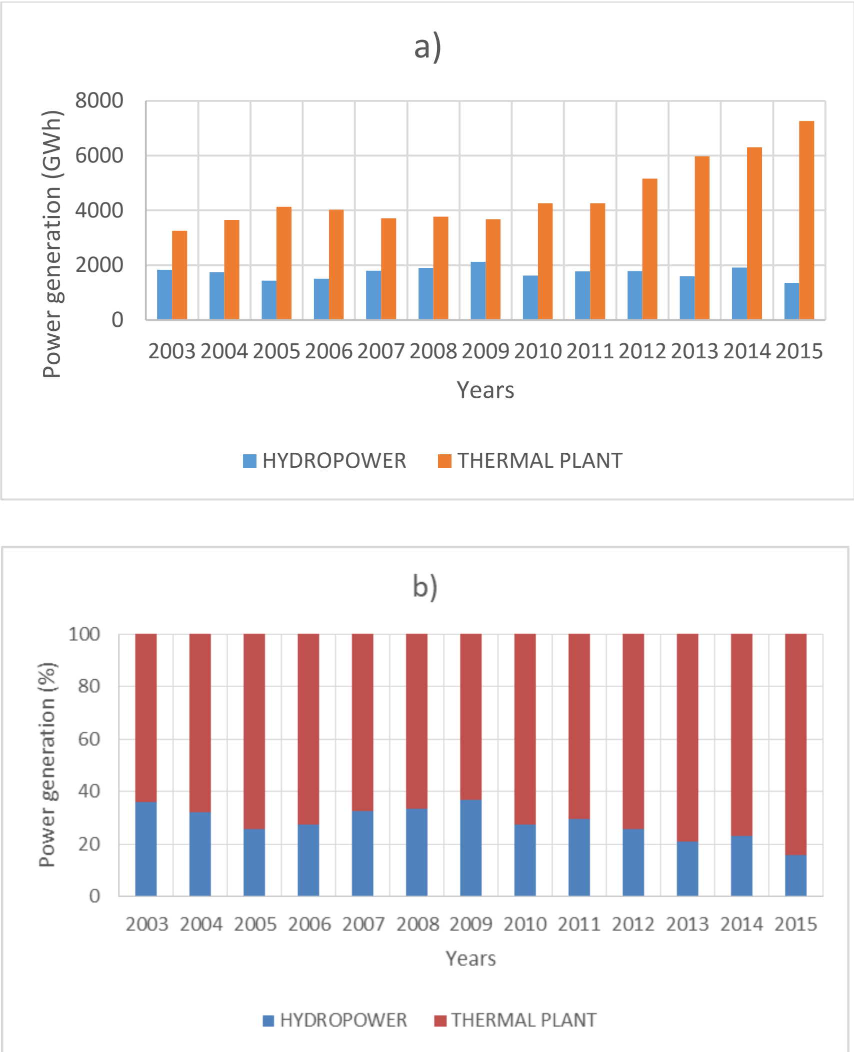

Figure IV-2: Evolution of electricity production by thermal and hydro power plants (a) and contribution of electricity production by thermal and hydro power plants (b).

IV-4 Evolution of total electricity consumption in Côte d'Ivoire

Annual data on the electricity consumption from 1990 to 2015, have been collected from the electricity company of Côte d'Ivoire (CIE) and extract to the work of Kondi et al., 2016. The figure VI-3 represents the evolution of the annual electricity consumption in Côte d'Ivoire from 1990 to 2015. That figure shows an increase in the electricity consumption from 1990 to

2015. It rises from 2095.6 GWh in 1990 to 7107.51 GWh in 2015, representing an annual average growth of 4.88% during that period from 1990 to 2015. While, we note a decrease of 96.2 GWh in 2011 compared to the electricity consumption in 2010 due to the political instability (political crisis) that destroy investment in critical energy infrastructure. At the end of the post electoral crisis 2011, the electricity consumption undergoes a rapid increase from 2012 to 2013. In 2012, the consumption is around 5876.4 GWh corresponding to an annual growth rate of 5.5% during the period from 2012 to 2015.

This increase of electricity consumption from 1990 to 2015 can be linked to economic development but also to many factors such as demography, temperature. In 1990 the population was estimated to about 11.23 million (already seen in chapter I) with the electricity consumption 2095.6 GWh and in 2015 the population was estimated to 23.10 million (according to World Bank), with an electricity consumption of 6900.7 GWh. Thus, more people can means a higher demand for electricity. Also during the summer, high temperature is likely to increase electricity demand for cooling. In the chapter below we will show the link between the consumption and temperature.

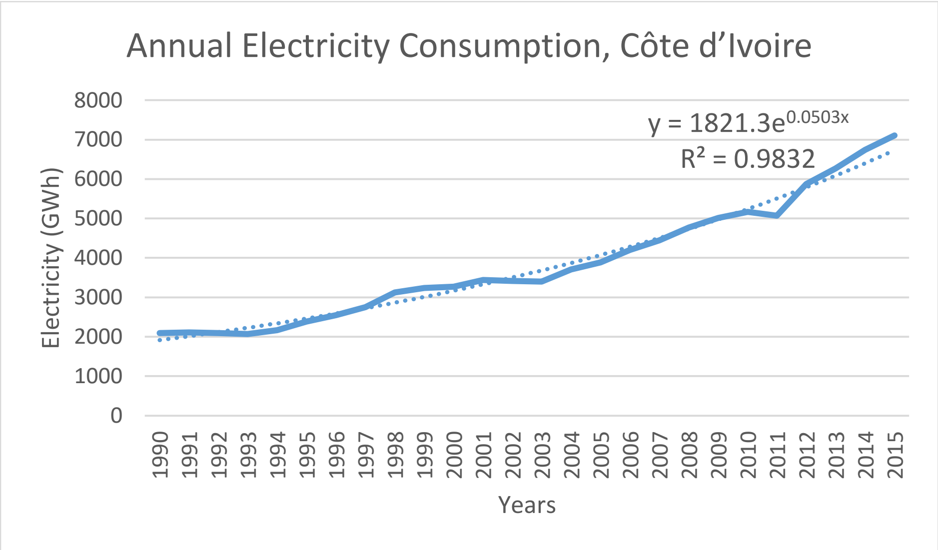

Figure IV-3: Annual evolution of the electricity consumption in Côte d'Ivoire from 1990 to 2015.

IV-5 Annual evolution of electricity per climate zone

Here, we collect annual electricity consumption data for each direction regional of the electricity company of Côte d'Ivoire (CIE) in the same electricity company and also from the same work of Kondi et al. 2016. We subdivide the electricity consumption in each climatic zone. Due to the lack of data, we divide the electricity consumption for the Direction Regional of Est (DRE) in two parts, 1/3 for the North and 2/3 for the center. The reason is that the north part representing the DRE have 267.167 inhabitants in 2014 (RGPH, 2014) and it is less industrialized compared to the rest part representing the DRE which contain 1227.507 inhabitants in that same year 2014 (RGPH, 2014), we note that the meaning and representation of each direction regional of CIE is already define in the chapter I.

- For the southern zone, we consider the direction regional of DRBC, DRSO, DRSE DRYO, DRABO, DRAN and DRAS.
- For the center zone, we consider the direction regional of DRC, DRCO, DRO, DRCS and 2/3 of the consumption in DRE.
- For the northern zone, we consider the direction regional of DRN and 1/3 of the consumption in the DRE.

Figure IV-4 represents the evolution of electricity consumption per each climatic zone of Côte d'Ivoire (Southern, Center and Northern zones). This figure shows an increase in the electricity consumption in all the zones from 1990 to 2015. The growth of the electricity consumption is exponential with the trend line equation (1):

- Southern zone: $Y = 1349.2e^{0.0528X}$
- Center zone: $Y= 396.98e^{0.0347X}$
- Northern zone: $Y = 83.491e^{0.0631X}$

Where Y and X denote the electricity consumption and the year respectively.

The consumption growth is very low in the North and Center parts compared to the one of Southern part. In general the southern area consumes more electricity than the center area and also the center area consumes more electricity than the north area.

For the southern zone, the consumption has a rapid increase from 1990 to 2015. It varies from 1531.99 GWh in 1990 to 5544.7 GWh in 2015, corresponding to an increase of 4012.71 GWh during that period. But in 2011, it decreased from 4125.31 GWh to 3974.24 GWh in 2012 before to restart to increase until 2015. This can be explained by the political crisis of 2011. The southern area is more industrialized, and it includes the capital city Abidjan.

For the center zone, the electricity consumption varies slightly from 1990 to 2015. The consumption varies from 450.21 Gwh in 1990 to 1068.99 GWh in 2015. This corresponding to an increase of 618.78 GWh.

For the northern zone, it varies from 114.71 GWh in 1990 to 498.26 GWh. The electricity consumption increase slightly from 2002 to2012, this situation is due to the socio-political crisis which have begun in 2002 in this region. The industries and investment during that period was stopped. And also many people in the cities in that zone migrated toward the rural area of which the electricity consumption is low, because the only use in the most can be TV and lighting. Then from 2012 to 2015, we have an increase in the consumption.

In 2015, the consumption is 78 %, 15 % and 7% in the southern, center and northern zone respectively.

The share of the total electricity consumption is seen in the figure IV-5, it confirms the high electricity consumption in the southern zone compared to the center zone, and also the high electricity consumption in the center zone compared to the northern zone. This figure IV-5 shows that, the southern zone consumes more than 70% of total electricity consumption from 1990 to 2015. In the center and northern zones, the consumption is around 15% and 7% of total electricity consumption respectively from 1990 to 2015. This disproportionality observed in the distribution electricity in the climate zones, can be due to fact that the southern zone is the most industrialized and contains the most inhabitant compare to those of center and northern zone.

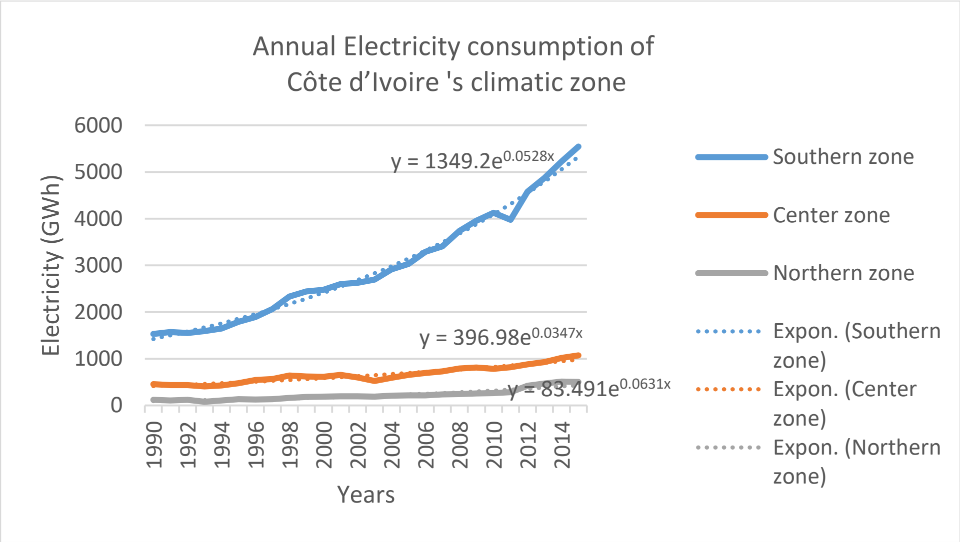

Figure IV-4: Annual evolution of electricity consumption in Southern, Center and Northern zones of Côte d'Ivoire.

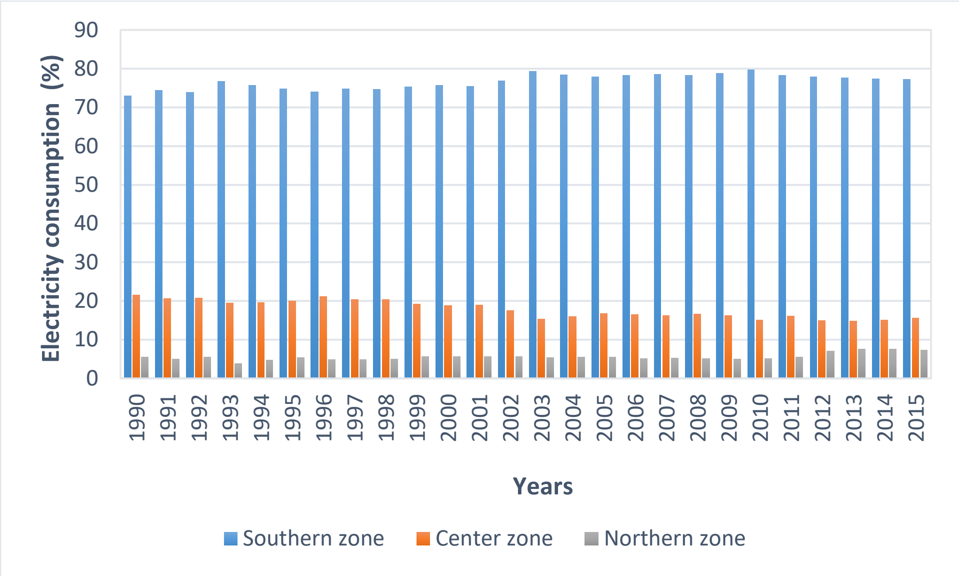

Figure: IV-5 Share of total electricity consumption in the different climatic zones of Côte d'Ivoire.

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IV-6 Monthly evolution of electricity consumption in the climate zone

The Monthly electricity consumption are been collected for each "direction regional" of the electricity company of Côte d'Ivoire (CIE) from 1990 to 2015, in the same electricity company and also from the same work of Kondi et al.,2016. The monthly evolution of electricity consumption in the southern, center and northern zones have been represented in the figure IV-6. The monthly electricity consumption in the southern and center zone have the same trend. In the both zones, the electricity consumption in each month differs from month to month. We have some months with low consumption and some others with a high electricity consumption. The consumption is low in the months of February, June, July, August and September compared to remaining months.

In the southern and center zones, the consumption reaches the first peak in March from where it decreases a little bit, and keeps it until September, and in October it restarts to increase until the last month December where it reaches a high consumption. In the mean seasonal cycle of the extreme temperature seen in the chapter III, we notice that, the electricity consumption have the same trend that of the temperatures. The consumption is high during the months where it is very hot. However, the high consumption of January and December can be also explained by the Christmas and New Year celebration during which population and industries consume more electricity.

In the southern zone, the consumption has an average value of around 264.71 GWh in March and 265.81 GWh in December during the period from 1990 to 2015.

In the Center zone, it has an average value of around 58.51 GWh in March during that same period. But compared to southern and center zone, the northern zone's electricity consumption is very low during all the year.

In the northern zone, the electricity consumption varies also from one month to another. In general, the electricity consumption in that zone, is high during the first months of the year (January, February, March, April, May) and the two last months (November, December). The lowest electricity consumption includes June, August, September and October. Here, the peak is still in March, with an average value 21.87 GWh and we have 21.51 GWh in December.

Electricity consumption is impacted by many parameters: economies, industries, demography, temperature and so on. All these parameters are more important in the southern zone than in the center and northern zones which is far more developed with many industries, infrastructures.

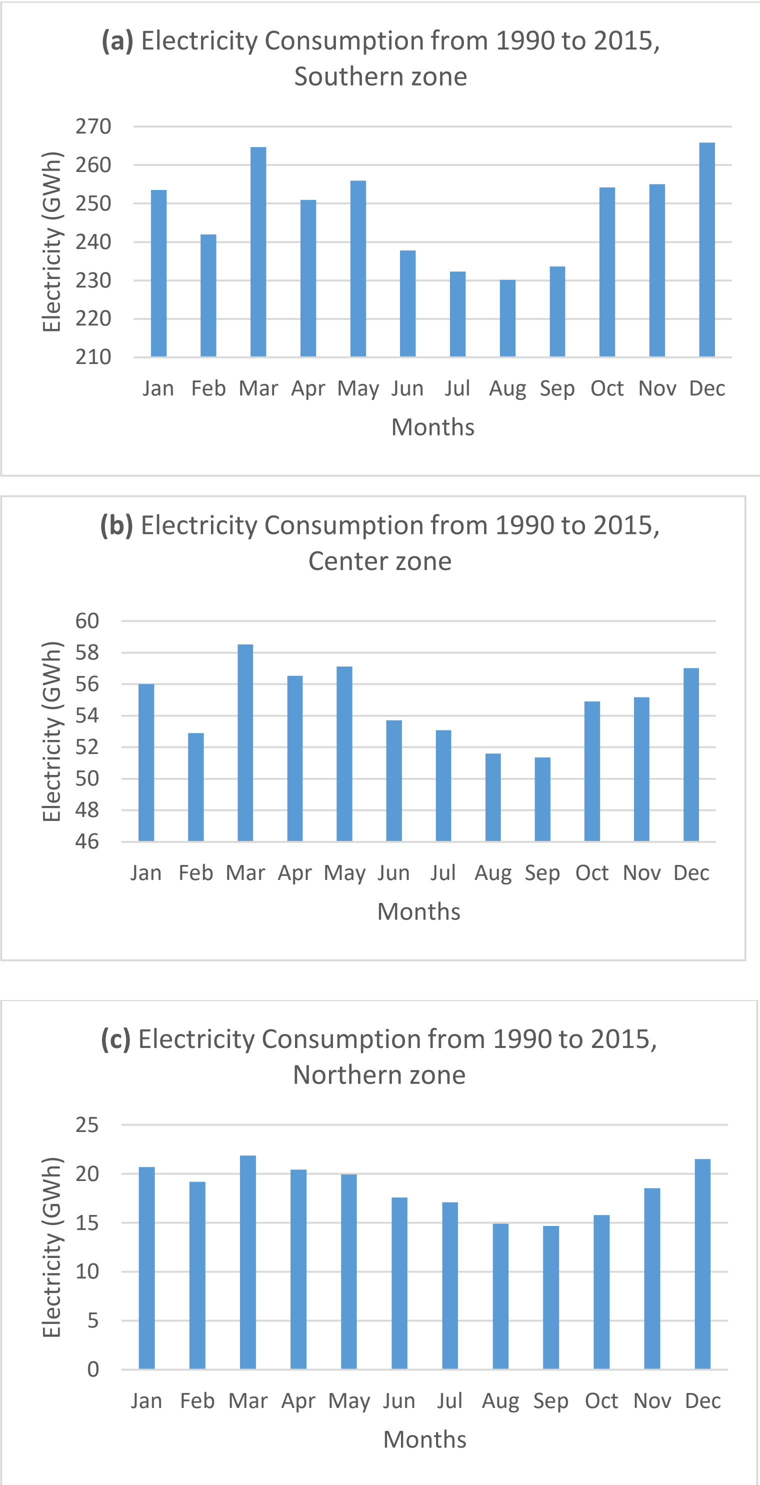


Figure IV-6: Monthly evolution of electricity consumption in southern (a), center zone (b) and northern zone (c).

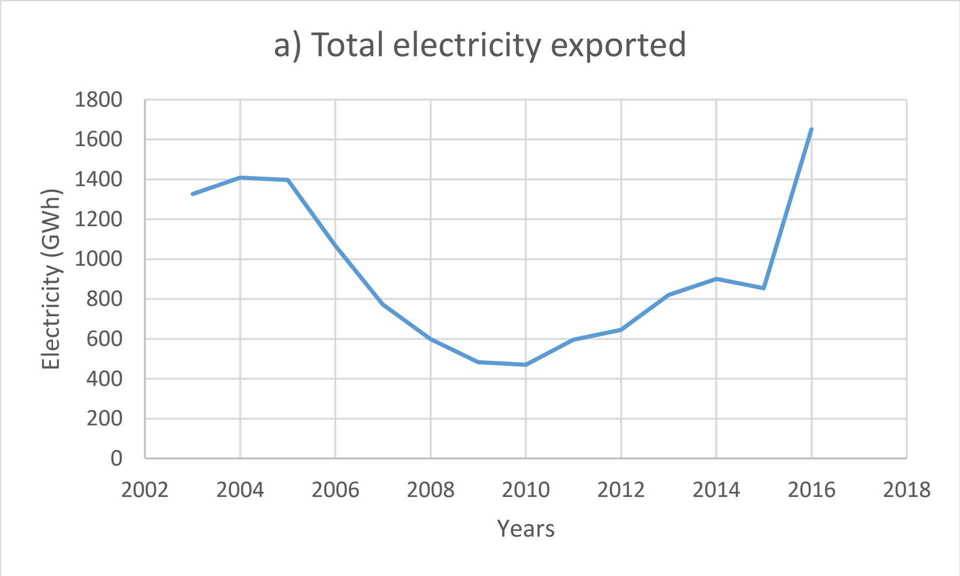
IV-7 Evolution of net electricity export

The electricity company of Côte d'Ivoire (CIE) which has in charge to supply the electricity in all the area of Côte d'Ivoire, export also electricity to Ghana, Benin- Togo, and Burkina Faso, Mali and Liberia. In this section, we will seek the evolution of the electricity net export from 2003 to 2016.

IV-7.1 Annual evolution of electricity net export

The figure IV-7 represents the net electricity exported (2003 to 2016) from Côte d'Ivoire to other neighboring countries (Ghana, Benin- Togo, and Burkina Faso, Mali and Liberia). This figure shows that, the electricity exported from Côte d'Ivoire to these countries varies from for the different years aforementioned. A sharp decrease of electricity exported was observed in figure IV-7 from 2005 to 2010.This reduction in exported electricity from Côte d'Ivoire could be attributed not only to improvement in the Ghanaian's electricity generation, as a result, this compelled reduction in the electricity imported from Côte d'Ivoire at this period, but also, other countries (Togo-Benin) were importing electricity from Ghana, this led to reduction of electricity imported from Côte d'Ivoire. Thereby, shifting focus away from the electricity company of Côte d'Ivoire.

While, since the years of 2010, Côte d'Ivoire, has increased its exports of electricity to its neighbors. In 2010, the total export electricity is 470.7 GWh and 1648.3 GWh in 2016. There is an increase of 1177.6 GWh of export electricity from 2010 to 2016. We, can justify this increase firstly by the increase in Côte d'Ivoire's electricity production and also the fact that Burkina Faso has increased its interconnection line which was before 2010, from Ferkessedougou (Côte d'Ivoire) to Bobo dioulasso , to now Ferkessedougou (Côte d'Ivoire) to Bobo dioulasso (bobo) to Ouagadougou (Capital city of Burkina Faso). Therefore, to meet its demand, Burkina Faso needs more electricity from Côte d'Ivoire. Moreover, Ghana and Mali have also increase in electricity import from Côte d'Ivoire during that period. According to Volta River Authority, Ghana have increased its electricity import from Côte d'Ivoire due to a supply deficit resulting from the power crisis in 2015 (extract from 54th Annual Report and Annual Accounts ,2015). The electricity exported from Côte d'Ivoire is expected to increase with the new interconnection from Côte d'Ivoire to Liberia, Guinea and Serria-Leone. One notices that the quantity of electricity export from Côte d'Ivoire to the different countries can be higher than the guaranty supply signed in the Agreements contract when his excess of electricity allow it.



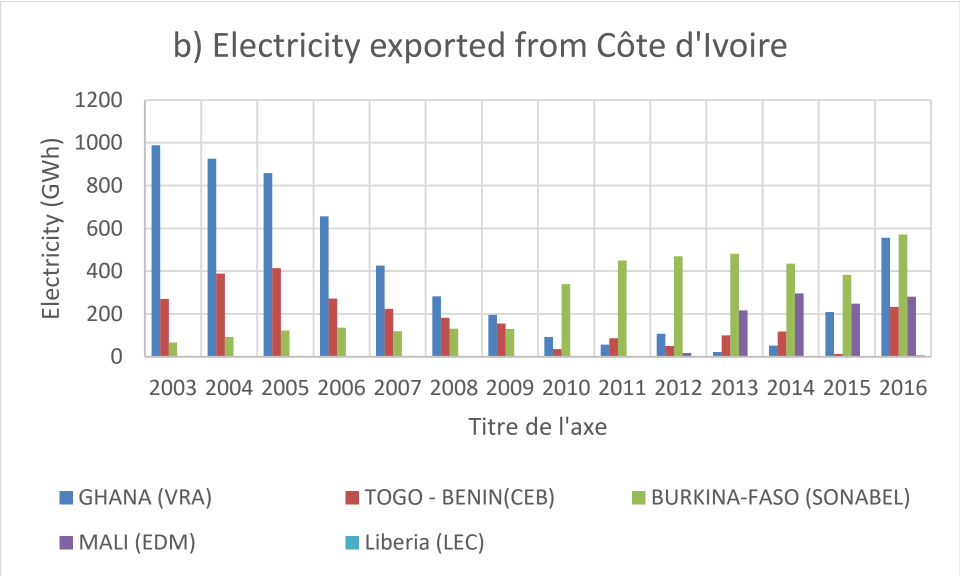


Figure IV-7: Annual evolution of total electricity export (a) from Côte d'Ivoire and electricity export from Côte d'Ivoire to each country: Ghana, Benin- Togo, and Burkina Faso and Mali (b).

IV-8 Conclusion

In this section, we can conclude that the electricity production has increased from 2003 to 2015, with an electricity production which reach 8607 GWh in 2015. Côte d'Ivoire supplies his local demand and also export his excess to the neighbors.

The electricity consumption in Côte d'Ivoire has increased from 1990 to 2015, we have 1531.99 GWh in 1990 against 7107.51GWh in 2015. Which give a difference of 4012.71GWh and corresponds to an annual average growth of 4.88% during that same period. The trend of electricity consumption follows an exponential trend. It is distributed differently in the climatic zone, while the southern zone consumes more than the center zone, and the center zone more than the northern zone. In 2015, the consumption is 78 %, 15 % and 7% in the southern, center and northern zone respectively.

For the monthly electricity consumption, the southern and the center zone follow the same trend, where the electricity in these both zones is more consumed in January, Mars, April, May and in October, November and December. While, in the northern zone, the consumption is more important from January to June and during the two last months of the year (October and December).

For the evolution of electricity exported from Côte d'Ivoire, we have an increase from 2010 to 2016, and it is expected to increase during the next year with the new interconnection from Côte d'Ivoire to Liberia, Guinea and Serria-Leone.

The variation of electricity consumption over the study period is affected by the population growth, and urban, economic and industrial development. However, it is very difficult to disconnect this variation from the weather effect.

CHAPTER V: RELATIONSHIP BETWEEN EXTREME TEMPERATURE AND ELECTRICITY CONSUMPTION

V-1 Introduction

In this section, we will determine the link between the extreme temperatures and the electricity consumption in each climatic zone. For all the zones, the electricity consumption includes the consumption from domestic, industries and so on.

V-2 Annual cross analysis between temperature and electricity consumption

V-2.1 Annual cross analysis between temperature and electricity consumption in the Southern zone

We put together the graphs of the annual evolution of both the extreme temperatures and the electricity consumption in the southern zone as indicated in the figure V-1. This will help to known the possible relationship between them. The data ranges from 1978 to 2016 for extreme temperatures and from 1990 to 2015 for electricity consumption.

This figure shows an increase in the trend of all the extreme temperatures (Tmax, Tmin and Tmean) and also in the annual electricity consumption in the southern zone.

In the temperature graphs, we have an increase of the minimum temperature, maximum and the mean temperature in the whole period. At the same time, we are a continuous increase in the electricity consumption.

From 1978 to 2016, we have around a 1.48ºC increase in the Tmax and around 0.95 ºC in the Tmean. This is a significant increase in terms of temperature and it can impact the electricity consumption. So, there may be a connection between the annual consumption and the extreme temperature in southern zone. A correlation between them will be seen later in order to have clear information about the link between them.

Figure V-1: Annual evolution of maximum temperature (Tmax), minimum temperature (Tmin).mean temperature (Tmean) and Annual evolution of electricity consumption in the southern zone.

V-2.2 Annual cross analysis between temperature and electricity consumption in the center zone

In the center zone, we put also together the graphs of the annual evolution of both the temperatures and the electricity consumption, the electricity consumption data ranges from 1990 to 2015 and temperature data range from 1973 to 2016 as represented in the figure *V-2*. This figure shows the same increasing trend for the extreme temperatures and the annual electricity consumption.

For the electricity consumption, we can see a rapid increase from 1990 to 2015 and that increase is seen in the extreme temperatures graphs. The consumption has an increase from 1990 to 2015, except in 2012 due to the political crisis.

In the temperature graphs, we have a continuous increase of the minimal, maximal and the mean temperature in the whole period.

According to electricity company of Côte d'Ivoire the evolution of the consumption depends on the number of customers and the economic development in this zone.

By analyzing these graphs, we can say that climate may also affect the electricity consumption in the center zone by the increase in the extreme temperature.

Even if there are other parameters affecting this electricity consumption in this zone, the temperature seems to have an effect on it. A correlation between them will be seen later in order to have clear information about the relationship between them.

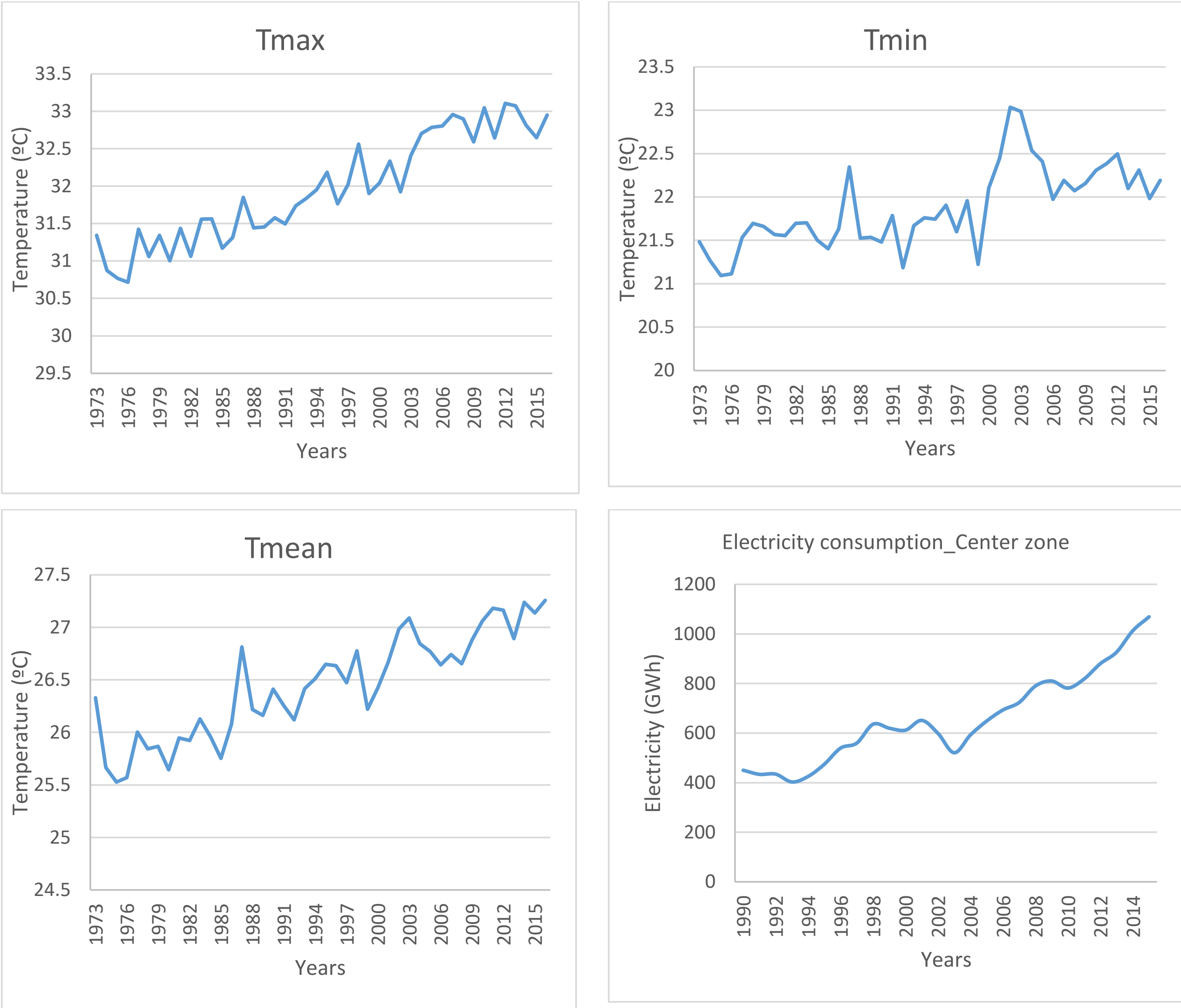


Figure V-2: Annual evolution of maximum temperature (Tmax), minimum temperature (Tmin).mean temperature (Tmean) and Annual evolution of electricity consumption in the center zone.

V-2.3 Annual cross analysis between temperature and electricity consumption in the northern zone

In northern zone also we did the same with the graphs, in order to see possible link between the temperatures and the electricity consumption. The data ranges from 1973 to 2016 for the temperatures and from 1990 to 2015 for the consumption. We notice that, the temperature data in the meteorological stations in that zone is not available from 2003 to 2014 from the temperature due to the political crisis.

A quick look at the graph in the Figure V-3, shows also the same increasing trend in temperature and electricity consumption in the northern zone from 1990 to 2002.

For the electricity consumption, we can see an increase from 1990 to 2002 and that increase is seen in the temperature graphs. In the period of 2003 to 2015, we may not really see the link between the temperature and the consumption, due to the lack of data in the temperature during this period .Therefore, it will be interesting to see later the correlation between them in order to have clear information about the impact of climate on electricity consumption.

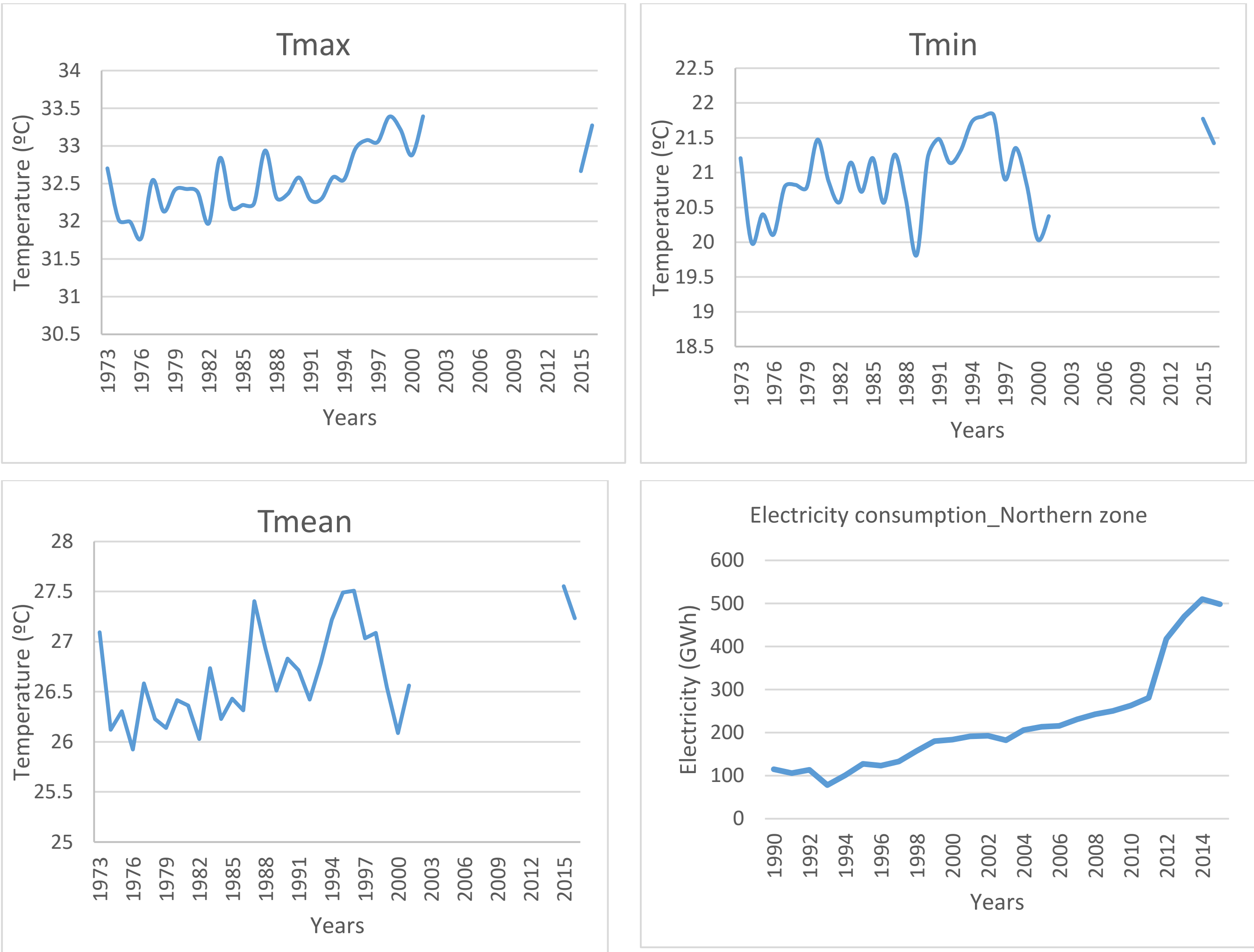


Figure V-3: Annual evolution of maximum temperature (Tmax), minimum temperature (Tmin).mean temperature (Tmean) and Annual evolution of electricity consumption in the northern zone.

V-3 Monthly cross analysis between temperature and electricity consumption

V-3.1 Monthly cross analysis between temperature and electricity consumption in the Southern part

Here, we have monthly variation in both variables, the electricity consumption and the temperatures (mean, minimum and maximum) in southern zone. One can notice that the temperatures and the consumption increase and decrease at the same time the years. The relationship between the both variables (extreme temperatures and consumption is clearly shows here.

In southern, the electricity consumption is low in June, July and September which correspond to the coldest months in that zone. It starts increasing in January to May and reaches his first peak in March which coincides with the first peak of the maximal, minimal and mean temperature. We have a decrease in June, July and September when we have the same decrease in the temperatures. From October to December, the electricity consumption restart to increase, when the temperatures also increase during that same months, and reach a second high consumption in December. One notice that the maximum temperature, minimum and mean temperature is high in February compared to January, so we expect to have a consumption greater in February than January and not the reverse. This is due, according to CIE, to the fact that the industries use more electricity to increase their productivity to satisfy their customers during the New Year celebration, the population also consumes more electricity during that festival.

So, even if there are other variables affecting the electricity consumption in the southern zone, it is clear that temperature has an impact on it.

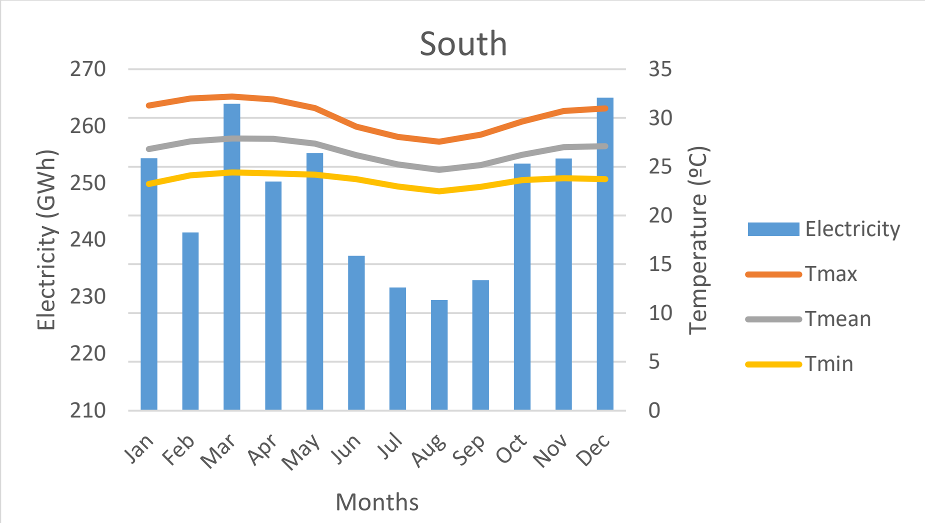


Figure V-4: Monthly evolution of maximum temperature (Tmax), minimum temperature (Tmin).mean temperature (Tmean) and Monthly evolution of electricity consumption in the southern zone.

V-3.2 Annual cross analysis between temperature and electricity consumption in the center part

In the monthly cross analysis, we have used the average monthly data from 1990 to 2015 for electricity consumption and average monthly temperature during that same period for the center zone. The figure V-5 represents the average monthly evolution of extreme temperature and electricity consumption in the center zone.

Here, we notice that the extreme temperatures particularly the maximum and mean temperature have the same variation with the consumption in the year. In fact the electricity consumption decreases and increases with the temperature at the same time in the year. It has also been noticed for the southern zone. We have also a clear relationship between the temperature and the electricity consumption. One can see the electricity consumption which increases during the hot months (January to May and in October to December) and decreases when it is cold (June, August and September).

During the months (October to December) which is less hot than the months from January to May, the consumption also is less than the hottest months

The consumption is high in the first months where the temperatures are very high from January to May. It decreases from June to September, where the temperatures (Tmean, and Tmax) are low. It restarts increasing from October until December where it is also high.

So, when the temperatures are low the consumption also is low and when they increase, the electricity consumption increases too.

Therefore, during the hottest months, we have a decreasing in the electricity consumption in February compared to January where the temperatures (Tmean and Tmax) is less great compared to February. We expect to have the reverse. This has also been observed in the southern zone and the same explanation has been given by company of electricity CIE. According to CIE, the industries use more electricity to increase their productivity to satisfy their customer during the New Year celebration, the population also consume more electricity during that festival. So even if there are others factors which can affect the trend of electricity consumption in the center zone, it has been show that Temperature (Tmean, Tmax) has a strong impact on the electricity consumption in that zone. We can see that there is a big link between them. It is also important to notice that there is not a clear link between the minimal temperature and the consumption in the center zone.

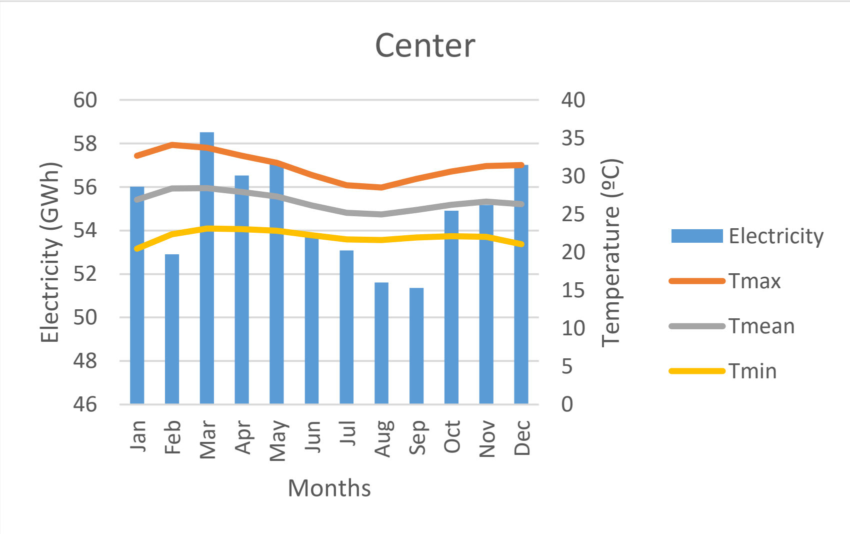


Figure V-5: Monthly evolution of maximum temperature (Tmax), minimum temperature (Tmin).mean temperature (Tmean) and Monthly evolution of electricity consumption in the center zone.

V-3.3 Monthly cross analysis between temperature and electricity consumption in the northern part

Here, due to the lack of temperature data from 2003 to 2014, we consider for this study, the average monthly the consumption and the temperatures (mean, minimal and maximal) data from 1990 to 2002 in the Northern zone. One can also notice that the temperatures (maximum and mean) and the electricity consumption increase and decrease at the same time in the years.

The relationship between the variables is showing here the same results as the ones we saw in center zone and southern zone.

In this climatic zone, the electricity consumption is high from January to June when it is hot. It starts decreasing from July to October when it is cold. It increases against from November and December when it is hot. The consumption reaches his peak in March which coincides with the peak of the maximum temperature and the mean temperature. So, it is clear that temperature has an impact on the electricity consumption in the Northern zone, even if there are other variables affecting it. As cited in the introduction, amongst the climate factors that may impacts the energy demand we have the temperature, the relative humidity, the solar radiation. So even if these other variables are affecting it, the temperature impact is clearly seen. As we saw with the center zone, the minimal temperature is not as well connected as the electricity consumption.

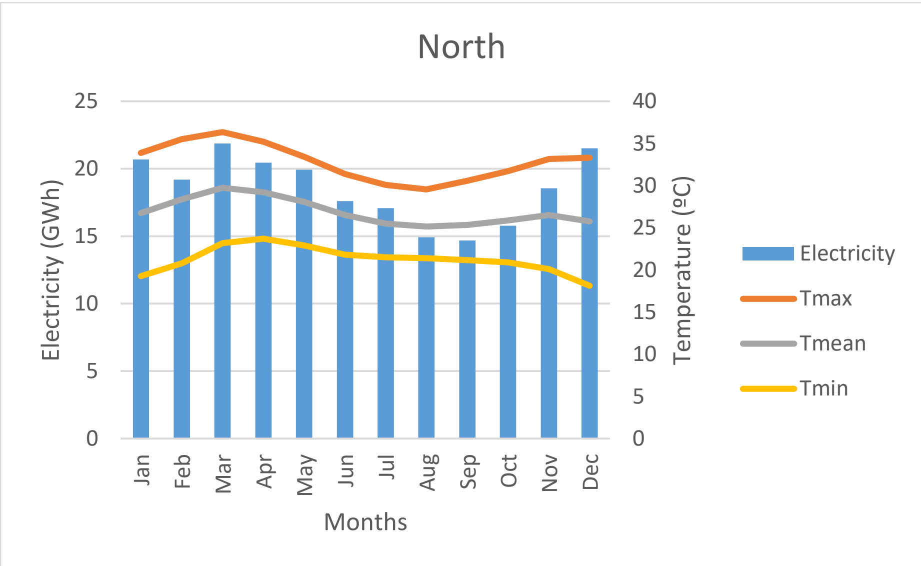


Figure V-6: Monthly evolution of maximum temperature (Tmax), minimum temperature (Tmin).mean temperature (Tmean) and Monthly evolution of electricity consumption in the northern zone.

V-4 Annual correlation between the temperatures and the electricity consumption

To evaluate the climate variable as temperature on the electricity consumption, we will seek the relationship between the extreme temperature (minimum, maximum and mean temperature) and the electricity consumption during the period from 1990 to 2015 for each climate zone by using the linear regression approach.

Method of the linear regression approach

Mathematically, the interdependence between air temperature and electricity demand using linear regression is given as: y = ax + b, where: y represents electricity demand, x denotes air temperature and a and b are the respective regression coefficients. The Pearson correlation coefficient is defined as r =$\frac{\sigma_{xy}{}^2}{\sigma_x \sigma_y}$

, where $\sigma_{xy}{}^2$ represents the covariance of the x and y time series, while σ_x and $\sigma_y$are the standard deviations of x and y, respectively. r-square (r2) is a coefficient used for evaluation of the representativeness of the regression model, which is based on analysis of the respective variance. It is defined as the ratio of the sum of squared deviations interpreted by regression and the total sum of squares of deviations. The coefficient ranges from 0 to 1 and the regression model is more representative if the indicator is closer to the upper value.

<u>Criteria</u>

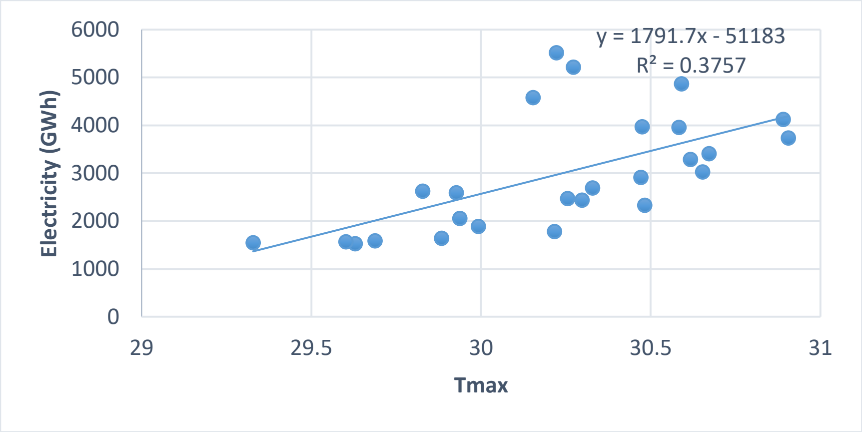
$0.3 < R^2 < 0.4$ represents a moderate linear correlation

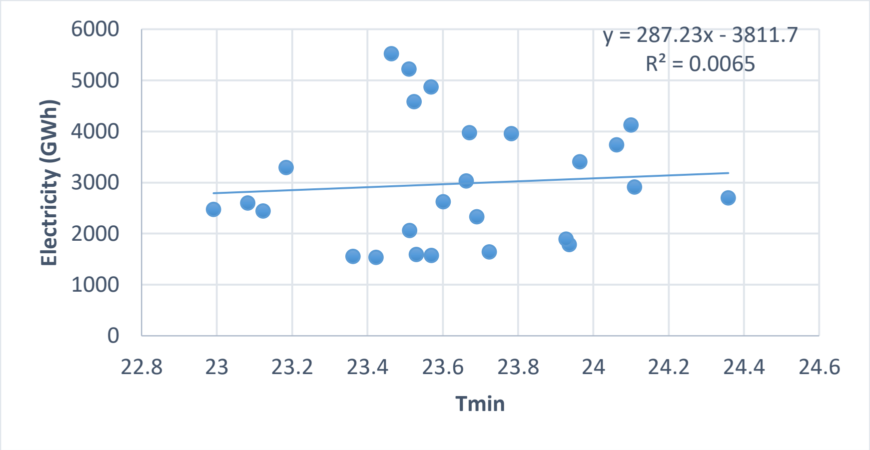
$R^2 \geq 0.41$ represents a strong linear correlation

V-4.1 Annual correlation between the temperatures and the electricity consumption in the southern zone from 1990 to 2015

In the figure below we have the correlation between the extreme temperatures and the electricity consumption in the southern zone. Here we have a clear picture of the dependency. The both variables, temperature and consumption are linked by the correlation coefficient (R^2). In the southern zone, the correlation coefficient between the electricity consumption and the maximum temperature is 0.38. This value are not statically negligible because greater than 0.3. So the weight of maximum temperature is very significant in the electricity consumption.

Therefore, the increase in the maximal temperature may increase the electricity consumption in the southern zone. The correlation coefficient between the consumption and the maximum temperature is higher than the ones of the mean and minimum temperature. This means that the consumption is more related to the maximal temperature than the others temperatures. So the maximum temperature is and remains a parameter impacting the most to electricity consumption in the southern zone.





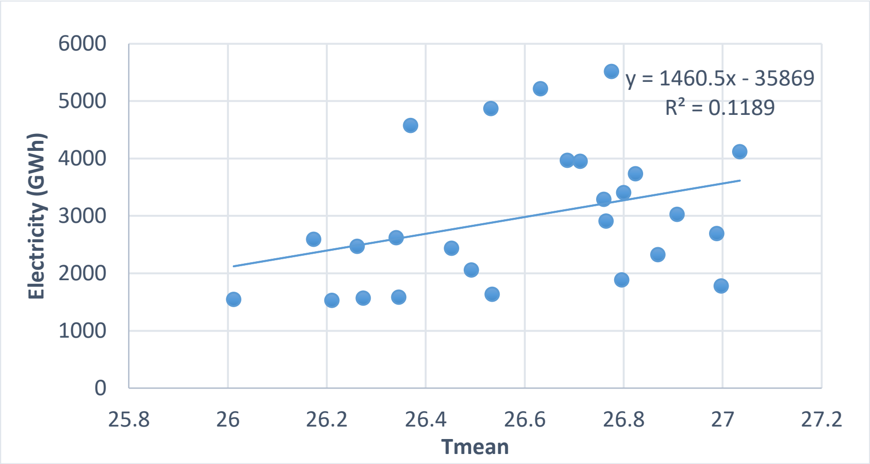
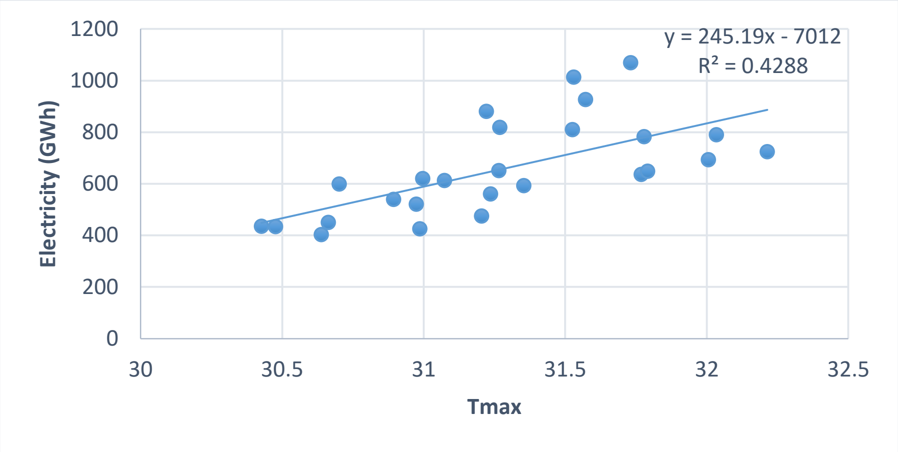


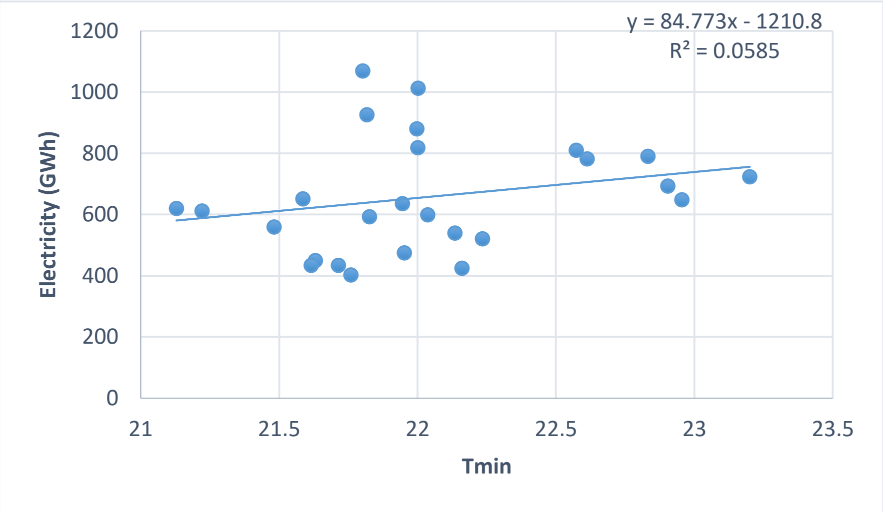
Figure V-7: Correlation between the annual extreme temperatures and the annual electricity consumption in the southern zone.

V-4.2 Annual correlation between the temperatures and the electricity consumption in the Center zone from 1990 to 2015

The figure below illustrates the linear regression between electricity consumption and the extreme temperatures in the center zone. Here, we have a positive correlation between electricity consumption and the extreme temperatures. The correlation coefficient between electricity consumption and maximal temperature is 0.43 and while with mean temperature, it is 0.24 and with minimum temperature it is 0.06. Thus, the relationship existing between consumption and maximal temperature is also significant as in the southern zone because the correlation coefficient existing between them is high than 0.3.

When maximum temperature increases, the consumption may also increase. We see here a clear dependence between the variables. So the maximal temperature is also a parameter which impacts the electricity consumption in the center zone.





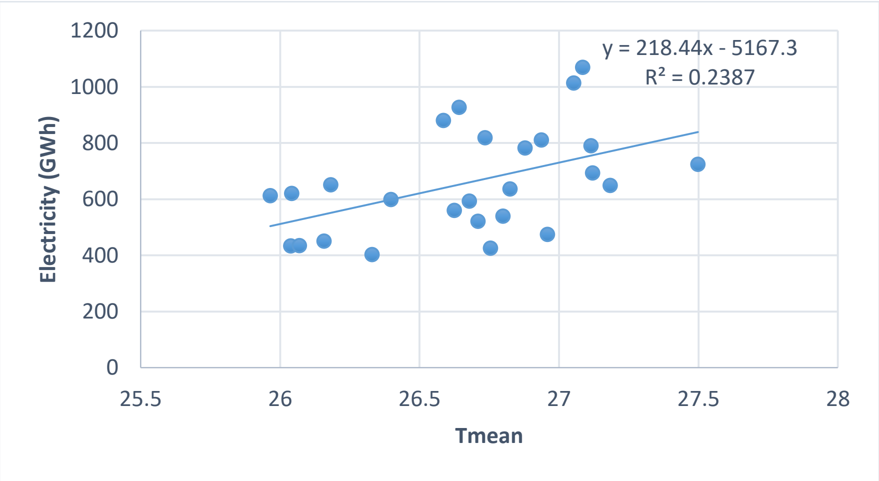


Figure V-8: Correlation between the annual extreme temperatures and the annual electricity consumption in the center zone.

V-4.3 Annual correlation between the temperatures and the electricity consumption in the northern zone from 1990-2002

The figure V-9 represents the correlation between the extreme temperature and the electricity consumption in the northern zone. Due to the lack of temperature data from 2003 to 2014 in the meteorological stations in that region, we have considered only the data from 1990 to 2002.

The correlation coefficient between maximum temperature and electricity consumption is 0.5. It is higher than 0.3 as for that of the others climatic zones. So the correlation between maximum temperature and electricity consumption in this zone is well defined. We can say that the maximum temperature affect the electricity consumption in that zone. Thus, the increase in maximum temperature is very linked to an increase in the electricity consumption. The maximum temperature is a parameter impacting the electricity consumption in this zone.

While, the correlation coefficient between consumption and the mean and the minimum temperatures is less than 0.3. That means that these temperatures are not really linked to the consumption.

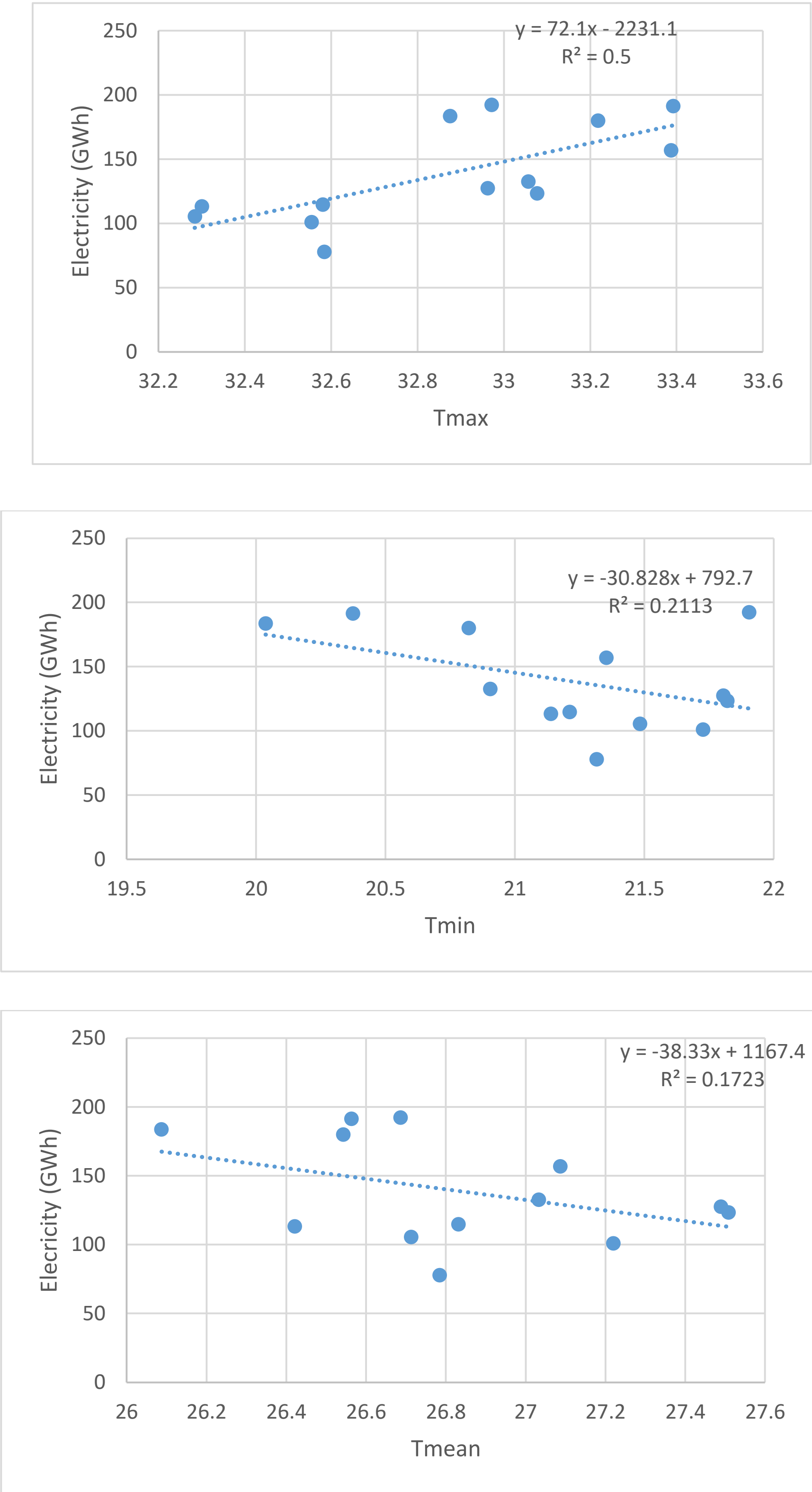


Figure V-9: Correlation between the annual extreme temperatures and the annual electricity consumption in the northern zone.

V-5 Conclusion

This section analyzes the relationship between the electricity consumption and the extreme temperature in different climatic zones of Côte d'Ivoire. It can be concluded that climate has an impact on the electricity consumption in the different climatic zone. The annual increase in the temperature is connected to the annual consumption in each zone. The temperature has an impact on the annual and monthly electricity consumption. . In all the climatic zone, the electricity consumption increases in the hot period (January to May and October to December) and decreases in the cold season (June to September). It can also conclude that a significant correlation exist between the electricity consumption and maximum temperature in each zone. But, the dependence differs from one zone to the other zone. The correlation coefficient between consumption and maximal temperature is 0.5 for the northern zone, 0.43 for the center zone and 0.38 for the southern zone. So, the maximum temperature is more linked to the electricity consumption in the northern zone compare to the center zone. And also, it is more linked to the electricity consumption in the center zone compare to the southern zone.

The remaining variables (minimum and mean temperature) analyzed in this section, showed a very weak correlation with electricity consumption.

CHAPTER VI: FUTURE ELECTRICITY CONSUMPTION

VI-1 Introduction

Electric energy plays a fundamental role in business operations all over the world. Our world runs because electricity makes industries, homes, and services work. Especially in Côte d'Ivoire where more than the half of the population have access to electricity. For example in the year 2015, around 80% of the population have access to electricity according to Côte d'Ivoire Energies (CI-Energies). Indeed, Côte d'Ivoire with a GDP growth rate of 8.75% in 2013 (World Bank) depend on the reliability of electricity in order to assure its socio-economic and technological development and to supply its exports market such as Burkina Faso, Mali, Togo, Benin, Liberia and Ghana with which it is linked by an interconnection line. The long-term electricity demand of Côte d'Ivoire is expected to grow rapidly in the next decades as consequence of many driving factors which impact the future demand such as high population growth rate, the on-going social changes, and the restructuring of Côte d'Ivoire economy together with the expected technological development particular in the industry and service sectors.

Motivated by these facts, the key to this section is to have accurate knowledge of future electricity demands. Hence, reliable electricity demand forecasting is needed in order to guarantee that electricity production can meet electricity demand in the future. In these sections, we will use MAED model for forecast the future electricity.

VI-2 Overview of MAED model

To analyze the future electricity demand for the country Côte d'Ivoire, the computer program Model for Analysis of Energy Demand (MAED) has been applied. The general approach of MAED relies upon the end-use methodology which was originally developed at the institute "Institut Economique et Juridique de l'Energie" (IEJE) of the University of Grenoble which is known as MEDEE-2.The International Atomic Energy Agency (IAEA) has developed the present MAED model. It is a scenario based planning tool, where each scenario can be considered a possible long term development pattern of a country. This Model take into account the evolution of the key drivers of energy demand like demography, socio-economy and technology (IAEA, 2006, 2009). For example the social need of the population such as the demand for lighting and air conditioning. The advantage of MAED model over the other models is that it allows for flexibility in switching between energy sources, thus reflecting structural changes in the economy over time.

Demand for energy (electricity) is disaggregated into end-use categories as a function of several variables such as Demography (urban/rural), population growth rate, and national priorities for the development of certain industries or economic sectors, energy forms, among others. The total demand for energy is combined into the following energy consumer sectors:

- ✓ Industry (Agriculture, Mining, Manufacture and construction)
- ✓ Household
- ✓ Service
- ✓ Transport

VI-3 Data and Methodology

VI-3.1 Data

The data used are the historical data affecting electricity demand, including demography (urban/rural) population, population growth rate, potential/active labour force, Total GDP , GDP structure by economy sectors, energy intensities for industry, and household usages (heating, cooling, kitchen, water heating).

VI-3.2 Methodology of the modelling of the future electricity consumption

The starting point of the model is the reconstruction of base year of electricity consumption patterns. This requires compilation, verification and reconciliation of necessary data in order to establish a base year balance. The base year balance present a current of energy in the country and it is used as the reference year for perceiving the evolution of the energy system in the future.
The next step is developing future scenarios, specific to a country's situation and objectives.

The scenario can be sub-divided into two sub-scenarios:

- ✓ One related to the socio-economic system describing the fundamental characteristics of the social and economic evolution of the country;
- ✓ The second related to the technological factors affecting the calculation of energy demand, such as the efficiency and market penetration potential of each alternative energy form.

The figure VI.1 shows the general structure of MAED's modelling procedure comprising the summary of the sequential calculation step:

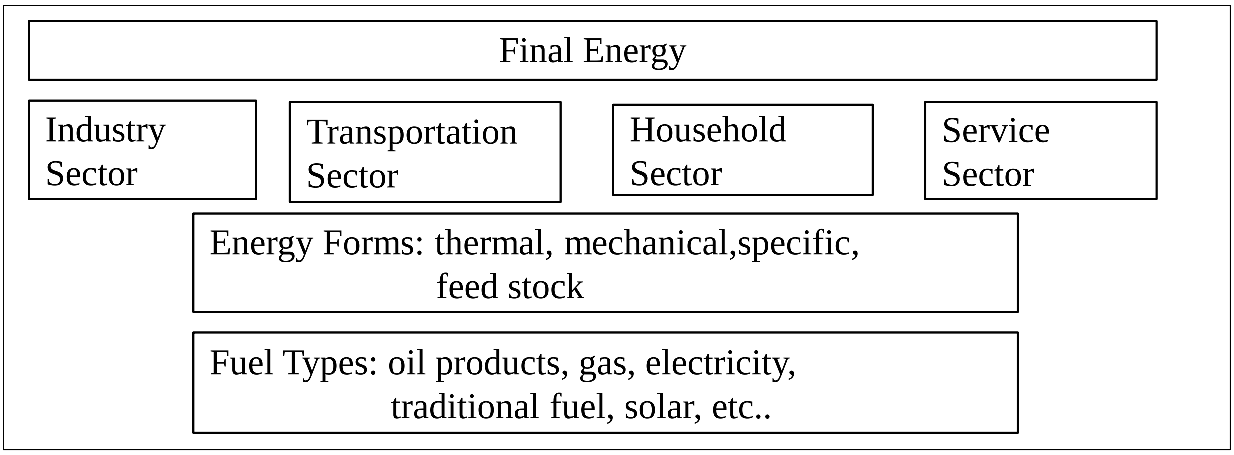
1-Breakdown of the total energy demand of the country or region into various consumption sectors of end-use in consistent manner by fuel type and energy form (see figure VI.1).

2-Identification of social, economic and technological driving factors influencing each category of final consumption and their relations to the final energy;

3-Reconstruction of the final energy consumption based on the statistical data available for the base year of the study (from 2013 to 2045)

4-Construction of consistent development scenarios with respect to the evolution of demographic, macroeconomic, socio-economic and technological factors influencing the energy demand;

5-Evaluation of the energy demand, corresponding to each scenario during the study period.



FigureVI-1: Breakdown of final energy by consumption sector and fuel type according to MAED approach.

VI-4 Mathematical Formulations

The pertinent mathematical function to future electricity needs in Côte d'Ivoire are presented in this section. The mathematical formulation have been extracted to (IAEA, 2006).

- **New population**

The determination of the new population refers to the population in one of the reference years. Firstly, data on the population in the base year is needed. This population is estimated through equation (1)

p(t)=p(t-dt)*(1+P.gr(t)/100)^(Y(t-dt)-Y(t)   (1)

p(t) is Population at time 't'

p(t-dt) is Population at previous time step

P.gr(t) is the Population growth rate in time dt

Y(t+dt) is the previous year

Y(t) is the year at time 't'

- **Electricity demand in Agriculture sector**

The total electricity demand in Agriculture sector is calculated based on the specific and thermal use of electricity in the agriculture sector. Equation (2) is the mathematical formulation of it.

ELAGR = ELSAGR + ELHAGR   (2)

With:

ELSAGR = $\sum_{I=1}^{NSAGR}(\mathbf{EI.ELS.AG(I)} * \text{YAG(I)}) * \mathbf{CF1}$ (Gwyr)

ELHAGR=$\sum_{I=1}^{\text{NSAGR}} \mathbf{EI.TU.AG(I)} * \text{YAG(I)}) * \text{CF1} * (\mathbf{ELPAGR}) / \mathbf{100})$

Where,

EI.ELS.AG(I) is the specific electricity consumption (for specific uses) per monetary unit of value added (energy intensity) of subsector I of Agriculture sector (Kwh/Monetary unit MU),

CF1=0.114155251 is a multiplication factor of the conversion from TWh to Gwyr

NSAGR is the number of subsectors in the agriculture sector.

YAG(I) is the GDP contribution of Agriculture sector, (10^9 MU).

EI.TU.AG(I) is Specific useful energy consumption for thermal uses per monetary unit of value added (energy intensity)

ELPAGR is Penetration of electricity into useful thermal energy for Agriculture (%)

- **Electricity demand in Industry (**ELIND)

The total electricity demand for the industry sector is the summation of agriculture, manufacture construction and mining electricity demand and its surrounding as shown in equation (3)

ELIND = ELAGR + ELCON + ELMIN + ELMAN (3)

Where

ELAGR is Total electricity demand in Agriculture sector

ELCON is Total electricity demand for Construction sector

ELMIN is Total electricity demand for Mining sector

ELMAN: Final electricity demand in manufacturing sector

- **Electricity demand for space heating in urban households**

Household's electricity is used for various activities (heating the space, heating water, power the air conditioning equipment and also appliance and lighting, cooking). The total electricity demand use in the urban households is calculation by the equation (4)

$$EL.UH.SH=[\sum_{I=1}^{NUDT}(PO * (PURB / 100) / CAPUH) * (UDWSH / 100) * \{(UDW/100) * UDWS \ (UAREAH / 100) * UK(I)\} * UDD * 24 / 1000000] [(ELP.UH.SH / 100) * (1 - (HPP.UH.SH / 100) * (1 - 1 / HPE.UH.SH))] \quad (4)$$

Where,

PURB: Share of urban population

CAPUH: Average household size in urban areas (persons/ household)

UDW: Fraction of urban dwellings

UDWSH: Fraction of urban dwellings in areas where space heating is required

UDWS: Average size of urban dwellings (sqm/dw)

UAREAH: Fraction of floor area that is actually heated in urban areas, by dwelling

UK: Specific heat loss rate by urban dwelling type (Wh / sqm / degree Celcius / hour)

UDD: Degree–days for urban dwellings

ELP.UH.HW: Penetration of electricity into water heating (HW) in urban households (UH)

HPP.UH.HW: Penetration of heating pumps into water heating (HW) in urban households (UH)

HPE.UH.HW: Coefficient of performance (COP) of (electric) heat pumps for water heating (HW) in urban households (UH)

- **Electricity demand for space heating in households**

Household is made of rural and urban part. Thus, the calculation of electricity needed for heating the space is the summation of electricity demand for space heating in urban and rural households

EL.HH.SH = EL.UH.SH + EL.RH.SH

EL.UH.SH is electricity demand for space heating in urban households

EL.RH.SH is electricity demand for space heating in rural households

- **Electricity demand for specific uses (appliances and lighting)in electrified urban dwellings (ELAPUH)**

The total electricity demand for the specific uses in electrified urban dwelling is presented by the mathematical formulation (5)

$$ELAPUH = PO * (PURB / 100) / CAPUH * (ELPU / 100) * ELAPUDW * (CF1 / 1000) \quad (5)$$

Where,

CAPUH: Average household size in urban areas (persons/ household)

ELPU: Electricity penetration for appliances in urban households

ELAPUDW: Specific electricity consumption (final energy) per urban dwelling for electric appliances (other end-uses than space and water heating, cooking and air conditioning), kWh/dw/yr

- **Electricity demand for specific uses (appliances and lighting) in households**

It is determined by the equation (6) below

ELAPHH = ELAPUH + ELAPRH

Where,

ELAPUH is electricity demand for appliances and lighting in urban

ELAPRH is electricity demand for appliances and lighting in rural households

- **Total electricity demand in Household**

The total electricity demand in household is the summation of Electricity demand for space heating in Household (EL.HH.SH), Electricity demand for water heating in Household (EL.HH.HW), Electricity demand for cooking in Household (EL.HH.CK), Electricity demand for air conditioning in Household (EL.HH.AC) and Electricity demand for specific uses (appliances and lighting) (ELAPHH)

ELHH = EL.HH.SH + EL.HHHW + EL.HH.CK + EL.HH.AC + ELAPHH (7)

- **Electricity demand for specific uses in Service sector**

$\text{ELSSER} = \sum_{I=1}^{\text{NSSER}} (\text{EI.ELS.SE(I)} * \text{YSE(I)}) * \text{CF1}$ (8)

Where,

EI.ELS.SE(I) = Energy intensity of electricity specific uses in subsector I of Service sector (final energy), kWh/MU

YSE(I) = GDP contribution, subsector I of Service sector, (10^9 MU)

- **Electricity demand in Service sector(**ELSER)

ELSER = ELSSER + EL.SER.TU + EL.SER.AC (9)

Where,

ELSSER is electricity demand for specific uses in Service sector

EL.SER.TU is electricity demand for Space heating and other thermal uses in Service sector

EL.SER.AC is electricity demand for air conditioning in Service sector

- **Total electricity demand**

The total electricity demand for a country (ELEC) is equal to the sum of all the electricity consumer by the economies sector (Industry (ELIND), transport (TELTR), household (ELHH) and service (ELSER). Giving by the equation (10). For the countries of West- Africa, electricity is not yet consume for transport sector. So we assume the TELTR =equal to zero,

ELEC = ELIND + TELTR + ELHH + ELSER equation (10)

VI-5 Drivers of electricity demand

Generally, the important factors influencing electricity consumption are GDP growth rates and their structural changes, population growth and its distribution in the country (urban and rural), changes in life style, population mobility growth, and market penetration of competing energy forms.

VI-6 Modelling Scenario

In modelling the Côte d'Ivoire's future electricity demand, four scenarios were proposed and used as follows:

Reference Scenario : 9% GDP Growth

High Growth Scenario : 10% GDP Growth

Low Growth Scenario : 7 % GDP Growth

Optimistic Scenario I : 11% GDP Growth

VI-6.1 Reference Scenario

The reference economic growth scenario is developed to assume a normal economic growth rate since the post electoral crisis 2011. The reference economic growth scenario has been assumed to follow trends of the past from 2011 to 2016 and no changes in country's policies will be made that affects those trends. This scenario is developed to accommodate a moderate population growth rate, GDP growth rate of 9 %.

VI-6.2 Low economy scenario (LS)

Low economy scenario is developed to assume a slower economic growth rate, with low GDP at a growth rate of 7% for the entire study period. As consequence of low level of internal and foreign investment due to unstable political situation in the region, and unexpected climatic, political and economic crisis. In life style the scenario assumed no improvement in household size. The improvement in the energy efficiency is low and the influence of conservation measure is less effective.

VI-6.3 High Economic scenario (HS)

The high economic scenario is characterized by high economic growth rate. It is presumed from an optimistic perspective based on the assumption that the country's economy will grow at a higher constant GDP growth rate of 10 % for the entire study period from 2013 to 2045. The main driving force to this growth rate is the increase in private and public investments. The country will be more industrialize. Energy efficient will be promote.

VI-6.4 Optimistic scenario (OS)

The optimistic scenario is characterized by a GDP growth rate of 11%. It is based on the strong development of all the economic sector, specially the industrial sector and manufacture sector with the creation of modern companies.

VI-7 Base Year Reconstruction

The selection of a base year for the study was from among the recent past years to represent the economic and energy background of the country. The year 2013 was chosen as the base year to present the economic and energy background of Côte d'Ivoire and the years 2020, 2025, 2030, 2035, 2040 and 2045 as the reference years. Main reason of the choice of 2013 as base year, is the economy stable and the availability of the data. Furthermore the year 2013 is well-matched with Côte d'Ivoire Vision 2020 which is to be the development pole of West Africa. The main data used are presented as follow:

Table VI-1 presents the share of GDP formation for each economic sector in the base year 2013 constant price of 2010. In 2013, the GDP is 28681616270 US$ at constant price of 2010

(World Bank) and the share of GDP at 2010 price for service sector was 17.7% of which transport sector constituted 15% of the service sector. Agriculture and fishing constituted 29.2% whereas construction was 7.5%, Mine and oil was 4.6%, manufacture was 13% and energy 13% (Mouisi, 2015).

Table IV-2 includes the main data on demography and life style. The total population in 1998 was about 15 366 672 million and it was estimated at 22.102 million in 2013 (World Bank) of which, we assume about 49.5% were in urban areas. The average household size was 5.4 and the population growth rate was 2.54%.The national electricity consumption was 6267,5 Gwh and 645.2 Gwh was exported to Ghana (VRA), Togo-Benin (CEB), Burkina-Faso(SONABEL),Liberia (LEC) and Mali (EDM). The potential labour force was estimated to be about 62.5% of total population.

Table VI-1: GDP formation in the base year 2013 at the constant price of 2010

Sector	Agriculture	Construction	Mining	Manufacture	Service	Energy
Share (%)	29.20	7.50	4.60	13.00	32.70	13.00

TableVI-2: Basic data on demography and life style of the base year 2013 (INS, Enquete Emploi 2013)

Parameter	Unit	Amount
Total population	Million	22.106
Population in urban areas	Million	10.942 (estimate by World Bank)
Potential labour force	Million	13.816250
Actual labour force	Million	7.281164
Labour force in service sector	Million	1.922227
Total number of dwellings	Million	4.094
Average household size	Pers/dwel	5.4

VI-8 Results and discussion

Modelling results for four scenarios formulated to represent possible developments trends in electricity consumption of Côte d'Ivoire based on social, economic and technological development are presented in the following sub-sections.

Analysis of electricity demand projection

Figure VI.2 presents the evolution of electricity demand of Côte d'Ivoire from 2013 to 2045 for the various scenario. The electricity demand under low growth rate, High growth rate, optimistic and reference scenarios are projected to increase. Electricity demand for reference scenario will increase to 112978.9 GWh in 2045 which is equivalent to average annual increase of 9.45 % against 6267.4 GWh in the base year 2013 (TableVI-3). The low growth rate, High growth rate and optimistic scenario will observe an increase in electricity demand of 77755.1Gwh and 176554.3 GWh and 295542.7 GWh respectively in 2045 which is equivalent to an increase of 8.18% and 10.99% and 12.79 % from base year value (TableVI-4). These electricity demand growth follow exponential trend with the trend line equation representing the growth for reference given as equation 1 whereas the corresponding trend line for Low, High and optimistic scenario are given by equations 2; 3 and 4 respectively.

(LS) ED = 4670.5e0.4042FY………………. (1)

(RS) ED = 4138.4e0.4711FY………….….. (2)

(HS) ED = 3815e0.5545FY……….……….. (3)

(OS) ED = 3582.6e0.6227FY……………… (4)

Where ED and FY denote electricity demand and future year forecast respectively.

The evolution of absolute amounts of electricity consumption differs considerable for the four scenarios.

For the reference scenario, the evolution of electricity demand will have a moderate evolution due to a medium economic growth and an improvement of the situation of the different sectors of economic activities.

For the high economic scenario, the evolution of electricity demand will undergo a significant evolution, which could be explained by the overall development of all sectors. This will be particularly the industrial sector with the creation of modern production companies, prospects for diversified mining and good economic growth.

The evolution of electricity demand in the case of the low scenario, will evolve slowly over the period 2013-2045.This trend will be characterized the weak development of the industrial sector.

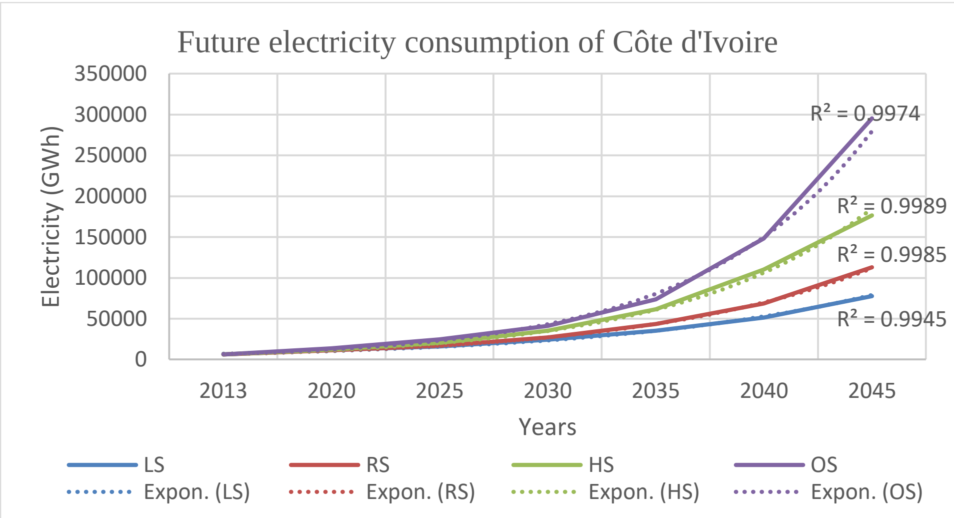


Figure VI-2: Projection electricity consumption of Côte d'Ivoire between 2013 and 2045.

TableVI-3: Electricity Demand Projections per Scenario, GWh

Years	Low Growth (7%) (GWh)	Reference (9%) (GWh)	High Growth (10%) (GWh)	Optimistic (11%) (GWh)
2013	6267.459	6267.459	6267.459	6267.459
2020	11589.45	11462.83	12202.75	13633.21
2025	16002.55	17043.86	20232.69	24630.96
2030	24466.93	27010.52	35207.35	41355.22
2035	35144.78	43385.9	61486.65	73896.64
2040	51346.31	68715.15	110121.3	148439.9
2045	77755.11	112978.9	176554.3	295542.7

Table VI-4: Growth rate of electricity consumption between the periods 2013 to 2045

Average electricity consumption growth rate (%)				Base year (GWh)	2045 (GWh)			
Low Growth (7%)	Reference (8.5%)	High Growth (10%)	Optimistic (11%)	Base year	Low Growth (7%)	Reference (9%)	High Growth (10%)	Optimistic (11%)
8.18	9.45	10.99	12.79	6267.45	77755.1	112978.9	176554.	295542.7

VI-9 Conclusion

One of the difficulties encountered during this work is that of access to reliable data. Nevertheless, the collected data make it possible to have an updated situation of the electricity demand.

It has been shown from the modelling results that electricity demand of Côte d'Ivoire is increasing exponentially for each scenario without change in the future climate (trend of temperature). The electricity growth rate will be 8.18% for low economic scenario, 9.45% for reference scenario and 10.99% and12.79% for high and optimistic scenario during the period

2013 to 2045. According to the result find to the chapter V, this future electricity consumption will increase if the trend of the future climate increase.

The parameter of climate (Temperature, precipitation) are not clearly appeared in the input of the MAED model. So, for evaluate the influence of the extreme temperature on the future electricity consumption, we can search the relationship between the extreme temperatures and the electricity consumption for the period of forecasting, here from 2012 to 2045.

VII-CONCLUSION AND PERSPERTIVES

This chapter presents the conclusion, and perspectives, of the current study and areas for further study based on the results presented in the different chapters. The aim of this work is to investigate the impact of temperature on electricity consumption in the different climate zone of Côte d'Ivoire. This study has been conducted by using the daily temperature data (minimum, maximum and mean temperature) from the Global Summary of the Day Dataset published by the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) and the national Meteorology stations of Côte d'Ivoire (SODEXAM) for the period from 1978 to 2016; the data of monthly electricity consumption data from 1990 to 2015 has been also used, it is recorded from the electricity company Côte d'Ivoire (CIE) and extract from the work of Kondi et al.,2016.

This study has shown a significant increase in trend of the maximum, minimum and mean temperature in the southern, center and northern zone of Côte d'Ivoire, leading the area to become warm. The increase in the maximum and mean temperature is more intense in the center zone compare to the others climate zone.

One have distinguished two main season in the temperature during the years:

- ✓ The hot season start from January to May and from October to December. The hottest period is from January to May.
- ✓ The cold season from June to September witch coincide with the period of rain season in the northern zone, and it also coincide with the period of Upwelling in the Gulf of Guinea in the center and southern zone.

This work has also revealed an increase in the electricity consumption and production in Côte d'Ivoire. Since 1994, Côte d'Ivoire is net export electricity to Ghana, Mali, Burkina Faso, Togo, and Benin and recently to Liberia. The excess of electricity is share between these countries depending on the agreement signed between them and Côte d'Ivoire.

The electricity consumption is unequally distributed on the Côte d'Ivoire region. The electricity consume in the southern zone is greater than that consume in the center zone. And the consumption in the center is also greater than the northern zone. In 2015, the percentage of the total electricity consumption is 78 %, 15 % and 7% in the southern, center and northern zone respectively.

One can also conclude that the annual increase in the temperature is connected to the annual consumption in each zone. The temperature has an impact on the annual and monthly electricity consumption. The consumption of electricity is connected to the temperature in the three areas.

The electricity consumption is higher in hot months compared to the cold months.
The correlation coefficient between electricity consumption and maximum temperature is 0.5 for the northern zone, 0.43 for the center zone and 0.38 for the southern zone. So, the maximum temperature is more linked to the consumption in the northern zone compare to the center zone. And also, it is more linked to the consumption in the center zone compare to the southern zone. While, the variables of minimum and mean temperature present a weak correlation with electricity consumption.

The use of MAED model has helped to estimate the future electricity demand following four scenarios: low, reference, high and optimistic scenarios, with 7%, 9%, 10% and 11% of GDP growth rate respectively. It shows an exponentially increase in electricity consumption for each scenario. The electricity growth rate will be 8.18% for low economic scenario, 9.45% for reference scenario and 10.99% and 12.79% for high and optimistic scenario during the period 2013 to 2045.This future consumption will be affected by the future temperature as we are shown in the chapter five.

So to address the issue of climate change particularly the increase in air temperature and also ensure the reliability of electricity supply to its local customers and export market for the coming years, the decision Maker or government of Côte d'Ivoire must firstly reduce the greenhouse emission that cause an increase in Earth atmosphere's temperature either by encouraging the agroforestry, reafforestation and by investing more in renewable energy for electricity production such solar energy, bio energy and small hydropower. Secondly, by expending the current electricity generation capacity, rehabilitate the old hydropower or build a new electricity production infrastructures.

The results given in this study need to be reinforced with other studies:
1-The determination of the future electricity consumption in the different climate zones, by taking in to account the possible change in the future temperature.
2- The introduction of other accurate climate parameter such as humidity data can be useful to understand the impact of climate on the electricity consumption.
3-The climate parameters (temperature, humidity, heat wave) must be taken into account for the projection of future the electricity consumption.

4-This work must be extended to other countries of the West Africa since the energy demand is mutually shared by these countries through electricity interconnection.

5- The extension of the field of this work can help to better understand the impact of climate change on the electricity system by looking at the possible impact of some climatic parameter such as (precipitation, temperature, heat wave), drought, and flood, on the electricity production (Hydropower plant; efficiency of the thermal plant) and also the interconnection line and the price of electricity.

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