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RESEARCH ARTICLE

A study of climate change and energy consumption in Madagascar island

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Abstract: Climate change effect can be either positive or negative on the human. Its impact on the energy consumption of a country for space heating and cooling purposes depends on the current and future regional climate, the required thermal comfort inside buildings, and the technical building features such as thermal insulation quality and occupants' habits. The aim of this research is to study the variation of the air temperature in several regions of Madagascar and then to simulate the impact of climate change on the need for energy consumption in household cooling and heating systems using degree-day index. The results showed that the temperature changes more rapidly in the rainy season than in the dry season. The energy demand for cooling is constantly growing in all the regions of Madagascar. Besides, an average around of 526 degree-day is expected in several regions of island by 2050. In the same year, air temperature is estimated to reach up to 2°C.

Keywords: climate change, energy consumption, residential, statistical study, Madagascar

1 Introduction

Energy is the foremost requirement of all nations for development. A good energy policy can therefore facilitate the rapid development of a country[1]. Today, the transition between renewable and fossil energy is extremely slow, despite several state summits summoned for this purpose[1]. Several companies and automobiles depend completely on oil and its derivatives for their operations[2]. Renewable sources of energy can be considered as the main energy source for the future, with all countries of the world investing in this area[3]. Several research works have proved that more than 2.3 billion people rely on wood or charcoal for cooking and heating purposes[1]. Given the importance of agriculture for developing countries, particularly with regard to food security, reducing the exposure of farmers to risks related to price volatility and increased climate variability is a major challenge, mostly in terms of development aid and international cooperation[4–6].

Some countries in Africa as Madagascar island do not have any sophisticated policy for energy production and consumption[7,8]. Today, the consequences of climate change are one of the main problems of the world[9]. Although the earth's climate keeps changing as a result of human activities, it is changing much faster now than it had done in the past thousand years. The impacts of climate change are now more visible[10].

In most countries in Africa, the temperature has risen, following the global trend, and the pattern of rainfall has changed appreciably. Delfani *et al.* reported that the surface temperature of Earth has risen by approximately 1.4-5.8°C[11].

According to Mike Shanahan *et al.*, international negotiations on climate change are unjust, as some countries use considerably more power than others, which is a subject of moral argument[12]. Globally, changes in the temperature and precipitation are not uniform. For example, the tropical and subtropical regions now experience humidification and reduced rainfall. Major studies conducted across the world are hugely concerned with global warming[13–19]. Concerning climate change and energy consumption, Invidiata and Ghisi, with A2 scenario, studied the impact of climate change on thermal comfort conditions and on heating and cooling energy demand in dwellings in three cities in Brazil[20]. They found that there will be an increase in the annual energy demand ranging from 19%-65% among the three cities in 2020. A comparison was made between a simple model based on articial neural network (ANN) and a model that is based on physical principles (EnergyPlus), to estimate energy consumption by Hernandez and Sanzovo[21]. It was found that both models are suitable for energy consumption forecast. Wang and Chenn[22] studied geographical dependency of the impact of climate

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change on future energy uses in United States. The results showed that it will have a big increase in source energy consumption by 2080. Radhi[23] showed that global warming is likely to increase the energy used for cooling buildings by 23.5% if the city of Al−Ain warms by 5.9°C. Dynamic computer simulation modeling was used to investigate energy requirements for space heating and cooling of residential buildings in Sweden by Dodoo *et al*.[24] The results showed that in the residential buildings, further space heating demand is reduced and cooling demand is increased. Asimakopoulos *et al*. found that energy demand for cooling could increase by as much as 248% until 2100[25]. Berger *et al.* carried out a dynamic thermal simulation of nine sample office buildings in Vienna and Austria from future climate scenarios. The results showed that cooling requirements generally rise signicantly[26]. Wan *et al.* showed that in China, increase in cooling energy use was 18.5% in Harbin, 20.4% in Beijing, 11.4% in Shanghai, 24.2% in Kunming and 14.1% in Hong Kong[27]. The impact of climate change on the heating and cooling energy requirements of residential houses in ve regional climates in Australia, varying from cold to hot and humid, was estimated by Wang *et al.*[28]. They conclude that energy demand should be from 48% to 350% by 2100.

In such as situation, vulnerable countries like Madagascar and Cameroon have a limited role compared to industrialized countries to contain climate change. Madagascar's climate is highly varied, largely due to its geographical position in the Indian Ocean, its wide range of altitudes, and the difference in the microclimates[7]. In Madagascar island , more than 75% of the population lives in rural areas. Agriculture contributes about 28.3% to the GDP of the country and employs about 70% of the active labor force[29]. Madagascar has expansive potential for agricultural and animal and fish husbandry, which is beneficial against the threat of climate change. Gradually, CDDs increase in all the regions in Madagascar and HDDs continue to decrease. The energy source is either natural resources such as biomass, forest, crop residues, water, sun, and wind or petroleum products.

The choice of Madagascar as the place for this study was not made randomly. Madagascar, according to WMO, is considered as the third-ranking country in the world that is most vulnerable to climate change. Many global risks of climate change are concentrated in urban areas[30]. Madagascar has severe problems with soil erosion and deforestation, which reduce soil fertility and productivity, increasing the vulnerability of agriculture and fishing-based livelihoods. Madagascar, despite the efforts made up to now, remains one of those countries in the world that is most vulnerable to climate change.

In this research, we studied the variation of outdoor climates in several cities of Madagascar. In addition, we assessed the demand for heating and cooling energy in buildings in the past, present and future.

2 Materials and Methods

Some of the results discussed in this paper have been drawn from two previous studies[1,2]. In fact, this work is a continuation of the study of climate change in Madagascar. The most recent data has been used for data interpretation.

2.1 Study area

Located between 20°00S and 47°00E, Madagascar lies almost entirely within the tropical region. It is an island in the Indian Ocean, covering an area of 592.000 km^2. It is the fourth largest island in the world, and it is separated from Africa by the Mozambique Channel by about 400 km. A mountainous spine of 1200-1500 m runs through the island from the north to the south along its length. This geographic situation, the landform, the maritime influence, and wind conditions aid in causing extremely varied climatic conditions encountered on the island. There are basically two seasons in Madagascar: dry, from May to October, and rainy, from November to April. Two short seasons of approximately 1-month duration separate these two seasons. From May to October, the climate is conditioned by an anticyclone to the Indian Ocean level that directs a wind regime of trade winds in southeastern Madagascar. During this season, the eastern part of the island experiences a humid climate "in the wind", while the western part undergoes a drought-like climate termed "down wind". In this section, we discuss dry season or cool season (or winter) depending on the altitude of the region. During the summer or the warm seasons, the anticyclone of the Indian Ocean weakens and the trade wind regime becomes less regular, although the eastern part of Madagascar always remains under this influence. During this season, unstable storm-like conditions develop almost daily in all the regions. The intertropical Convergence Zone (ITCZ) extends its influence intermittently on Madagascar. The southwest coast experiences rainfall of 350 mm to nearly 4000 mm. Some climatic characteristics of different regions are listed in Table 1 and Table 2.

2.2 Climatic data

In accordance with another study, daily outdoor data of the past 44 years (1961-2005) for temperature (minimum and maximum), precipitation, and sunshine was obtained from 16 meteorological stations[8]. The vari-

Table 1. The geographical coordinates of the zones studied in MAGICC

Region	City	Latitude	Longitude	Altitude (m)
1	Antsiranana	12°28S	49°28E	50
2	Mahajunga	15°43S	46°19E	22
3	Morondava	20°17S	44°19E	8
4	Toliara	23°21S	43°40E	11
5	Taolagnaro	27°10S	47°01E	129
6	Mahanoro	19°54S	48°48	3
7	Toamasina	18°09S	49°24E	6
8	Sainte-Marie	14°47N	60°59O	767
9	Sambava	14°10S	50°06E	10
10	Maevatana	13°52S	48°70E	70
11	Antananarivo	18°54S	47°31E	1276
12	Antsirabe	19°51S	47°02E	1500
13	Fianarantsoa	21°27S	47°05E	1115
14	Vohemar	13°22S	50°00E	10
15	Ambohitsilaoza	17°41S	48°27E	-
16	Farafangana	12°34S	49°17E	1200

Table 2. Some characteristics of study regions

Region	Area (km^2)	Population (2014)	Climate
1	43406	260000	Transition tropical
2	150023	2463185	Transition tropical
3	46121	70000	Humid tropical
4	16140	161405	Hot and semi-arid
5	878	46000	Humid tropical
6	3968	238467	Humid tropical
7	71911	3807075	Humid tropical
8	200	74948	Altitude tropical
9	4780	339250	Humid tropical
10	-	236500	Humid tropical
11	58283	5932607	Altitude tropical
12	16599	250245	Altitude tropical
13	103272	4586775	Altitude tropical
14	8269	255080	Transition tropical
15	15	118194	Semi-arid tropical
16	5360	587041	Altitude tropical

ous data were measured from 3 to 10 min height from the ground, with a frequency of 10-15 min. Figure 1 illustrates the distribution of different stations used for studying the climate trends.

Tadross *et al.* reported that[7], in Madagascar, the annual average temperature was 14-27.5°C. On the coast, the temperature changed with the latitude and ranged from 27°C in the north and 23°C in the south. The west coast is warmer than the eastern coast by 1-3°C. On the plateaus, the average annual temperature is 14-22°C. The average temperature reaches its minimum in July across the country, while the maximum is encountered in January and February at most regions, except in a few places of the highlands and the northwest region where the maximum temperature was noted in November. The average

Figure 1. Weather stations of the studied cities

air temperatures and the average precipitation for these regions are given in Figure 2 and Figure 3. According to these figures, in Madagascar, warming began in the southern part in 1950 and then spread to the North by 1970. In 2000, the warming level of the southern part of Madagascar was more noticeable than that of the north. The dry sequences lie in the central highlands and the eastern coast. In the highlands, this is due to the decline in the rainy season. The changes in precipitation in Madagascar vary from one region to that in another. Rainfall has become more intense in the western region. Over the past 100 years, the level of rainfall in Madagascar has seen large variability. In the southern part, rainfall increases with temperature. In the northern part, precipitation increases with decreasing temperature. The annual precipitation quantity decreases from the east to the west, with a maximum of 3700 mm/year and from the north to the south, with a minimum of 350 mm/year, while the seasonal increases in the same directions. From the west to the south, the dry season becomes longer and more and more pronounced[7,8].

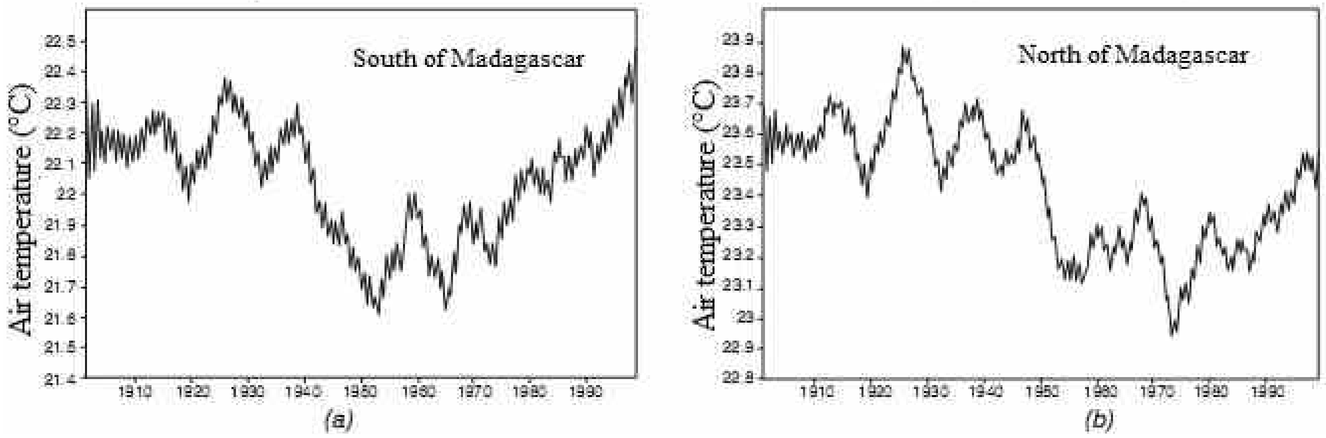

Figure 2. The average outdoor air temperature between 1901 and 2000 a) in the South of Madagascar (43-51°E, 27-20°S) and b) in the North of Madagascar (43-51°E, 20-11°S)[7]

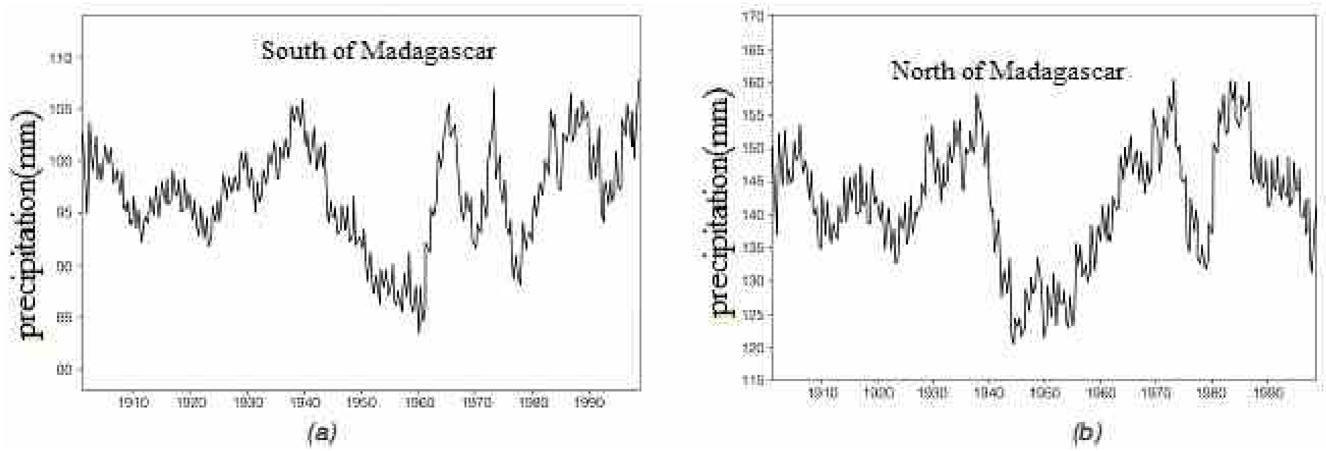

Figure 3. The average monthly precipitation between 1901 and 2000 in a) the South (4351°E, 2720°S) and b) North (4351°E, 2011°S) of Madagascar[7]

2.3 Climate change models

Several types of models and different scenarios can be used to simulate the variation on the air temperature and precipitation rate. Table 3 illustrates some examples of the GCM models. Like in a previous study, in this research, 13 GCM models (BCM2,CGMR,CNCM) were firstly used, and three scenarios A2, A1B and B1 were considered.

The hourly outdoor data relating to air temperature, wind speed, relative humidity, radiation, and atmospheric pressure recorded over the last 30 years were used as inputs by software to enable the forecasting.

It is important to know that the RCM models were associated to Representative Concentration Pathway (RCP) scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5). According to the latest IPCC report, the lowest RCP was RCP 2.6 (also referred as RCP3-PD), which peaks at 3 Wm-2 and then declines to approximately 2.6 Wm-2 by 2100. The medium-low RCP4.5 and the medium-high RCP 6.0 aim for stabilization at 4.5 and 6.0 Wm-2 respectively around 2100, while the highest one, RCP 8.5, implies a radiative forcing of 8.5 Wm-2 by 2100.

Nematchoua *et al.*, in one of recent research, showed the evolution of the radiative balance of the earth over the period 1850-2250. Globally, RCP8.5 is the highest, A2 and A1B scenarios are more significant than the new scenarios(RCP 4.5 and RCP 6.0), while the RCP 2.6 is the lowest[32]. This previous research describes the strong action of the new scenarios(RCPs), but also highlights the importance of scenarios A2, A1B, B1). In the Literature, several researches showed the discrepancies between the results of RCMs and GCMs[33–35]. Meanwhile, the simulated increase of seasonal temperature seems to be relatively similar when comparing GCMs and RCM, although large differences (more than 1°C) exist locally.

Other differences are also found for extreme-event re-

Table 3. General circulation models of the atmosphere used in SCENGEN[31]

Founder country of the model	Specialized name of SCENGEN
Norway	BCCRBCM2
USA	CCSM-30
Canada	CCCMA-31
France	CNRM-CM3
Australia	CSIRO-30
Germany	MPIECH-5
China	ECHO-G
USA	FGOALS1G
USA	GFDLCM21
USA	GISS-EH
USA	GISS-ER
Russia	INMCM-30
Japan	MIROC-HI
Japan	MRI-232A
Japan	MIROCMED
USA	NCARPCM1
UK	UKHADCM3
UK	HADGEM

lated quantities. Indeed, the most significant input of these models is the rate of emission of greenhouse gases in the future eras. However, a precise final determination is not possible.

Finally, for limiting this study, alone the A2 scenario was adopted for forecasting.

The A2 family of scenarios is characterised by a world of independently operating, self-reliant nations, continuously increasing population[10].

Accordingly, different emission scenarios involving a variety of gases have been considered for the future. On the other hand, to define the effect of global warming by means of the rise in global temperature, it was necessary to employ the LARS-WG model. LARS-WG is one of the most well-known meteorological stochastic data-generating models used for quantifying the generation of rainfall, solar radiation, and daily maximum and minimum temperatures in both the present and future climates of a meteorological station[36, 37].

The first version of this model was invented as a tool for statistical exponential micro scaling in Budapest in 1990[36]. In a LARS-WG model, complex statistical distributions are used for model making of meteorological variables, and Fourier's series estimates the temperature. Daily maximum and minimum temperatures are simulated as stochastic processes with daily standard deviations and mean, depending on the dry or wet conditions of the relevant day[38]. In this assessment, Madagascar's temperature data in the time intervals of 1901-2000 were selected as the basic data, and the temperature changes for the years 1961-2005 were studied based on the proposed scenario such that the proper model accords with the experimental data of temperature in the proposed years. After testing the best model with Pearson correlation coefficient, the changes in the temperature of 16 regions of Madagascar were predicted in the worldwide heating bed for a 100-year period (2000-2100). Based upon these changes, the degree-day (DD) index values were calculated and compared with those in the past and present.

2.4 Model validation

Chi-square test was applied for comparing the simulation and the observed data, by taking as reference the year 2000. The test was carried out with the SPSS software. It allows to compare two groups (or two measures) and to easily take the best possible decision. Nowadays, this kind of test knew lot of success[39–41]. All the analysis were carried out with a 95% confidence level (CL), considering a level of significance equal to 5%. The range of significance can be freely selected; indeed, it is a quantitative estimate (called the p-value) of probability, and the observed differences are random. As highlighted, the test is significant for $p < 0.05$ (5%). In this research, for all cases applied to each city, p-value was higher than 0.05. It shows the convergence between simulation and observed data. Basing on these results, the model was adopted for forecasting outdoor climate of these cities.

2.5 Calculation of HDDs and CDDs

DD methods are simple, yet efficient and fairly reliable for quantifying the heating and cooling energy demands in a building. Estimations are accurate when the internal temperature, thermal gains, and building properties are relatively constant. The severity of a climate can be characterized concisely in terms of DDs. The space 18-24°C was adopted for this survey.

In order to estimate the amount of cooling needed in an N-day definite period, Equation 1 was used.

$$CDD = \sum (T - \theta_2) \quad \theta_2 = 24 \qquad (1)$$

In Equation 1, the CDD is the required amount of cooling and T is the daily mean temperature. The temperature threshold θ_2 considered for Madagascar is 24°C.

In order to calculate the need of θ_2 to heating, Equation 2 must be employed.

$$HDD = \sum (\theta_1 - T) \quad \theta_1 = 18 \qquad (2)$$

In this equation, HDD is the need for heating on the basis of DD and T and $\theta 1$ have the same concept as in the previous equation. The temperature threshold θ_2 considered for Madagascar is 24°C.

The HDDs and CDDs can be dened in accordance with the SIA Standard (1982) (McCarthy *et al.*, 2001, ASHRAE, 2009) as Equation 3 and Equation 5:

$$HDD\ (\theta_i,\ \theta_{th}\ )\ =\ \sum(\ \theta_i\ \ -T\ ) \tag{3}$$

Where, θ_i is the internal temperature, $\theta_{e,k}$ the daily mean external temperature, θ_{th} the threshold temperature for heating, and k is the day-number in the year.

In this sense, the annual heating demand of a building Qh may be written as Equation 4:

$$Q_h\ =\ K_{tot}\ HDD -\ \ \eta Q_s \tag{4}$$

Where, K_{tot} is the total thermal losses due to transmission and inltrations, Q_s is the internal heat sources and solar gains, and η is an efficiency to factor in the share of Q_s that serves to reduce the heating demand.

In Equation 5, $_2$ is the threshold temperature for cooling:

$$CDD\ =\ \sum(T - \theta_2\ ) \tag{5}$$

Finally, it is interesting to note that, if the building properties are assumed to be constant, the cooling energy demand is proportional to the number of CDDs.

3 Results and Discussions

3.1 Variation of outdoor environment

3.1.1 The case of great North

Figure 4 shows the temperature variation in the three regions of northern Madagascar from 1970 to 2100. Linear curve was adopted, function of seasonal change of temperature regarding every region. Before adopting Equation 6, Equation 7, Equation 8 and Equation 9, a statistical t-test was carried out for comparing simulation and observed results. Indeed, a t-test can be used to determine if two sets of data are signicantly different from each other, by following a statistical t-distribution[42,43]. When the test is applied for the comparison of the observed and simulated results, it allows confirmation whether both provide similar results or not and if there is a big difference. All the statistical analyses were carried out by means of IBM SPSS 24.0 Statistical software. In this study, a 95% of confidence level (CL) was considered (level of significance equal to 5%), which is one of the most common used for the t-test application. The interval of significance can be freely selected; it is a quantitative estimate (called the p-value) of the probability that the observed differences are random. The results showed that the P value was higher than 0.05, therefore the error is negligible, and these equations can be implemented.

The different regions can be divided between transition tropical climate (Antsiranana city) and humid climate tropical (Vohemar and Sambava). The original temperature increment from the year 1970 represents the year when the temperature began to grow in this zone for most cities. It was found that, after simulation in this region, precipitation increased while the temperature decreased. The minimum and maximum temperatures did not always remain constant. The minimum and maximum annual temperature of the north of Madagascar is estimated to increase by 0.4-3.7°C and -0.6-2.4°C, respectively, between 1901 and 1970. These conclusions confirm some results provided on the last IPCC rapport[30]. Indeed, at the current trends, it's expected an average air temperature over the period 2081-2100 will be 0.3- 4.8°C higher than that over 1986-2005.

3.1.2 The Case of variation in the annual minimum temperature

In the north of Madagascar, from the year 1970 onward, the minimum annual air temperature has increased according to the geographic regions associated with their type of climate. In the transition tropical region (Antsiranana), the minimum temperature increased by 0.004°C every year, while in the wet tropics (Sambava and Vohemar), the annual minimum temperature increased from 0.037°C and 0.021°C, respectively. In 2050, the annual minimum temperature will increase to 0.34°C in the transition tropical climate (Antsiranana) and 2.96°C and 1.68°C in the humid tropical climate (Sambava and Vohemar). Unless some actions are taken to fight against global warming, an increase of 0.46, 4.07, and 2.31°C is expected in Antsiranana, Sambava, and Vohemar, respectively, in the year 2080 (Figure 4b, 4d and 4f). The minimum temperature is now rising faster in the rainy season than in the dry season.

3.1.3 Case of variation in the annual mean air temperature

In 1975, for the relative humidity of 61.489.5%, the annual mean temperature in Antsiranana, Sambava, and Vohemar was 25.861, 23.336, and 24.008°C, respectively. These temperatures will be 26.644, 24.112, and 25.083°C, respectively, in 2025. Then onward, the temperatures are expected to increase to 27.424°C in the transition tropical region and to 24.886°C and 26.158°C in the tropical humid regions Sambava and Vohemar, respectively, by 2075. This variation can mainly be attributed to human activities and industrial pollution[7].

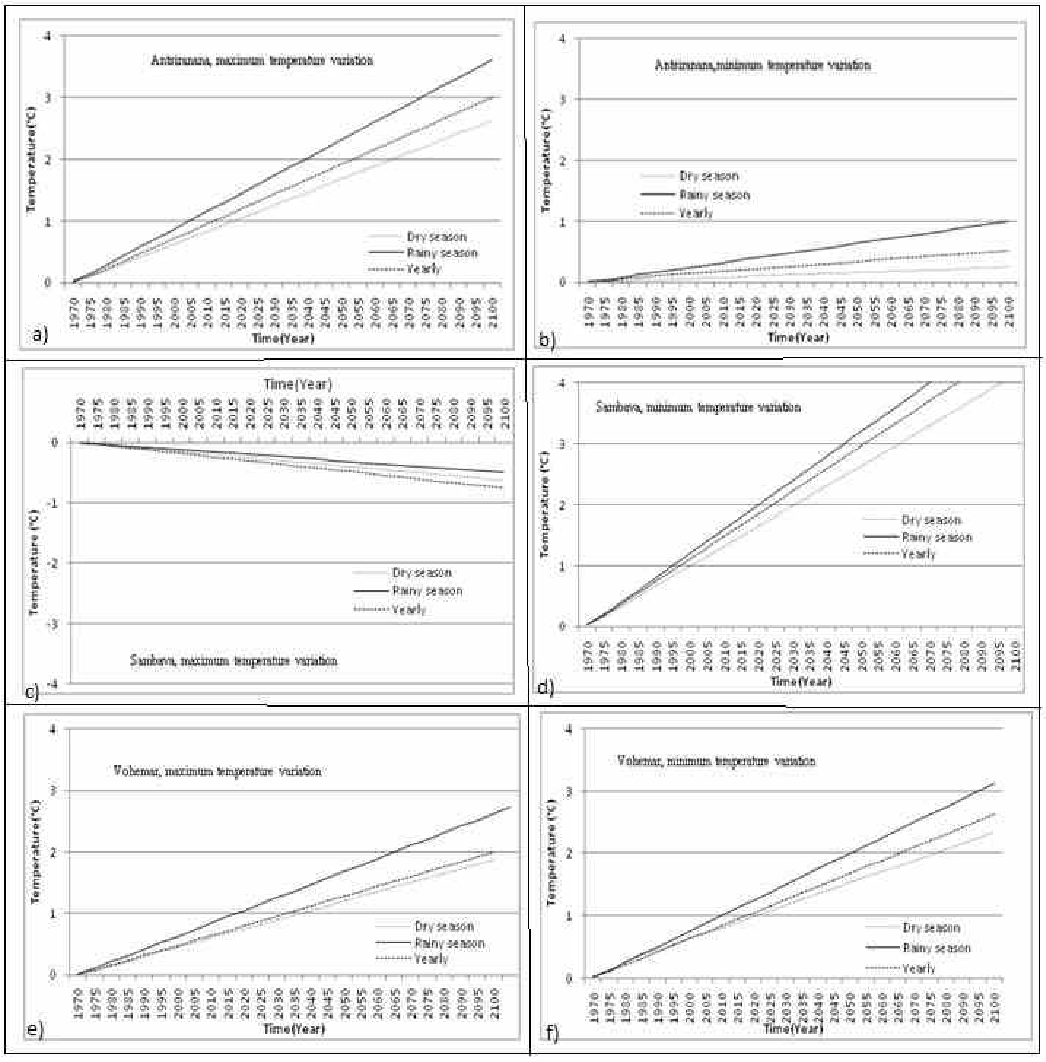

Figure 4. Yearly temperature increment in North of Madagascar

3.1.4 Case of variation in the annual maximum temperature

In the transition tropical region (Antsiranana city), the maximum temperature increase of 0.024°C every year, while in the wet tropics (Sambava and Vohemar, cities), the annual maximum temperature decreased by 0.006°C in Sambavacity and increased by 0016°C in Vohemar city. In 2050, the maximum temperature is expected to increase by 1.68°C in the dry season and by 2.32°C in the rainy season, with a yearly change of 1.92°C. In the next 25 years (by 2025), the maximum temperature will increase by 1.155, 1.595, and 1.321°C in the dry season, rainy season, and annually, respectively. On the other hand, a further 25 years later (by 2075), the said temperatures will increase by up to 2.205, 3.045, and 2.52°C in the dry season, rainy season, and annually in the transition tropical climate (Antsiranana city) (Figure 4a). In 2050, in the humid tropical region in Sambava city, the maximum temperature will decrease by 0.4, 0.32, and 0.48°C in the dry season, rainy season, and annually, respectively. In 2025, in the same city, the decrease would be up to 0.275°C (dry season), 0.22°C (rainy season), and 0.33°C (annually). After 50 years since 2025, the maximum temperature will decrease by up to 0.525, 0.42, and 0.63°C in the dry season, rainy season, and annually, respectively (Figure 4c). On the other hand, in Vohemar city , in the year 2050, the maximum temperature will increase by up to 1.2, 1.68, and 1.28°C in the dry season, rainy season, and annually, respectively. In the year 2075, the maximum temperature is expected to increase to 1.575, 2.205, and 1.68°C in the dry season, rainy season, and annually (Figure 4e). The maximum temperature is now rising faster in the rainy season than in the dry season in the Great North of Madagascar, except in the humid tropical climate (Sambava), where the maximum temperature tends to decrease faster in the dry season than in the rainy season. Vulnerabilities of climate change varied according to geographic position. Nematchoua *et al.*, in a study carried out in Cameroon, found rather that the maximum temperature tends to increase faster in the dry season than in the rainy season[41]. It's important to note that the consequences of this calamity are visible and vary from one country to another.

The following equations were established after analysis of the evolution of different temperatures in Antsiranana. These equations can be established for every region in this zone as in a recent research published by Nematchoua *et al.*:[4]

$$\Delta t_{max} = 0.024 \cdot \tau \quad (6)$$

$$\Delta t_{min} = 0.004 \cdot \tau \quad (7)$$

where, t_{max} and t_{min} are the maximum and minimum annual temperature increment (°C), respectively, and τ is the time (years). The different temperature variations of the cities examined in this region are shown in Table 4. An analysis of the data in this table showed that the minimum temperature is rising faster than the maximum temperature, but this variation is smaller compared to that in the South and the East of Madagascar.

These results are not surprising. Indeed, the strong increase of air temperature is observed in several African cities. Annual temperature is predicted by Atmosphere Ocean General Circulation Models (AOGCMs) to increase by as much as 2.4°C in northern Africa, from +1.7 to +1.9°C in central Africa, and from +1.4 to +2.5°C in southern Africa by around 2050[44].

3.1.5 Case of the Great South

The following equations were established after analysis of the evolution of different temperatures in Fianarantsoa city.

$$Deltat_{max} = 0.027 \cdot \tau \quad (8)$$

$$Deltat_{min} = 0.033 \cdot \tau \quad (9)$$

These equations can be established for each city located in this region regarding the variation of air temperature.

Figure 5 shows the temperature variation in the three regions located to the south of Madagascar from 1950 to 2100.

These different regions are divided between the altitude tropical climate (Fianarantsoa city), hot and semi-arid tropical climate (Toliara city), and the hot and humid tropical climate (Taolagnaro city). The temperature increment origin is considered to be the year 1950, which represents the year when the temperature began to grow in this region for most cities. The precipitation rate has also softened the climate, as simulation studies revealed that precipitation increases with temperature in this region. The minimum and maximum temperatures showed a similar trend. Furthermore, the maximum temperature was changing faster than the minimum temperature, except in Fianarantsoa city. In the south of Madagascar, after a decade, the minimum annual temperature is expected to increase by 2.6-3.3°C, and the maximum annual temperature is expected to increase by 2.74.0°C as compared to that in the 19012000-period. These variations can be due to the various human anthropogenic activities in this region[45].

3.1.6 Case of variation in the annual maximum temperature

The maximum annual temperature increased by 0.040; 0.033; and 0.027°C in the semi-arid tropical climate (Toliara), hot and humid tropical climate (Taolagnara), and altitude tropical climate, respectively (Figure 5a 5c 5e). In the year 2025 (that is 75 years from 1950), unless some actions are taken to combat climate change, a temperature increase by 2.925, 3.075 and 3°C is expected in the dry season, rainy season, annually, respectively, in comparison to that in the 1901-1950 period. In Fianarantsoa city, during the same year (2025), the maximum temperature is expected to increase by 2.175, 2.10, and 2.025°C in the dry season, rainy season, and annually, respectively. In Taolagnara, in 2025, the increase could reach 2.7, 2.625 and 2.475°C in the dry season, rainy season, and annually, respectively. In addition, in 2050, the maximum variation of the maximum temperature in the region will probably be 3.9, 4.1 and 4°C, in the dry season, rainy season, annually, as compared to the variation during the 1901-1950 period. In tropical regions, during the same year (2050), the maximum temperature will increase by 2.9, 2.8 and 2.7°C in the dry season, rainy season, and annually, respectively. However, in the hot and humid tropical regions, the maximum temperature will increase by 3.6, 3.5 and 3.3°C, respectively, in the dry season, rainy season, and annually. In the year 2075, as compared to that in the 1901-1950 period, the maximum variation of the maximum temperature in this region will probably be 4.875, 5.125 and 5°C in the dry season, rainy season, and yearly. During the same year in Fianarantsoa city, the maximum temperature will increase by up to 3.625, 3.5 and 3.375°C in the dry season, rainy season, and annually. Meanwhile, in the hot and humid tropical region of Taolagnara city, the dry and rainy seasons of the 2075 would experience the maximum temperature increase of up to 4.50 and 4.37°C,

Table 4. Variation in the air temperature in some regions of the North of Madagascar

City	Maximum temperature increment (°C)			Minimum temperature increment (°C)		
	Dry season	Rainy season	Yearly	Dry season	Rainy season	Yearly
Antsiranana	0.021	0.029	0.024	0.002	0.008	0.004
Sambava	−0.005	−0.004	−0.006	0.033	0.04	0.037
Vohemar	0.015	0.021	0.016	0.018	0.025	0.021

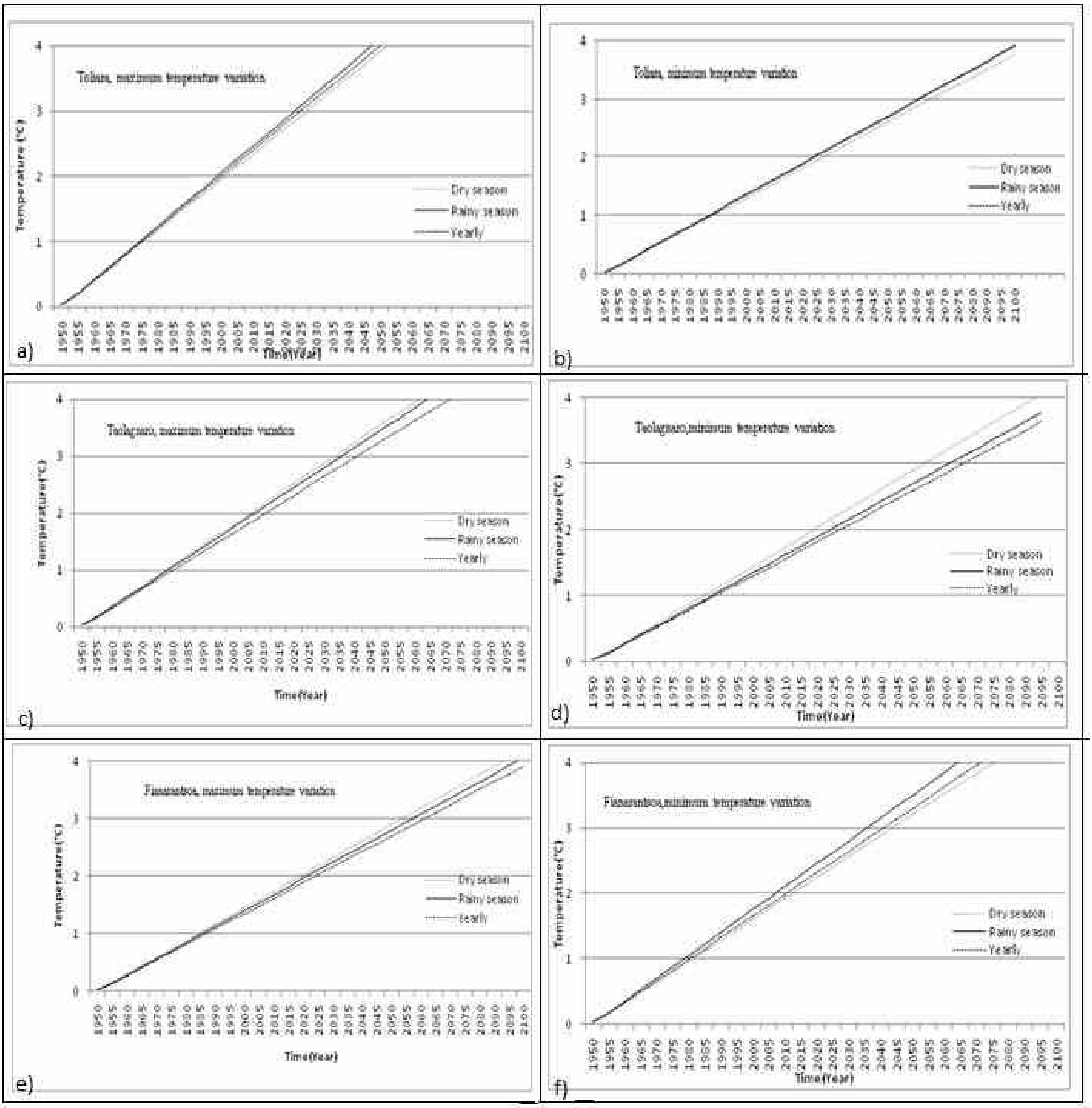

Figure 5. Yearly temperature increment in South of Madagascar

respectively. These results imply that the maximum temperature is increasing by a 55% faster rate in the dry season than in the rainy season in the Great South of Madagascar. In this regard, it is important to recognize that the anthropogenic signal in the global temperature record is expected to increase and that past changes are no guide to how the future will develop.

3.1.7 Case of variation in the annual mean air temperature

In January, 1975, the relative humidity was 35.78-80.58% and the mean temperature was 25.881-21.944°C in the semi-arid tropical and altitude tropical climate regions. In July of the same year, the mean temperature was 19.958-20.796°C in the same regions. On the other hand, in January and July of the year 2000, the mean temperature reached 26.719°C and 22.694°C, 20.796°C and 17.035°C in Toliara and Fianarantsoa, respectively. In addition, in 2025, the mean air temperature in January and July is expected to be 27.556°C and 21.633°C in Toliara, and 23.444°C and 17.785°C in Fianarantsoa, respectively. By 2075, the mean air temperature will increase up to 29.231°C in January and 23.309°C in July in the semi-arid tropical. The actual trend shows that temperature variations depend on location and altitude.

3.1.8 Case of variation in the annual minimum temperature

The minimum annual temperature has increased by 0.026, 0.026 and 0.033°C in the semi-arid tropical climate region of Toliara, the hot and humid tropical climate region of Taolagnara, and the altitude tropical climate region of Fianarantsoa, respectively (Figure 5b 5d 5f). In the year 2025 (*i.e.*, 75 years after 1950), the maximum increase in the minimum temperature in this region is expected to reach 2.4, 2.625 and 2.475°C in the dry season, rainy season, and yearly, respectively, as compared to that in the 1901−1950 period. In the semi-arid tropical climate region of Toliara, during the same year (2025), the minimum temperature will increase by up to 1.95, 2.025 and 2.025°C in the dry season, rainy season, and yearly, respectively. In the hot and humid tropical climate region of Taolagnara, during the same year (2025), the increase is expected to reach 2.175; 2.025, and 1.95°C in the dry season, rainy season, and yearly, respectively, as compared to that in the 1901−1950 period. In addition, in 2050, (*i.e.*, 100 years after 1950), the maximum change in the minimum temperatures in this region is estimated to be 3.2, 3.5 and 3.3°C in the dry season, rainy season, and yearly, respectively, as compared to the 1901-1950 period. However, in the hot and humid tropical climate regions, the maximum temperature would increase by 2.9, 2.7 and 2.6°C, respectively, during the dry season, rainy season, and annually. Finally, in the year 2075, as compared to that in the 1901-1950 period, the maximum change in the minimum temperatures in the region would probably be 4.00, 4.375 and 4.125°C in the dry season, rainy season, and annually. During the same year, in Toliara, the minimum temperature is expected to increase by 3.25, 3.375 and 3.375°C in the dry season, rainy season, and annually, respectively. Meanwhile, in the hot and humid tropical climate region of Taolagnara, during the dry and rainy seasons of 2075, the minimum temperature is expected to increase by 3.625°C and 3.375°C, respectively. These results suggest that the minimum temperature in the studied regions is increasing faster in the rainy season than in the dry season, except in the semi-arid tropical climate region. The different temperature variations in the different cities are shown in Table 5. This variation is almost identical to that observed in several countries in the Sub-Saharan Africa[46].

According to IPCC, it is important to know the type of climate and approximate values for the external temperature to carry out forecasting of the impact of global warming. Table 6 gives some trends of annual temperature and precipitation around 2050 in Africa[47,48].

The steep topography causes the warm and moist air masses to rise, producing rainfall and leaving less moisture for rainfall further west. Table 6 shows that annual precipitation change is very significant in all part of Africa.

3.2 Energy demand of buildings

3.2.1 Time-scale of the past and present

This part of the research includes the study of Madagascar's buildings to understand their need for cooling and heating energy in the past, the present, and the future. The past time scale is related to the data of 1975, the present time scale includes the data of 2000, and the future includes the time periods of 2025, 2050, and 2075. According to the study conducted on the need for heating energy for 1975, the results indicated that June, with an average of 160 DDs, had the highest rate in comparison with other months toward meeting the need for heating energy (Figure 8). In fact, the regions (11 = Antananarivo, 12 = Antsirabé, 13 = Fianarantsoa and 15), situated in the center of Madagascar, had high heating energy demand. In all the regions studied, in the rainy season (between October and April), there was no need for heating energy because it was hot during this period. The annual heating energy was higher in Antsirabe (643 DDs) than in the others regions which shows that Antsirabe remains the coldest city of Madagascar. The HDD rate has oscillations from 0 to 700 DDs during a year for different regions of Madagascar, and its annual aver-

Table 5. Variation in the air temperature in some regions of the South of Madagascar

City	Maximum temperature increment(°C)			Minimum temperature increment(°C)		
	Dry season	Rainy season	Yearly	Dry season	Rainy season	Yearly
Fianarantsoa	0.029	0.028	0.027	0.032	0.035	0.033
Toliara	0.039	0.041	0.04	0.026	0.027	0.027
Taolagnara	0.036	0.035	0.033	0.029	0.027	0.026

Table 6. Annual temperature and precipitation change scenario for the period centered around 2050, simulated by 20 Atmosphere Ocean Circulation Models

Region	North Africa	Central Africa	Southern Africa	Eastern Africa
Temperature Change, (°C)	from +1.7 to +2.4	from +1.7 to 1.9	from +1.4 to +2.5	from +1.6 to +2.1
Precipitation Change, (mm)	from -2.0 to +6.0	from +0.4 to +2.6	from -14.0 to-2.7	from +8.0 to +13.0

age for the entire of Madagascar were calculated to be 329 DDs. The heating energy demand was weak in region15 (53 DDs) and inferior to the average for region13 (Fianarantsoa). Meanwhile, more than 25% of annual heating energy demand was saved in region11 (Antananarivo) in Madagascar. In the same time period of 1975s, the maximum requirement for energy for cooling houses is observed in October for 122 DDs (Figure 6). The months between June and August do not have any need for cooling energy as they are slightly colder months, except some regions in the north of Madagascar. But, as the annual mean, 440 DDs of energy is required for cooling houses in Madagascar (Figure 6 and Figure 7) and this rate oscillates between 0 and 828 DDs. The minimum need for energy for cooling houses in a year is related to regions such as 7 and 9, which include the Great East, and the north of Madagascar, and its maximum is related to regions 1, 2 and 8, including some regions in the northeast and east. As a continuation, this process has been carried out for the present time scale for the indicative year 2000, and the results show relative changes. But the monthly data reveal that it is June which needed the maximum energy of 132 DDs to provide heating for houses as before. Likewise, the months from October to March do not need energy for supplying heat since they are hot months. The interesting point is that in April, August and September, the need for energy for heating has decreased and in June and July it has increased (Figure 8a 8b 8c 8d). But the result concluded from the difference of annual data is that the need for energy for heating has an average decrease of 81 DDs in central Madagascar. Overview, the energy-efficient or high star rating houses may experience less absolute changes in energy requirement[23]. The average annual cooling energy was 526 DDs in Madagascar this year, which is an increase of 86 DDs as compared to that in the year 1975.

Energy demand increased to 19.6% between 1975 and 2000. These results are similar at those estimated by Christenson *et al*.[41], who showed that the heating degree-days were reduced by 11-18% during 1901-2003, but reached 1387% between 1975 and 2085. Some researchers showed that the extent of reduction in heating and increase in cooling varies from one region/climate to another and depends very much on the prevailing local weather conditions and energy efficiency measures[25–27].

3.2.2 Future time-scale

For 2025, it has been estimated that the heating energy for the month of June would be an average of 104 DD, with the maximum need for heating energy in this month than in other months. Also, no heating energy requirement is necessary from October to April, because these are hot months. However, according to the annual average temperature calculated for the center of Madagascar, 136 DDs have been estimated for heating houses; in comparison with the previous periods, this rate has decreased (Figure 8). From among the different regions of the country, this rate of annual need for heating energy has oscillated from 0 DD related to regions such as 1-9 to 249 DDs related to a region such as 12. With regard to the need for cooling energy for cooling houses, often, the months of MayJuly do not need cooling energy, except for in the regions 1-3 in the north of Madagascar. A maximum annual requirement of 1136 DDs was obtained in region 2. A comparison of these months with the previous periods indicated that, in most months of the year, the need for cooling energy is more, as evident from Figure 7a 7b 7c. Increase in CDD was the highest in the north and the lowest in the center of Madagascar. In this study, regarding the increase of the need for cooling energy in most of the months, consequently, its annual rate was decreased and its average was calculated to be 482

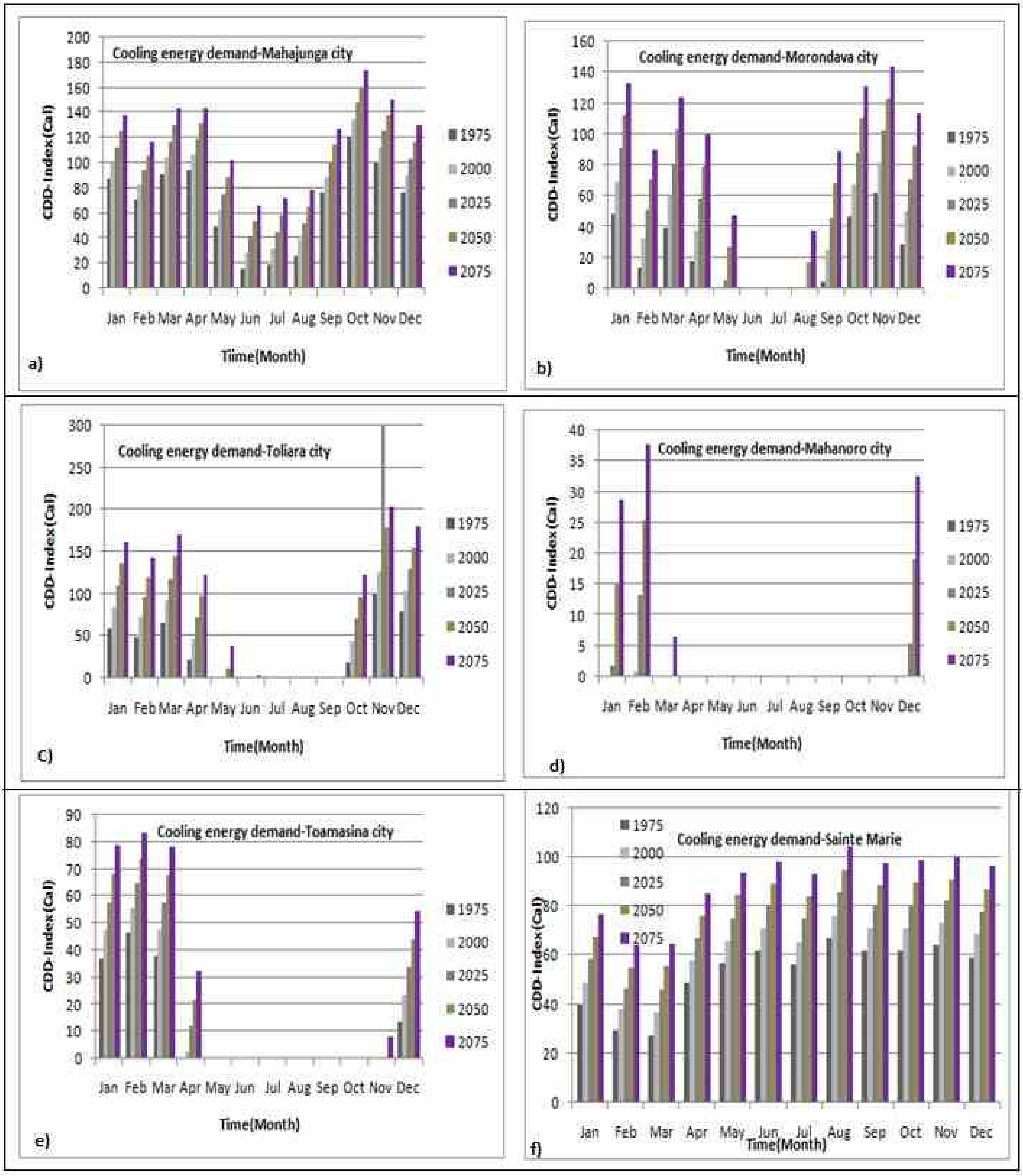

Figure 6. Calculation of the monthly average of CDD index for regions 2-8 in Madagascar during the five study periods

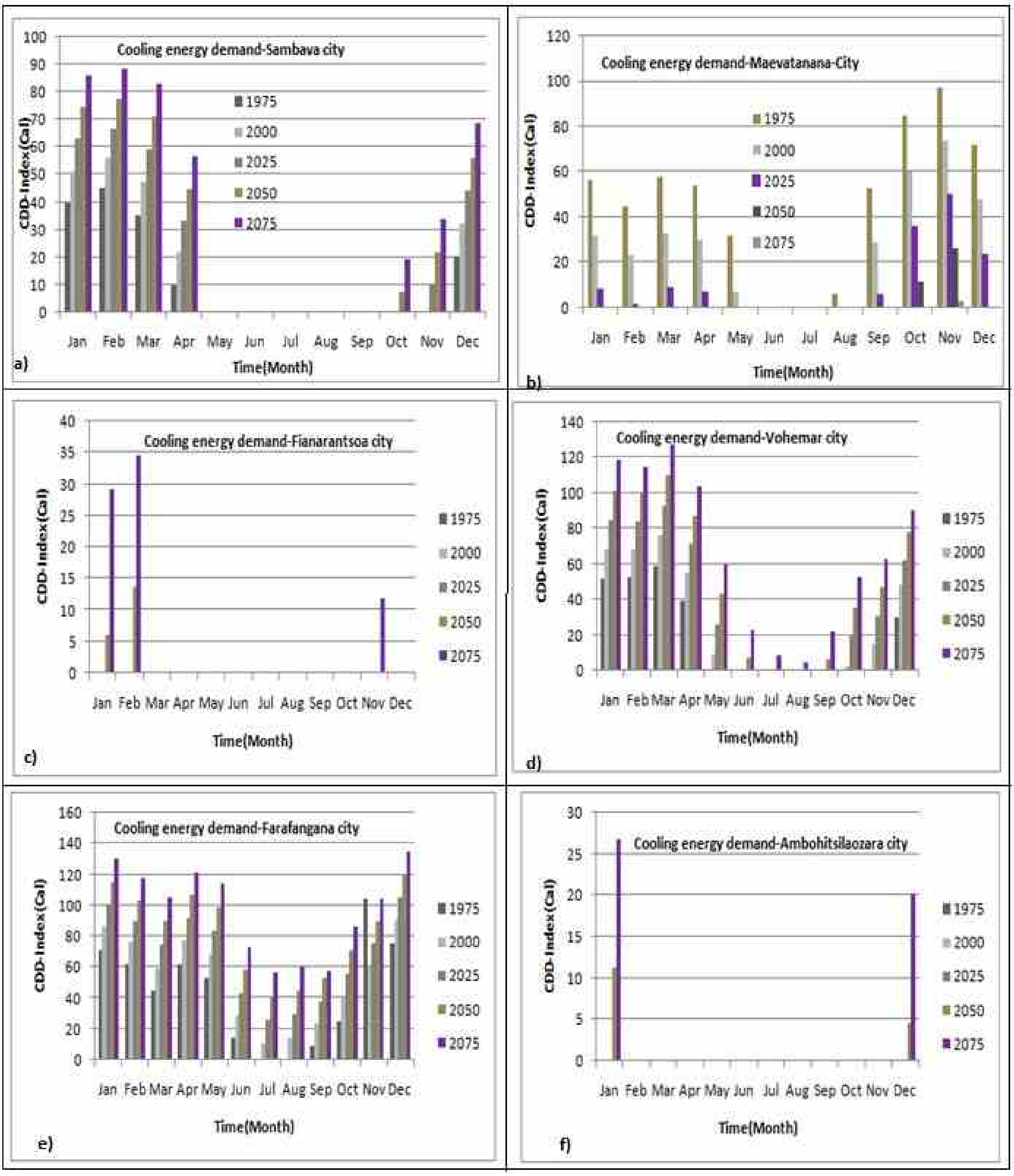

Figure 7. Calculation of the monthly average CDD indexfor regions 9,10,13, 15 and 16) in Madagascar during the five study periods

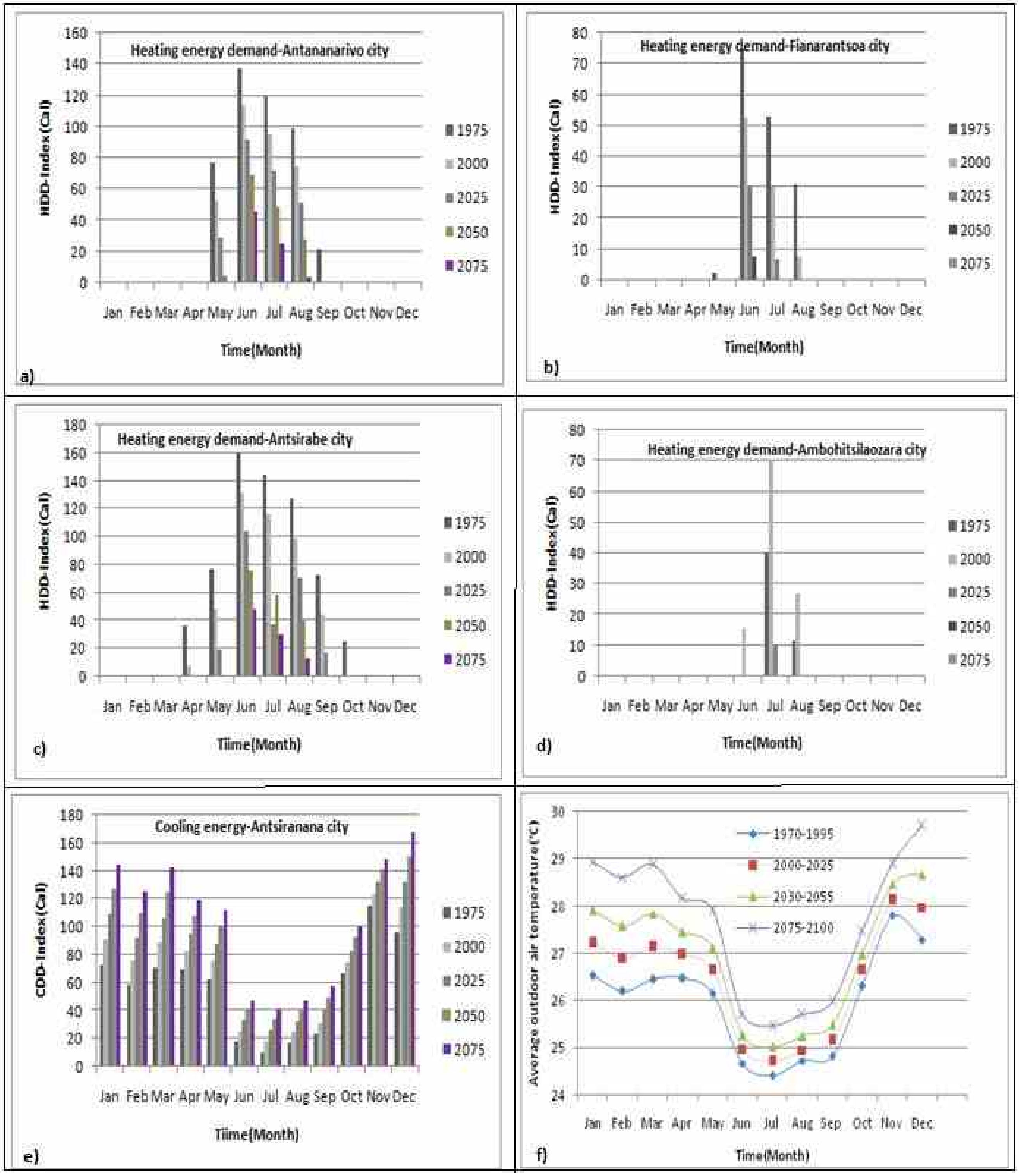

Figure 8. Calculation of the monthly average of HDD and CDD index for Madagascar during the five study periods

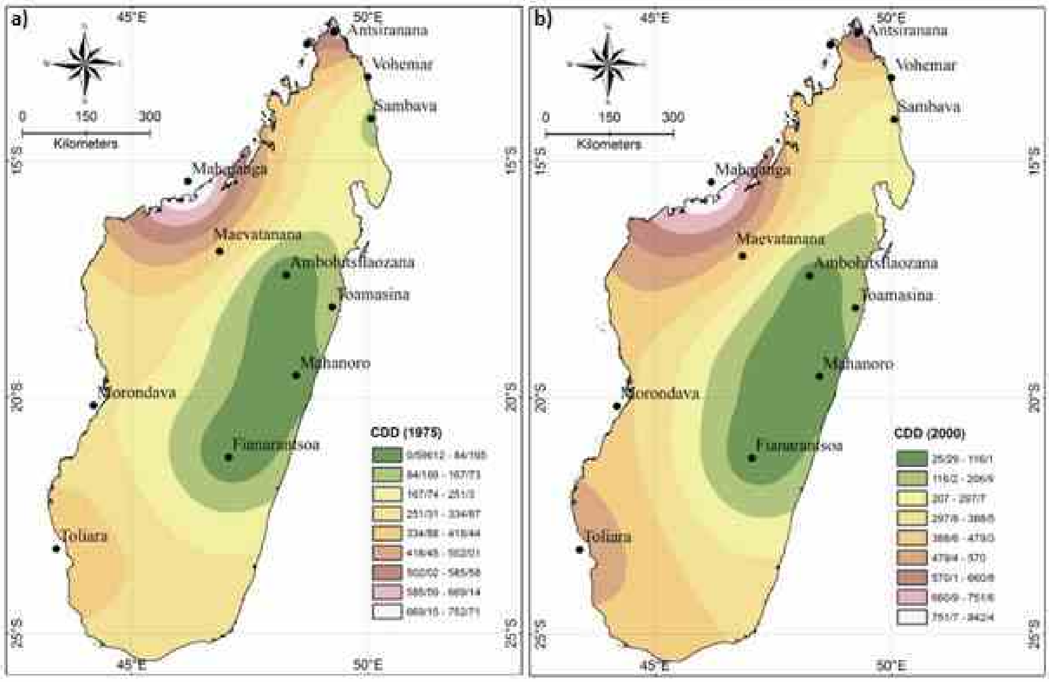

Figure 9. Zoning the values of need for CDD in the study period of (a) 1975 and (b) 2000

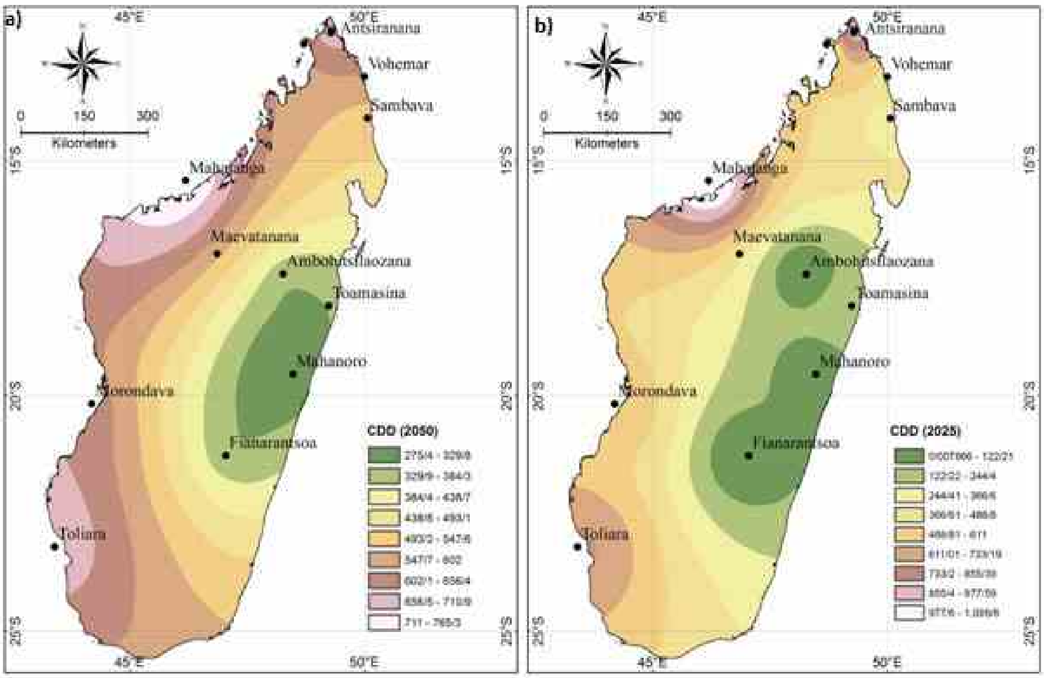

Figure 10. Zoning the values of need for CDD in the study period of (a) 2025and (a) 2050

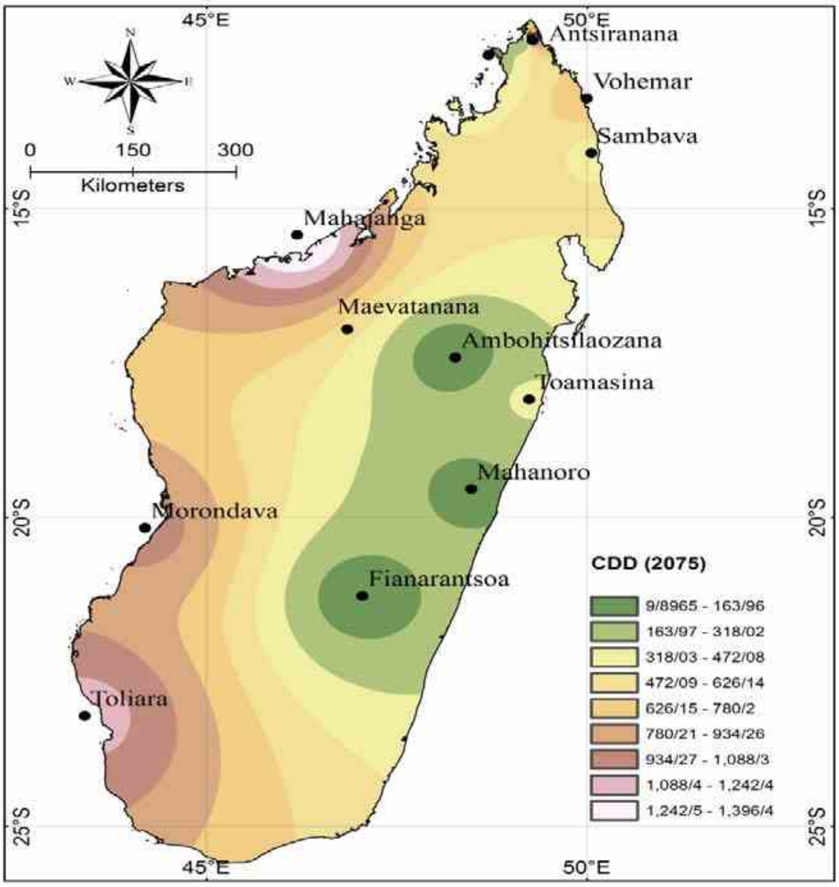

Figure 11. Zoning the values of need for CDD for the study period of 2075

DDs for Madagascar (Figure 6 and Figure 8). By 2050, it has been estimated that the month of June would be the coldest month of the year with 77 DDs need for heating energy. Notably, the months of July and August, except for the period between September and August which do not need heating energy, would not need any energy for heating buildings due to global warming. It was noticed that in region 15, there was no heating energy demand during this year. In all these regions, during this year, the slowest annual heating energy saved was only 8 degree-days. In this study, an annual average of 84 HDDs was established; as such, the need for HDDs has decreased to 52 DDs (Figure 8b 8d), as compared to that in year 2025. In this annual average, as before, several regions saw a decrease in its annual heating. Region12 (Antsirabe) had the maximum requirement for heating energy, with an annual average of 177 DDs. With regards to the energy supply for cooling houses, August had the lowest requirement with an average of 1.01 DDs for cooling houses and November has the highest requirement with 178 DDs. But, the annual average was 575 CDDs for the entire of Madagascar, which has increased by 93 DDs in comparison with that in the last studied period, as illustrated in Figure 6 and Figure 7. It's showed that, a raising of air temperature up to 2°C, could result in signicant energy savings and have great mitigation potential[47,48]. The simulation of DD index values for the year 2075 suggest that regions 13 and 15 would have no need for heating energy consumption for the first time. However, regions 11 and 12 will need heating energy during JuneAugust, with all the months showing a decreasing trend in heating energy consumption. In this simulation study, energy consumption in the heating section showed a decrease by 42 DDs in comparison with that in the year 2050 and by 287 DDs in comparison with that in 1975. In 2075, the oscillations of the need for energy consumption ranged from 0 in regions 13 and 15, to 92 in region 12 (Figure 8). Now, regarding the simulation of the values of need for energy consumption for cooling houses in the year 2075, it can be concluded that, in all the months of the year, without any exception, the cooling energy consumption showed an increase in comparison with that in the previous years, and the maximum value of this increment was observed for November with 203 DDs. The annual average of energy consumption in the cooling section also showed an uptrend since 1975, reaching its peak at 790 DDs in 2075, thus, the increase in the energy consumption in comparison with the year 1975 was by 350 DDs, as detailed in Figure 6a 6c 6d 6f and Figure 7a 7c 7d 7f. Globally, heating energy demand will decrease by about 55%, while cooling energy will increase by an equal 50.2% up to 2075. This strong variation of energy was mainly due to strong concentration of greenhouse gas. In Greece, Asimakopoulos[25] found that the energy demand for heating the building sector, could decrease by about 50%, until 2100. The increase cooling energy demand is really significant. Zoning the values of need for CDDs in the study periods of 1975, 2000, 2025, 2050 and 2075 is manifested in Figure 9, Figure 10 and Figure 11. The cooling energy demand was very weak for areas located in the "Green Malachit", from 0-84 DDs in 1975 to 116 DDs in 2000, and to 163 DDs in 2075. It was weak for regions located in the "Green Almond" from 84-167 DDs in 1975s, to 206 DDs in 2000, and to 318 DDs in 2075. It was slightly low for regions in the "Yellow Breath" from 167-251 DDs in 1975s, to 297 DDs in 2000, and to 472 DDs in 2075. In addition, the means for regions in the "Yellow Orpiment" from 334-416 DDs in 1975s, to 479 DDs in 2000, and to 780 DDs in 2075, and higher in regions in the "Onion Skin Pink Zone" from 502-585 DDs in 1975s, to 660 DDs in 2000, and to 1088 DDs in 2075. All these results showed that energy demand is instable and varies according to region. At the end, the cooling energy demand was very high for areas located in the "Tingray" zone from 669-752 DDs in 1975, to 842 DDs in 2000, and to 1396 DDs in 2075. Based on the findings of this study, the design of new buildings for these regions must consider the future outdoor mean temperature to define the wall insulation, the technical characteristic of HVAC systems, and others parameters.

4 Conclusion

In this research, a survey was conducted to evaluate the heating and cooling energy demand in Madagascar. The outdoor climate and projection were studied using several GCM models in varying scenarios. Several investigations in different sectors evidenced climate change. The effects of climate change are visible, especially in Madagascar, where the frequency of flooding has increased in the coastal cities. The temperature and precipitation vary among regions of the same country. The average annual energy consumption in the cooling area has also seen an uptrend since 1975 and is estimated to 790 DDs. For several terrestrial and marine species, an evolution of the distribution area has been observed with respect to seasonal activities and migration. Madagascar suffers from the impact of the warming of the Earth, such as, other Sub-Saharan Africa and poor countries. The air temperature is expected to increased upto 4°C, in several cities in Madagascar in the next decade. The emission levels in Madagascar are less than 1/200th of those registered in the US and Canada, leaving little scope to reduce their levels further. However, the need to reduce emissions globally is extremely urgent and requires the individual contributions of all the countries in the world.

This study recommends a direct implication of all the population for reducing the impacts of climate change in Madagascar and in the world.

In the next study, it is important to assessment in this region, the variation of air temperature and energy, using the Representative Concentration Pathway(RCP) scenarios such as RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5.

Conflicts of interests

The author declares no conflicts of interests.

References

[1] IEA. World energy outlook 2010. Paris: International Energy Agency, 2010.

[2] Goldemberg J. World energy assessment, energy and the challenge of sustainability. New York: UNDP, 2000.

[3] Nematchoua MK, Yvon A, Roy SEJ, *et al*. A review on energy consumption in the residential and commercial buildings located in tropical regions of Indian Ocean: A case of Madagascar island. Journal of Energy Storage, 2019, **24**: 100748
https://doi.org/10.1016/j.est.2019.04.022

[4] Orosa MKNJA and SigridReiter. Climate change: Variabilities, vulnerabilities and adaptation analysis – A case of seven cities located in seven countries of Central Africa. Urban Climate. 2019, **29**: 100486.
https://doi.org/10.1016/j.uclim.2019.100486

[5] Badjeck B, Ibrahima NC and Slaviero F. Mission fao/pam d'évaluation de la sécurité Alimentaire à madagascar, 2013, **9**: 5-72.

[6] Programme d'action national d'adaptation au changement climatique. Ministere de l'environnement, des eaux et forêts Direction generale de l'environnement, **2013**: 8-67.

[7] Tadross M, Randriamarolaza L, Rabefitia Z, *et al*. Climate change in Madagascar: Recent past and future. Meteo Malgasy, 2008, 118.

[8] Rabefitia Z, Randriamarolaza LYA and Rakotondrafara ML. Changement climatique à Mada–gascar, **2008**: 8-30.

[9] IPCC, 2007. The physical science basis. In: Solomon S, Qin D, Manning M, *et al*. (eds) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

[10] Jump up. "Technical Summary", 3. Review of Past IPCC Emissions Scenarios, inIPCC SRES, **2000**: 24.

[11] Delfani S, Karami M and Pasdarshahri H. The effects of climate change on energy consumption of cooling systems in Tehran. Energy and Buildings, 2010, **42**(10): 1952-1957. https://doi.org/10.1016/j.enbuild.2010.06.001

[12] Shanahan M, Shubert W, Scherer C, *et al*. Le changement climatique en Afrique: Guide à l'intention des journalistes. Publié en 2014 par l'Organisation des Nations Unies pour l'éducation, la science et la culture, 2014, **11**: 105.

[13] Belzer DB, Scott JM and Sands RD. Climate change impacts on U.S. commercial building energy consumption: an analysis using sample survey data. Energy Source, 1996, **18**: 177-201. https://doi.org/10.1080/00908319608908758

[14] Cartalis C, Synodinou A, Proedrou M, *et al*. Modifications in energy demand in urban areas as a result of climate changes: an assessment for the southeast Mediterranean region. Energy Conversion and Management, 2001, **42**: 1656-1674. https://doi.org/10.1016/S0196-8904(00)00156-4

[15] Pretlove SEC and Oreszczyn T. Climate change: impact on the environmental design of buildings. Proceedings CIBSE. Build Service Engineering Research and Technology, 1998, **19**: 55-58. https://doi.org/10.1177/014362449801900110

[16] Roberts S. Effects of climate change on the built environment. Energy Policy, 2008, **36**: 4552-4557. https://doi.org/10.1016/j.enpol.2008.09.012

[17] Hulme MR, Doherty T, Ngara MN, *et al*. African Climate Change: 1900-2100. Climate Research, 2001, **17**(2): 145-168. https://doi.org/10.3354/cr017145

[18] IPCC (2001). Climate Change 2001: The Scientific Basis. Contribution of Working group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK. New York, US, Cambridge University Press.

[19] IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

[20] Invidiata A and Enedir Ghisi. Impact of climate change on heating and cooling energy demand in houses in Brazil. Energy and Buildings, 2016, **130**: 20-32. https://doi.org/10.1016/j.enbuild.2016.07.067

[21] Neto AH and Fiorelli FAS. Comparison between detailed model simulation and articial neural network for forecasting building energy consumption. Energy and Buildings, 2008, **40**: 2169-2176. https://doi.org/10.1016/j.enbuild.2008.06.013

[22] Wang HJ and Chen QQ. Impact of climate change heating and cooling energy use in buildings in the United States. Energy and Buildings, 2014, **82**: 428-436. https://doi.org/10.1016/j.enbuild.2014.07.034

[23] Hassan R. Evaluating the potential impact of global warming on the UAE residential buildingsA contribution to reduce the CO_2 emissions. Building and Environment, 2009, **44**(24): 51-62. https://doi.org/10.1016/j.buildenv.2009.04.006

[24] Ambrose D, Gustavsson L and Bonakdar F. Effects of future climate change scenarios on overheating risk and primary energy use for Swedish residential buildings. Energy Procedia, 2014, **61**: 1179-1182. https://doi.org/10.1016/j.egypro.2014.11.1048

[25] Asimakopoulosa DA, Santamourisa M, Farroua I, *et al*. Modelling the energy demand projection of the building sector in Greece in the 21st century. Energy and Buildings, 2012, 49: 488-498. https://doi.org/10.1016/j.enbuild.2012.02.043

[26] Berger T, Christoph, Amann, *et al*. Impacts of climate change upon cooling and heating energy demand of ofce buildings in Vienna, Austria. Energy and Buildings, 2014, **80**: 517-530. https://doi.org/10.1016/j.enbuild.2014.03.084

[27] Kevin KWW, Danny HWL, Pan WY, *et al*. Impact of climate change on building energy use in different climate zones and mitigation and adaptation implications. Applied Energy, 2012, **97**: 274-282. https://doi.org/10.1016/j.apenergy.2011.11.048

[28] Wang XM, Chen D and Ren ZQ. Assessment of climate change impact on residential building heating and cooling energy requirement in Australia. Building and Environment, 2010, **45**: 1663-1682. https://doi.org/10.1016/j.buildenv.2010.01.022

[29] Mission fao/pam d'évaluation de la sécurité Alimentaire à Madagascar 9 octobre, **2013**: 2-75.

[30] IPCC. Climate change: Impact, adaptation and vulnerability. Summary for Policymakers, working group ii contribution to the fifth assessment report of the climate. Cambridge University Press, 2014.

[31] Roshan GR, Orosa JA and Nasrabadi T. Simulation of climate change impact on energy consumption in buildings:Case study of Iran. Energy Policy, 2012, **49**: 731-739. https://doi.org/10.1016/j.enpol.2012.07.020

[32] Kameni Nematchoua M, Ricciardi P, Reiter S, *et al*. Thermal comfort and comparison of some parameters coming from hospitals and shopping centers under natural ventilation: the Case of Madagascar Island. Journal of Building Engineering, **2017**: S2352710217302437. https://doi.org/10.1016/j.jobe.2017.07.014

[33] Laprise R, Hernández-Díaz L, Tete K, *et al*. Climate projections over CORDEX Africa domain using the ifthgeneration Canadian Regional Climate Model (CRCM5). Clim Dyn. 2013. https://doi.org/10.1007/s00382-012-1651-2

[34] Mariotti L, Coppola E, Sylla MB, *et al*. Region climate model simulation of projected 21st century clima change over an all-Africa domain: comparison analysis of neste and driving model results. J Geophys Res, 2011, **116**(D15): D15111. https://doi.org/10.1029/2010JD015068

[35] Mariotti L, Diallo I, Coppola E, *et al*. Seasonal and inter seasonal changes of African monsoon climates in 21st centur CORDEX projections. Clim Chang, 2014, **125**: 53-65. https://doi.org/10.1007/s10584-014-1097-0

[36] Racsko P, SzeidlL and Semenov M. A serial approach to local stochastic weather models. Ecological Modeling, 1991, **57**: 27-41. https://doi.org/10.1016/0304-3800(91)90053-4

[37] Semenov MA and Barrow EM. LARS-WG a stochastic weather generator for use in climate impact studies. User's manual, Version 3.0. http://www.rothamsted.ac.uk/mas-models/download/LARS-WG-Manual.pdf

[38] Orosa A, Roshan GR and Negahban S. Climate change effect on outdoor ambiences in Iranian cities. Environ Monit Assess, 2014, **186**: 1889-1898. https://doi.org/10.1007/s10661-013-3502-y

[39] Nematchoua MK, Yvon A, Kalameu O, *et al*. Impact of climate change on demands for heating and cooling energy in hospitals. An in-depth case study of six islands located in the Indian Ocean region. Sustainable Cities and Society, 2019, **44**: 629-645. https://doi.org/10.1016/j.scs.2018.10.031

[40] Nematchoua MK, Ricciardi P, Orosa J, *et al*. A detailed study of climate change and some vulnerabilities in Indian Ocean: A case of Madagascar island. Sustainable Cities and Society, 2018, **41**: 886-898. https://doi.org/10.1016/j.scs.2018.05.040

[41] Nematchoua MK, Ricciardi P and Buratti C. Statistical analysis of indoor parameters an subjective responses of building Occupants in a hot region of Indian ocean; a case of Madagascar island. Applied Energy, 2017, **28**: 1562-1575. https://doi.org/10.1016/j.apenergy.2017.08.207

[42] Lehmann EL and Romano JP. Testing statistical hypotheses. Springer, 2005.

[43] Boslaugh S. Statistics in anutshell. 2nd ed. O' Reilly Media, Inc, 2012.

[44] Lioubimtseva E. Africa and global climate change impacts, vulnerabilities and adaptation challenges. Taylor & Francis, Chapter, 2014, 219-230. https://doi.org/10.4324/9780203803929-22

[45] Anapalli SS, Fisher DK, Reddy KN, *et al*. Vulnerabilities and Adapting Irrigated and Rainfed Cotton to Climate Change in the Lower Mississippi Delta Region. Climate, 2016, **4**(4): 55. https://doi.org/10.3390/cli4040055

[46] Nematchoua MK, Roshan GR, Tchinda R, *et al*. Climate change and its role in forecasting energy demand in buildings: A case study of Douala City, Cameroon.Journal of Earth System Science, 2015, **124**(1): 269-281. https://doi.org/10.1007/s12040-014-0534-9

[47] Yu J, Yang C, Tian L, *et al*. Evaluation on energy and thermal performance for residential envelopes in hot summer and cold winter zone of China. Appl Energy, 2009, **86**: 1970-1985. https://doi.org/10.1016/j.apenergy.2009.01.012

[48] Yu J, Yang C, Tian L, *et al*. A study on optimum insulation thickness of external walls in hot summer and cold winter zone of China. Appl Energy, 2009, **86**: 2520-2529. https://doi.org/10.1016/j.apenergy.2009.03.010