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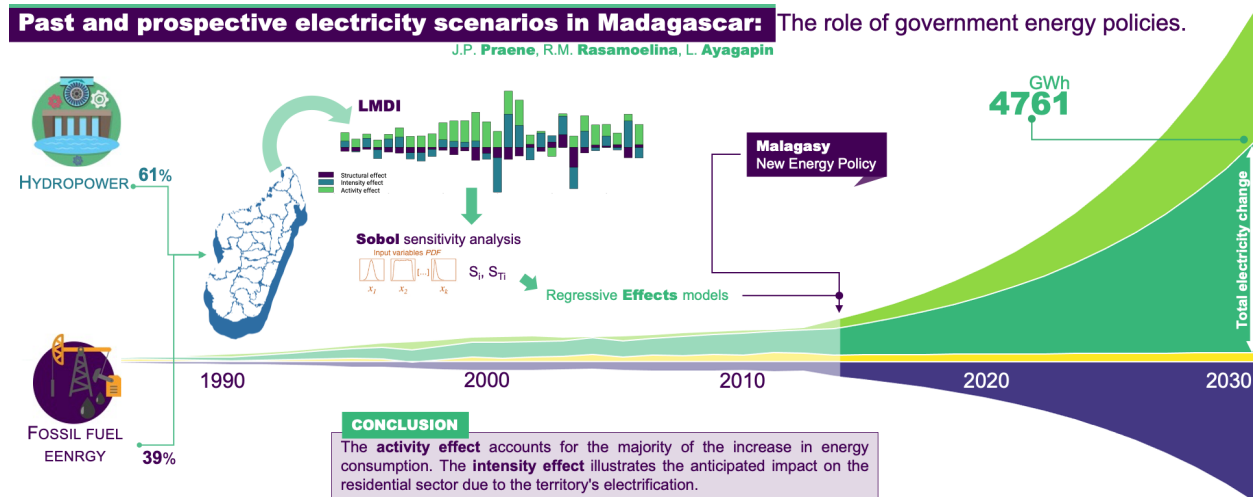
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Graphical Abstract

Past and prospective electricity scenarios in Madagascar: the role of government energy policies.

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Past and prospective electricity scenarios in Madagascar: the role of government energy policies.

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Abstract

A thorough understanding of the mechanisms influencing electricity use is imperative for the implementation of energy scenarios. This study first explores Madagascar's electricity consumption during the 1987-2015 period using a decomposition method. Next, a sensitivity analysis (SA) is conducted, which allows factors that have a significant influence on the different effects (activity, structure, and intensity) to be defined. Scenarios are then designed from regression models based on the SA. The main results revealed the following. (1) This study confirmed that the activity factor was the driving force of energy growth, accounting for more than 107.5% of the total electricity consumption. (2) The negative impacts of structural and intensity effects are particularly marked in periods of political disruption. (3) National energy policy (called "New Energy Policy" (NPE)) based scenario shows a significant electricity variation of 4084 GWh over the 2015-2030 period.. By minimizing the intensity effect change to 9.87% between 2015 and 2030, the NPE scenario's total consumption increase is limited to 4084 GWh. By contrast, this amount is 398 GWh for the BAU scenario with a 22% intensity effect. These developed scenarios seek to illuminate the tradeoffs entailed by the various development paths toward Madagascar's ambition to become an emerging country.

Keywords: Prospective, Scenario planning, Sensitivity analysis, Energy consumption, Madagascar

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Nomenclature

List of acronyms

ADER Agence de Développement de l'Électrification Rurale

CREAM Center for Research, Studies and Support to Economic Analysis of Madagascar ("Centre de Recherches, d'Études et d'Appui à l'Analyse Économique de Madagascar")

EFAST Extended Fourier amplitude sensitivity test

GDP Gross domestic product

IMF International Monetary Fund

INSTAT Institut Nationale de la Statistique

JIRAMA Jiro sy Rano Malagasy

LMDI Logarithmic mean Divisia index

NPE New Energy Policy ("Nouvelle Politique Énergétique")

P2RSE Electricity Sector Recovery and Restructuring Project ("Projet de Redressement et de Restructuration du Secteur de l'Électricité")

PND National Development Plan

SA Sensitivity analysis

Parameters

ΔE_{act} Variation in electricity consumption according to the activity effect

ΔE_{int} Variation in electricity consumption according to the intensity effect

ΔE_{str} Variation in electricity consumption according to the structural effect

E Electricity consumption

I Energy intensity, expressed by electricity consumption per subscriber

Q Number of subscribers

S Share of subscribers by sector

1. Introduction

Energy supply is a key issue at the heart of modern society. Among the various driving forces for the socioeconomic development of a country, electricity quality (security, equity and sustainability) is one of the most important [1–3]. Previous studies have shown that the percentage of the population with access to electricity is both a reliable indicator and a determining parameter of the good economic performance of a country [3, 4]. The percentage of the world’s population with access to electricity increased from 76.7% in 1993 to 89.57% in 2018 [5]. Industrialization, population growth, and living standards have contributed to a substantial increase in global primary energy consumption [6]. According to the IEA’s newly published International Energy Outlook 2020 [7], global energy consumption would increase by nearly 31% between 2020 and 2040. The majority of this growth comes from countries outside the Organization for International Cooperation and Development (OECD), and it is concentrated in regions with high economic growth, most notably Asia. The Sustainable Development Scenario (SDS) depicts how electricity becomes even more decisively central to the energy scene with accelerated electrification.. According to World Bank statistics [8], the total percentage of people in the least-developed countries¹ who have access to electricity was 51.6% in 2018. Madagascar has a rate of 25.9%, but this figure should be interpreted cautiously. The MEH’s² most recent 2020 energy balance estimates a rate of 16.4%, which is more in line with the country’s realities [9] and places the country fourth on the list of countries with the least access to electricity.

1.1. Motivation of the paper

Madagascar is particularly subject to energy price shocks and consequent disruptions in energy supply. Like many isolated territories [10], this situation is mainly due to the heavy reliance in Madagascar on imported fossil fuels for electricity generation. To overcome this situation, since August 4, 2015, the Malagasy Government has introduced a new energy policy called NPE³ that is focused on five objectives: access for all to new energy, affordability of prices, quality and reliability of services, energy security, and sustainability. Initially, the 2030 vision targeted two main objectives:

- increase the household electricity access rate to 70% by 2030;
- gradually replace existing thermal power plants with renewable energy plants.

The achievement of these objectives depends on specific energy planning strategies that integrate all the characteristics of the energy situation of Madagascar. Since production is highly correlated with demand, an understanding of consumption remains essential for analyzing the energy situation of any territory. Only three studies have examined the electricity sector and opportunities for renewable energy development in Madagascar [11–13], and none of the existing studies have examined the evolution of electricity consumption in Madagascar. This work is therefore focused on addressing this gap.

¹UN classification

²Ministry of Energy and Hydrocarbons

³New Energy Policy for 2030

1.2. A brief literature review

Currently, climate change and the need for an energy transition are pressuring the energy system to evolve [14–16]. Energy production systems should shift towards decarbonization in the coming decades if global warming is to be kept below 1.5°C and if adaptation to planetary limits is to be achieved, [17]. Energy transition means technological and institutional transformations related to energy systems [18–21]. Therefore, an in-depth analysis of the characteristics of energy consumption is a prerequisite for determining the trajectories of these transformations [18]. The analysis of electricity consumption has thus attracted interest in recent years. Electricity is at the heart of the territory, and its evolution is linked to the economic, environmental and social dimensions of the territorial system [22]. Although empirical results differ in the literature depending on the country’s situation, some broad ideas emerge.

In economics, the relationship between electricity consumption and economic growth has been widely studied [23]. For some, electricity consumption drives economic growth, while for others, economic growth leads to increased energy consumption. Electricity consumption is considered an indicator of economic development [24]. In the case of African countries, with respect to electricity consumption, a time series analysis of 17 African countries for the period 1971-2001 showed that there is a long-run relationship between electricity consumption per capita and real GDP per capita for only 9 countries and the presence of bidirectional causality between energy consumption and economic growth for only 12 countries [3].

From an environmental point of view, a number of studies have shown that population and economic growth lead to an increase in electricity consumption and a concomitant increase in environmental impacts if changes are not made to current production and consumption patterns [25, 26]. Such changes come down to the need for an energy transition. This hypothesis is valid for Sub-Saharan African countries. Esso et al. [27] examined the causal relationship between energy consumption, carbon emissions and economic growth for 12 selected countries in Sub-Saharan Africa over the period 1971-2010. In the long run, the empirical results confirmed the presence of unidirectional causality between energy consumption and economic growth and carbon emissions. However, historical analyses also show that the integration of renewable energy and the reduction in fossil fuel use [28], energy efficiency measures and structural change within the energy system are factors limiting environmental impacts.

On the social side, studies focus on the drivers and trends of electricity consumption in households and industries. In general, the approaches used are based on model building using econometric methods and index decomposition. Electricity consumption per customer can be explained by the electronic devices they own and the frequency of their use [29, 30]. Because of its effects on consumer comfort and usage, climatic variables, such as temperature, also influence the evolution of electricity consumption [24]. Econometric models have shown that population, GDP, household income and the consumer price index are variables of interest in explaining residential electricity consumption [31]. Access to quality energy has been shown to affect people’s access to education, employability, food and even health [32, 33].

The various assumptions in the literature on understanding electricity consumption highlight the difference in the characteristics, challenges and possible futures of the electricity sector in developed and developing countries, especially in the least-developed countries [20]. With a stagnant demographic growth rate, a fully electrified population, and a high economic level, electricity consumption has not only stabilized, but decreases have even been observed due to the application of energy demand management strategies. The main challenge is therefore decarbonization [34].

Unlike developed countries, the least-developed countries are in a phase of economic transition and electrification expansion [12, 35]. Therefore, important structural, functional and institutional transformations of the territory are expected for developing countries [12, 36]. These potential transformations will generate an increase in the demand for electricity:

- Ensuring access to electricity for all means increasing the number of consumers and therefore electricity consumption [37, 38]
- An economic boom could potentially be accompanied by an increase in energy intensity [2, 3]
- An increase in the standard of living of the population could provide an incentive to grow energy production: As developing countries (including the least-developed countries) achieve a better standard of living for the population and the same technological conditions are maintained, energy consumption per capita is expected to increase [22]

As a result, the challenges for the electricity sector in least-developed countries are to increase power generation, ensure the reliability of supply, avoid carbonization, and ensure system sustainability [38–40].

The above characteristics mean that foresight models are less transferable between developed and developing countries and even within developing countries and least-developed countries. An in-depth analysis of each country’s characteristics is needed to develop scenarios and strategies that are appropriate for that country.

1.3. Contribution and aim of work

Considering the objectives of the Malagasy government, it is important to analyze the parameters that significantly influenced the change in electricity consumption in Madagascar over the period 1987-2015. This paper therefore focuses on a historical analysis to help implement a prospective vision of the country’s electricity sector. Indeed, its aim is to understand the general trend of electricity consumption through a historical analysis and then to identify the factors that influence the identified changes. In this study, we aim to provide a simplified model of electricity consumption based on the most significant parameters. This aim is crucial because access to data in developing countries is somewhat challenging. Therefore, it is necessary to retain only the significant parameters of consumption and aim for higher quality databases. This will ensure the reproducibility of data collection and the sustainability of the models developed.

Based on previous studies, this paper applies the IDA method, which has been extensively applied to the decomposition of electricity consumption. The methodology applied in this article is based on a logarithmic mean Divisia index (LMDI) decomposition approach, which it combines with a sensitivity analysis (SA) based on the EFAST method and linear regression. The result of this paper is a proposed regressive model to define the first prospective analysis for Madagascar. This paper is the first of its kind to discuss the electricity structure and changing trends by combining SA and LMDI. The results will be particularly valuable in providing a perspective on and identifying the driving forces of Madagascar’s future energy landscape. Based on these findings, policy implications and the outlook for more sustainable electricity generation by expanding renewable energy are discussed.

1.4. Organization of the paper

The remainder of the paper is arranged as follows. Section 2 offers an overview of Madagascar's socioeconomic and energy situations. Section 3 first presents the methodology used and then describes the data used and the scenario design. Section 4 discusses the results of the LMDI decomposition and the prospective analysis. Section 5 concludes the article and provides some policy recommendations for the energy future of Madagascar.

2. Current status of Madagascar

Madagascar is a large island located between the Indian Ocean and the Mozambique Channel; it has a total surface area of 587,295 km² with a population of 26.97 million in 2019. The island has a subtropical climate characterized by hot summers and warm winters, except for the highlands, where temperatures can fall to as low as 0°C. The country has six major cities that currently account for {37.861% of the urban population in 2019,[41]. Madagascar is in an economically fragile state due to political instability. The country experienced three "*political disruptions*"⁴ in 1991, 2002 and 2009. Unintended consequences of these political fluctuations include both an economic slowdown and the weakening of an already vulnerable population; see Figure 1. Of the total population, 70% lives below the poverty line (less than \$ 2 / day). To put the economy back on a healthy and sustainable growth path at a level at least equal to 5%, the IMF⁵ decided in 2016 to grant an extended credit facility to Madagascar of 305 million USD. This fund was backed by a three-year reform program (2016-2019), for which energy is one of the cornerstones. In this context, the energy sector appears to be of substantial interest in that this resource is necessary for the growth of all productive sectors in the country. The Doing Business indicator ranks Madagascar as 185 of 190 in 2019 for electricity access [42]. Thus, electricity sector development is the country's main energy challenge for the next ten years.

In Madagascar, only 50% of the population in urban areas has access to electricity, [11], and this value decreases to less than 5% in rural areas [45]. The global rate has declined since 2010 due to aging facilities and population growth. The reasons for load shedding vary in different locations. In the capital of Antananarivo, load shedding originates with the obsolescence of distribution equipment and overloading caused by illegal connections. By contrast, in the provinces, there is insufficient production capacity given electricity demand. During the summer period, particularly in January, the duration of electricity blackouts can reach 4 hours, especially during peak hours at the end of the day (6 - 9 pm). Electricity in Madagascar is produced by JIRAMA⁶, the state-owned company that is both the national water and the electricity utility boards. JIRAMA is in a monopoly position given that it has been the only entity generating, transmitting and distributing electricity since 1975. The electricity supply in rural areas is ensured by ADER⁷, which subcontracts with approximately 30 private operators. As shown in Table 1, from 1990 to 2015, electricity generation in Madagascar increased by nearly 1 TWh, 39% of which was from diesel-fired plants, and the remainder being from hydroelectric plants.

⁴This refers to political instability

⁵International Monetary Fund

⁶JiRo sy RAno Malagasy

⁷Agence de Développement de l'Électrification Rurale

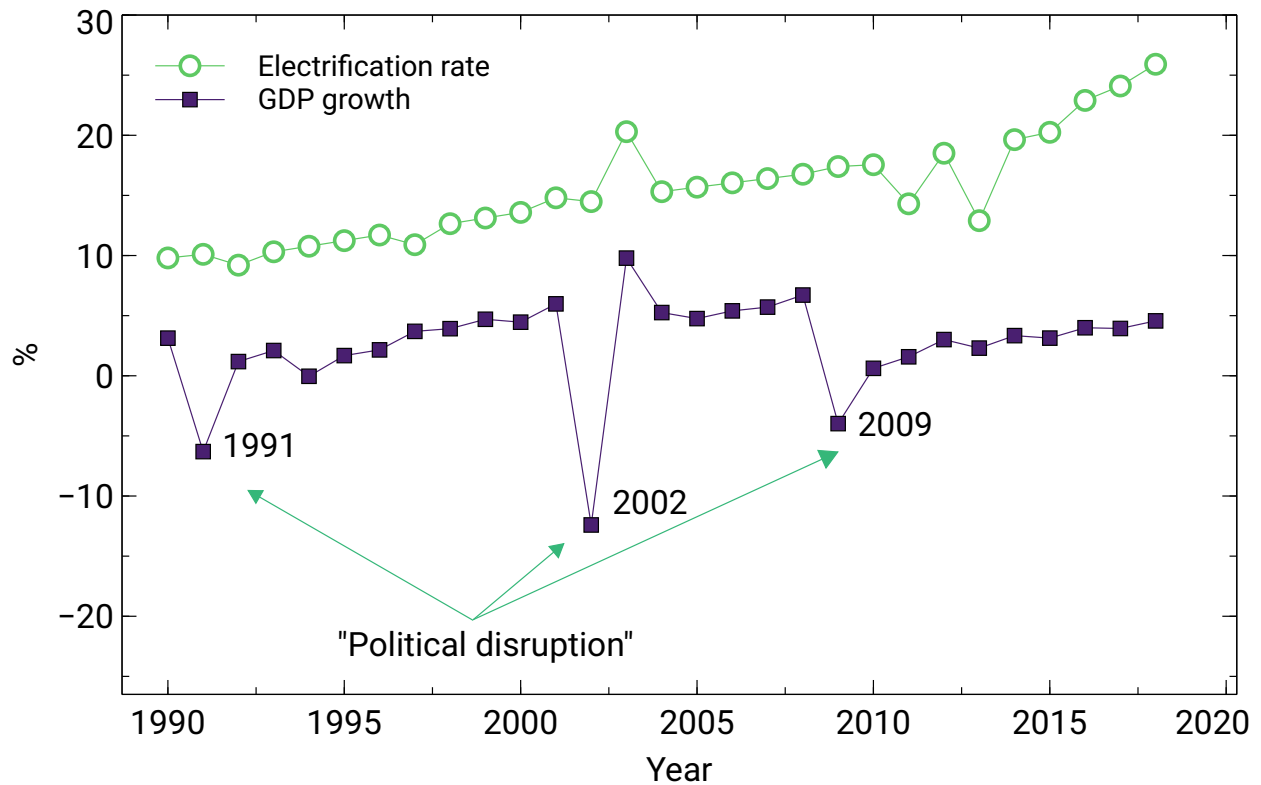


Figure 1: Evolution of the electrification rate and GDP growth during the 1990-2017 period - Data from Ref. [43, 44]

Table 1: Electricity mix produced by JIRAMA

Energy Sources	1990		2000		2010		2015	
	GWh	Share (%)	GWh	Share (%)	GWh	Share (%)	GWh	Share (%)
Hydropower	341.3	71%	539.6	69%	711.0	60%	934.8	61%
Thermal (Diesel)	138.8	29%	240.2	31%	478.8	40%	607.4	39%

3. Materials and methods

3.1. Overall methodology

This study focuses on retrospective and prospective analyses through a combination of LMDI decomposition and SA using linear regression. Compared to the methods already exploited, the approach used in this article has the advantages of being easier to implement and interpret. Thus, the models' objective is to use relevant and accessible variables that allow the retranscription of national policy ambitions. One of the major challenges we face is the availability and reliability of temporal databases. It is, therefore, necessary for the scenarios to reduce to a minimum the variables useful for modeling.

The main objectives to be achieved are as follows:

- diagnose the situation of Madagascar's electricity consumption by identifying influential parameters;

- perform projection scenarios based on this diagnosis.

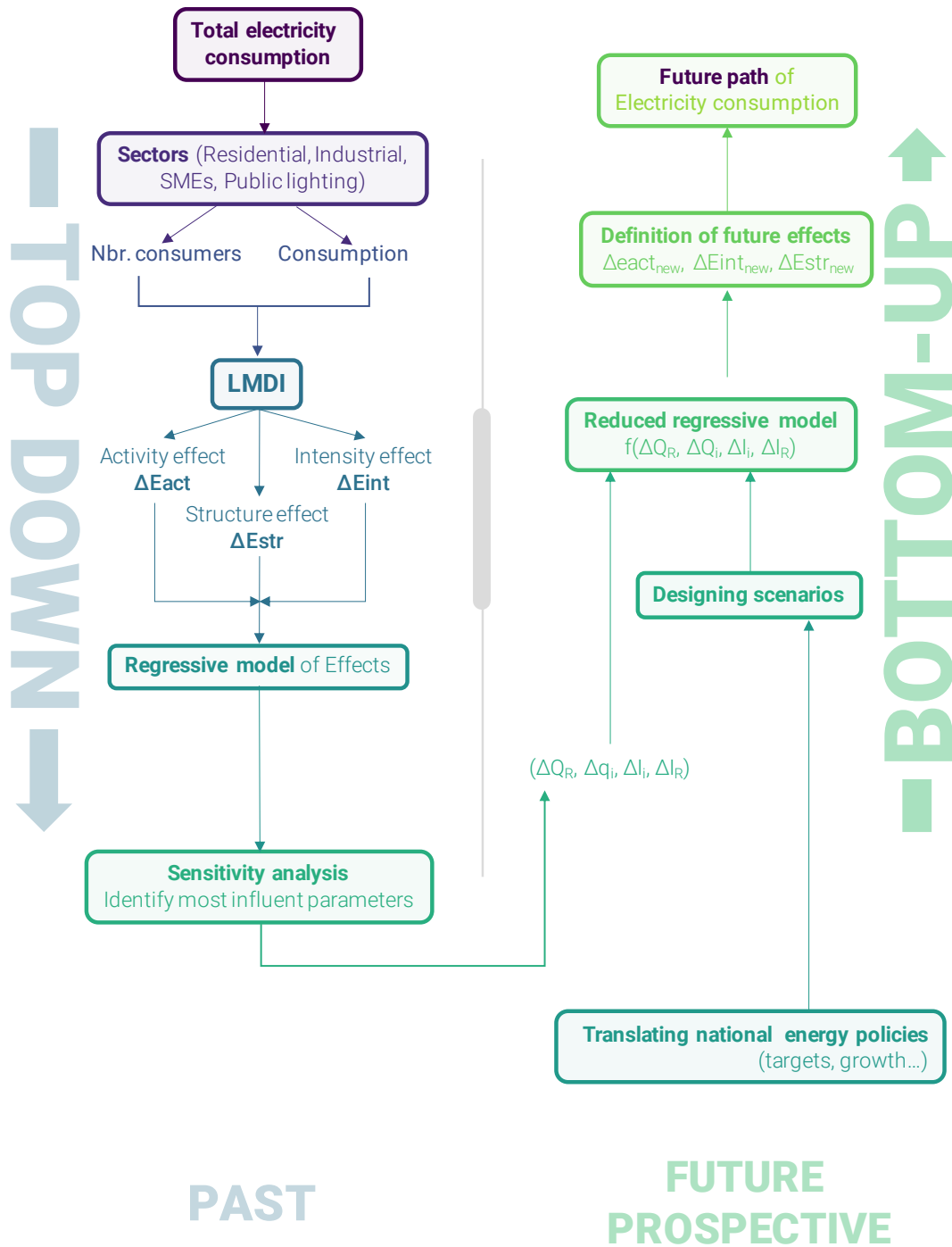


Figure 2: Overall methodology for building prospective scenarios.

As described in Figure 2, we will proceed as follows:

- Application of LMDI decomposition to electricity consumption. The data input are the characteristics of each sector. As a result (output 1), we obtain the 3 different effects that influence the variation in electricity consumption: the activity effect ΔE_{act} , the structural effect ΔE_{str} , and the intensity effect ΔE_{int} .
- Application of combined SA - linear regression on output 1.

Linear regression is then applied to each effect according to the variation in the number of consumers (ΔQ_i) and the electricity consumption per consumer (ΔI_i) of each sector. The objective is to transform the expression of the three effects into a linear model that integrates ΔQ_i and ΔI_i simultaneously. Next, we perform an SA of the obtained models to determine the influencing parameters of each effect. Finally, we carry out a linear regression of each effect based on the most influential parameters. The metamodells obtained are as follows:

$\Delta E_{act} = f(\Delta Q_R)$: activity effect expressed as a function of the number of consumers in the residential sector.

$\Delta E_{str} = f(\Delta Q_I, \Delta Q_R)$: structural effect expressed as a function of the number of consumers in the industrial and residential sectors.

$\Delta E_{int} = f(\Delta I_I, \Delta I_R)$: intensity effect expressed as a function of the electricity consumption per consumer in the industrial and residential sectors.

More details are presented in the results section.

- Electricity consumption scenarios based on output 2.

3.2. Data description

In Madagascar, electricity consumers are divided into four sectors: residential, industrial, SMEs/services, and public lighting. The LMDI decomposition presented in this article used these four sectors as "categories". The residential sector is denoted by "R", the industrial sector by "I", SMEs/services by "SME" and public lighting by "PL." The number of consumers and the electricity consumption of each sector from 1987 to 2015 are used as inputs for the analysis. JIRAMA provided all the data presented in this paper.

3.3. LMDI decomposition

Let E be the total energy consumption. The different sector categories are represented by index i, and the reference time is represented by j, where j = t at time t and j = t+1 at time t+1.

The variation in E will be quantified by evaluating the impacts of the following effects:

- activity effect, denoted by Q;
- structural effect, denoted by S: $S_i = Q_i/Q$;
- intensity effect, denoted by I: $I_i = E_i/Q_i$.

Considering the early works of Ang [46, 47], the LMDI is described by the following equations:

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i QS_i I_i \quad (1)$$

$$\Delta E_{tot} = E^{t+1} - E^t = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \quad (2)$$

$$\Delta E_{act} = \sum_i \frac{E_i^{t+1} - E_i^t}{\ln E_i^{t+1} - \ln E_i^t} \ln\left(\frac{Q^{t+1}}{Q^t}\right) \quad (3)$$

$$\Delta E_{str} = \sum_i \frac{E_i^{t+1} - E_i^t}{\ln E_i^{t+1} - \ln E_i^t} \ln\left(\frac{S_i^{t+1}}{S_i^t}\right) \quad (4)$$

$$\Delta E_{int} = \sum_i \frac{E_i^{t+1} - E_i^t}{\ln E_i^{t+1} - \ln E_i^t} \ln\left(\frac{I_i^{t+1}}{I_i^t}\right) \quad (5)$$

For this study, the purpose of the LMDI is to determine the explanatory effects of changes in electricity consumption in Madagascar for the period 1987 to 2015. E refers to the total electricity consumption. The superscripts t and t+1 denote the current and next year used in the decomposition. The different sector categories (i) considered are industrial, residential, SMEs/services, and street lighting. According to the available data, our choice of effects is similar to that of the studies conducted by [48]:

- The activity effect Q is determined by the number of subscribers (Q = total number of subscribers, and Q_i = number of subscribers per sector).
- The structural effect S is determined by the percentage of subscribers by sector.
- The intensity effect I is determined by the electricity consumption per subscriber.

LMDI decomposition will then be performed using a time series decomposition approach. In other words, the decomposition equations will be applied to each pair of years during the period under review. The reference year is therefore not stable but rolling. Indeed, the time series decomposition approach is well suited to provide better visualization and interpretation of the influence of factors on the decomposed term [49, 50].

3.4. Sensitivity analysis

The SA is used to study the effects of a change in one variable on the other variables and especially on the final results [51]. It allows us to simplify and better understand a model by directing the focus to specific influential modules. Additionally, it can validate a model and help in establishing future experiments. Different methods of SA have been developed, including differential methods [52], screening methods such as the Morris method [53], and methods based on analysis of variance such as the FAST (Fourier amplitude sensitivity test) and EFAST (extended Fourier amplitude sensitivity test) methods [54–56]. In this study, the analysis will be conducted using the EFAST method. This method calculates the first-order sensitivity index (S_i) and the total order index (S_{Ti}) using the same set of samples. These sensitivity indices are expressed according to the expectation (E) and the variance (V) of an output Y (X_1, X_2, \dots, X_k):

$$S_i = \frac{V[E(Y | X_s)]}{V(Y)} \quad (6)$$

$$S_{Ti} = \frac{E[V(Y | X_{\sim i})]}{V(Y)} = 1 - \frac{V[E(Y | X_{\sim i})]}{V(Y)} \quad (7)$$

where

- S_i : contribution of the main effect of the i^{th} input factor to the output value.
- S_{Ti} : contribution of the effect of the i^{th} input factor to the output value taking into account its interactions with the other factors of the model.

The classical FAST method was introduced in the 1970s to calculate only the sensitivity indices of the first order. Later, Saltelli et al. [54] improved it to the EFAST method, which is also able to compute higher order and total indices. The principle of the FAST method is to associate a frequency w_i with each factor and to generate values according to the function

$$X_i = G_i(\sin(\omega_i s)) \quad (8)$$

It is recommended this function be transformed into

$$X_i = \frac{1}{2} - \frac{1}{\pi} \arcsin(\sin(\omega_i s)) \quad (9)$$

Thus, the output of the model can be extended with a Fourier series as follows:

$$Y = f(X_1, X_2, \dots, X_k) = f(s) = A_0 + \sum_{j=1}^{\infty} (A_j \cos(js) + B_j \sin(js)) \quad (10)$$

$A_0 = (\frac{1}{2\pi}) \int_{-\pi}^{\pi} f(s) ds$ is an approximation of the expectation of Y.

$A_j = (\frac{1}{2\pi}) \int_{-\pi}^{\pi} f(s) \cos(js) ds$ and $B_j = (\frac{1}{2\pi}) \int_{-\pi}^{\pi} f(s) \sin(js) ds$ are the Fourier coefficients. The variance in Y is obtained by equation 11:

$$V(Y) = (\frac{1}{2\pi}) \int_{-\pi}^{\pi} f^2(s) ds - [E(Y)]^2 \simeq \sum_{j=1}^{\infty} (A_j^2 + B_j^2) - (A_0^2 + B_0^2) \simeq 2 \sum_{j=1}^{\infty} (A_j^2 + B_j^2) \quad (11)$$

3.5. Scenario definition

As shown in Section 3.2, the electricity data are provided by JIRAMA. The demographic data were obtained from INSTAT. For the prospective analysis, the scenario assumptions are determined based on Madagascar's energy planning documents:

- A study carried out by Mavethic Consulting for the Ministry of Energy as part of the P2RSE (Energy Sector Recovery and Restructuring Project), established in 2013 [57], which is based on two planning scenarios, both in terms of production and consumption, in the energy sector: the "Probable Scenario", which is driven by an upward trend in the GDP growth rate, which reaches 5% in 2017 and then remains constant until 2030, and the "Voluntarist Scenario", which is driven by a continuation of this upward trend to reach 7% in 2022 before remaining constant until 2030.
- The New Energy Policy (NPE): Established in 2015, its vision for 2030 targets an electrification rate of 70% and an electricity mix from renewable energy of up to 85% [58].

Thus, four scenarios will be studied: the reference scenario (business as usual), the probable scenario of the P2RSE, the voluntarist scenario of the P2RSE and the scenario of the NPE.

3.5.1. Scenario 1: BAU

The BAU scenario is based on projections of different data according to their past trend. It is therefore a scenario without any particular intervention. For this, time series modeling is used. Thus, based on the results obtained, the assumptions of this scenario are as follows:

- For the residential sector, the number of subscribers ranges from 483,442 in 2015 to 772,252 in 2030. The specific consumption by these residential customers increases by 14.705 kWh per year per subscriber from 2015 to 2030.
- For the industrial sector, the scenario foresees the connection of 12 new HV subscribers per year from 2015 to 2030, which results in 1237 industrial subscribers by 2030.

Between 1987 and 2015, an average increase of 1424.30 kWh/year per subscriber was observed, corresponding to an annual growth rate of 0.27%. The BAU statement suggests that this increase from 331,054.23 kWh/subscriber in 1987 to 371,580 kWh/subscriber in 2030 occurs.

3.5.2. Scenario 2: Probable Scenario of the P2RSE

Scenario 2 considers the following assumptions:

- Population growth of 2.9% per year.
- An electrification rate of 30% in 2030.
- For the residential sector, an increase of 11 kWh per year per subscriber until 2020 and of 7 kWh per year per subscriber in the following years.
- The GDP produced by the secondary sector grows by 7% per year on average. This induces electricity consumption in the industrial sector of 771,311 kWh by 2030.
- In the P2RSE scenarios, electricity consumption in the industrial sector is estimated solely on the basis of the GDP growth rate produced by this sector. In other words, the P2RSE does not specify any hypothesis concerning the evolution of the number of subscribers in this sector or the consumption per subscriber. As no particular development in the number of industries in Madagascar is planned in the PND (National Development Plan), we will assume that this increase in electricity consumption in the industrial sector is mainly due to the increase in consumption per subscriber of the sector. Thus, with a growth rate of GDP produced by the secondary sector of 7%, the consumption per subscriber in the industrial sector grows by 3.93% to reach 623,290 kWh per subscriber, which is almost twice the consumption per subscriber considered in the reference scenario.
- Regarding the number of subscribers in the industrial sector, the BAU scenario assumption will be used.

3.5.3. Scenario 3: Voluntarist Scenario of the P2RSE

For the voluntarist scenario, we take a growth rate of 3%, which corresponds to the high scenario of the INSTAT demographic study.

This scenario differs from the probable scenario, particularly in terms of changes in the industrial sector. Indeed, the growth rate in GDP produced by the secondary sector is projected at 9% per year; consequently, the consumption per subscriber of the industrial sector grows by 5.64% per year

to reach 796,338 kWh per subscriber in 2030.

In addition, as in the “probable scenario”, the electrification rate is 30% in 2030, and the increase of 11 kWh per year per subscriber until 2020 and 7 kWh per year per subscriber in the following years are maintained.

3.5.4. Scenario 4 : Scenario of the NPE

Mainly focused on the residential sector, the NPE predicts an electrification rate of 70% by 2030. This is an ambitious goal and far superior to that envisaged by the P2RSE.

The industrial sector keeps its current evolutionary trend in terms of the number of subscribers as well as energy intensity.

4. Results and discussion

4.1. Understanding the past

4.1.1. LMDI decomposition results of electricity consumption

The results of the additive decomposition with the rolling reference are presented in Fig. 3. The results depict the evolution of the electricity consumption of Madagascar from 1987 to 2015. Fig. 4 shows the results of the additive decomposition with a fixed reference year (1987). We opted to decompose according to a fixed reference year to be able to keep track of structural changes in electricity consumption and extract general trends. We can thus obtain an interesting result: on the one hand, information on the trend type as in the time series and, on the other hand, annual information on the distribution of the different effects. In the interpretation of the results, a positive value indicates an increase and a negative value, a decrease

According to Fig. 3, changes in total electricity consumption (total effect) are generally discontinuous and irregular, and the trend is variable. A negative peak was observed between 1990 and 1991, followed by a positive peak in 1992-93. The variation decreased between 1994 and 1995. This decline was followed by an increase in the 1995-96 period and stagnation between 1997 and 2000. After that, between 2000 and 2010, there was a phase of instability in the variation in Madagascar’s electricity consumption. Two negative peaks are highlighted in 2001-2002 and 2008-2009, each corresponding to a period when the country was plunged into political crisis. Between 2010 and 2015, the variation was more or less stable. By relating these results to the history of the country, it was observed that the peaks of the variation in electricity consumption are linked to the socio-political context of the country. This observation is detailed in Section 4.1.2.

The change in the number of subscribers does not have a significant influence on the annual electricity consumption (year by year); see Figure 3. However, as can be observed in Figure 4, the growth trend in electricity consumption (blue line) is closely linked to the evolution of the number of subscribers (green line).

Concerning the intensity effect, its yearly change is similar to that of the total effect (Figure 3), but its evolution from 1987 to 2015 is stagnant in general (Figure 4). Thus, the evolution of Madagascar’s electricity consumption is mainly due to changes in the number of subscribers, but significant increases or decreases can be explained by changes in energy intensity.

The overall average trend in the year-on-year change in the structural effect is stagnant (see Figure 3). From 1987 to 2015, the distribution of the number of subscribers in each sector did not change the trend in electricity consumption.

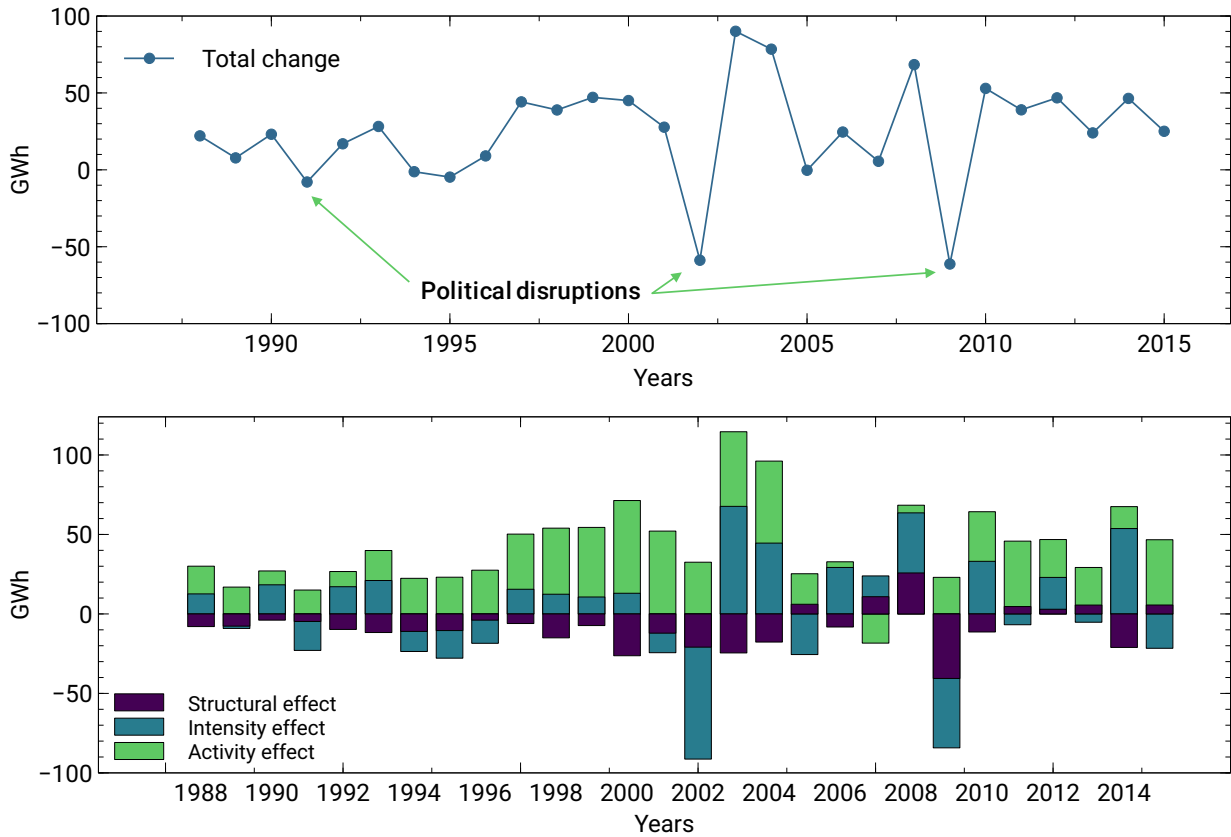


Figure 3: Additive decomposition results of total electricity consumption in Madagascar, 1987-2015.

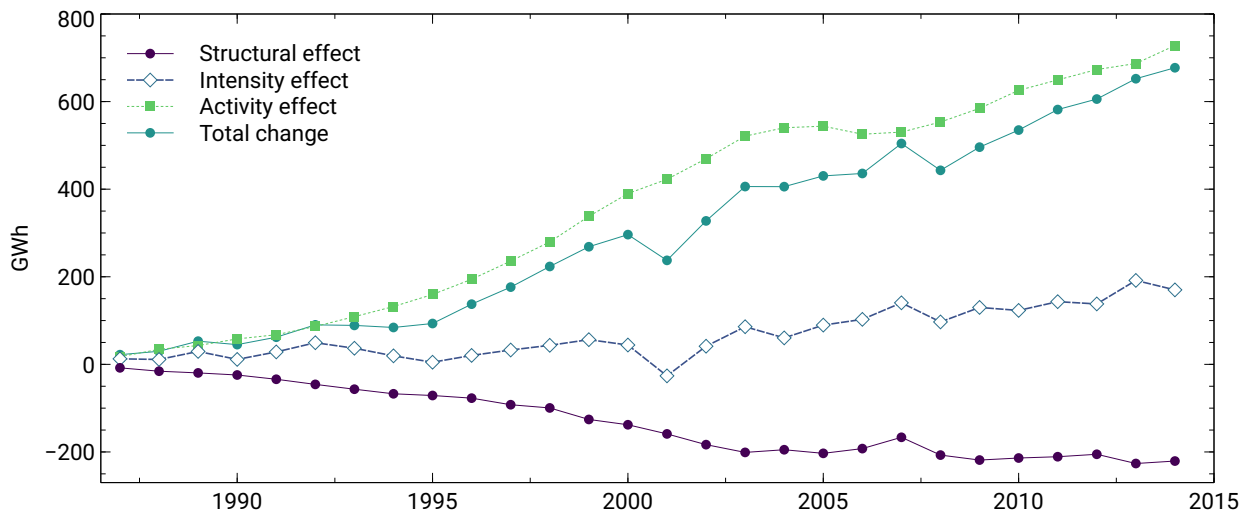


Figure 4: Additive decomposition based on the reference year 1987.

4.1.2. Historical analysis of electricity consumption

In view of the dynamics of variation in the different effects, it is possible to relate the socio-political context of the country to the variation in its electricity consumption. Indeed, each signifi-

cant negative peak corresponds to a socio-political crisis. Each period of decline is then generally followed by a significant increase, which corresponds to the stabilization of the economic situation of the country following the end of the crisis.

1990-1991: Electricity consumption decreased by 1.97% (-7.92 GWh). The intensity effect (ΔE_{int}) is the greatest contributor to this decrease (-18.2 GWh or -4.54%), supported by the structural effect (-4.74 GWh or -1.18%), while the activity effect contributes positively (+15 GWh or + 3.75%). This period is characterized by a series of manifestations aimed at the repeal of the Socialist Constitution of 1975 and the dismissal of President Didier Ratsiraka.

1991-1993: This period is marked by the positive influence of the activity effect (ΔE_{act}) and the intensity effect on total electricity consumption despite the negative contribution of the structural effect (ΔE_{str}). This increase occurs in relation to the return of calm in Madagascar after the political crisis of 1991. The State High Authority (HAE) adopted a new management policy for state corporations: the privatization of several state-controlled enterprises. This led to the arrival of many investors and the development of free trade areas in the capital of the island.

1994-1995: The decrease is 1.08% (-4.73 GWh). The intensity effect ΔE_{int} is -12.60 GWh (-2.88%), and the structural effect ΔE_{str} is -11 GWh (-2.40%). However, the activity effect ΔE_{act} is positive, with a value of +22.4 GWh (+5.11%). This period is marked by the passage of the cyclone Geralda (February 1994), which greatly affected Madagascar; in total, more than 40,000 houses were destroyed, with 356,000 people affected. The cyclone killed 231 people and caused more than 10 million dollars (USD 1994) of damage.

2001-2002: The total variation ΔE_{tot} is -9.12% (-58.8 GWh) and is caused by an intensity effect ΔE_{int} of -70.4 GWh (-10.93%), a structural effect ΔE_{str} of -20.9 GWh (-3.24%), and an activity effect ΔE_{act} of +32.5 GWh (+ 5.05%). The decrease in this period is ten times greater than that in 1994-95, especially the decrease caused by the intensity effect. Indeed, the postelection crisis of 2001-02 had serious consequences for the country, as roadblocks to isolate the capital led to a fuel shortage in Antananarivo Province, resulting in problems with JIRAMA's power generation. Moreover, many "Free Trade Zone" companies whose activities focused on exporting products had to close their doors because the crisis was not conducive to exports. Consequently, the country experienced a significant decline in economic and industrial activity, reflecting a decline in JIRAMA industrial subscribers and a decrease in subscriber consumption. To these issues, inflation was added.

2002-2003: Within a year, we can see the revival of Madagascar's electricity consumption after a period of decline. This is reflected in a total change of 90.1 GWh, or 15%, over the previous year. The new boom was strongly influenced by the intensity effect and the activity effect, despite a negative structural effect. The end of the first half of 2002 marked a new era for Madagascar. A new president was officially proclaimed and invested. Towards the end of that same year, economic recovery was discussed. Madagascar was reintegrated into the Organization of the African Union; additionally, the new president engaged in a policy of privatization and openness to foreign capital, which paid off because Madagascar's economy grew. The export market was therefore relaunched.

2008-2009: The total change is -7.19% (-61.2 GWh), caused by an intensity effect of -43.7 GWh (-5.12%), a structural effect of -40.6 GWh (-4.76%) and an activity effect of +23 GWh (+2.70%). A political crisis erupted in January 2009 when Andry Rajoelina (then mayor of Antananarivo, the capital) took power, and this stopped the economic growth of the country, resulting in a decline in GDP, income and inflation and a rise in unemployment. In other words, economic and social indicators were declining.

2010-2015: No significant change in the variation in electricity consumption is observed. This coincides with the economic and political stability of the country after experiencing the 2009 crisis. At the end of January 2009, A. Rajoelina set up the High Transitional Authority (HTA), of which he took the lead. What was supposed to be only a transitional government actually remained in power until 2015 [59]. The continuation of this regime was achieved at the cost of the ongoing reshuffling of ministerial positions and the absence of political opposition. In 2011, a roadmap was signed to eliminate this situation. The withdrawal of international aid in the country put it in a critical economic situation, pushing authorities to exploit essential resources such as rosewood [60]. The uncertainty surrounding the pseudostability of the transition period also hindered investment in and the development of the industrial sector.

Finally, from 1987 to 2015, the total electricity consumption increased nearly three times. The effect of the number of subscribers led to a 3.46-fold increase in electricity consumption. This is mainly due to population growth and the intensive development of urban areas (urban sprawl of main cities), leading to an increase in the number of subscribers. Beyond the increase in the number of subscribers, this increase can be explained by the evolution of technological conditions, electronic devices and household usage frequencies [37, 38]. Indeed, additionally, within this increase, 1.21 times was due to the intensity effect, which is much lower than that due to the activity effect of 2.95 times. As shown in Figure 4 the intensity effect and total change curves are highly correlated. Therefore, this demonstrates the significant challenge of limiting energy intensity growth in projections of electricity demand. Finally, the share of the structural effect in the change in electricity consumption was negative at 0.66.

This decrease occurred because the distribution of the number of subscribers in each sector is a limiting factor in national electricity consumption.

4.2. Modeling futures

4.2.1. Reduced regressive models

An initial linear regression is performed on the activity effect, the intensity effect and the structural effect as a function of the number of subscribers and the consumption per subscriber of the different sectors. Then, a SA is applied to reduce the models. The results of the SA, see Table 2, deepen and reinforce those obtained previously by the LMDI decomposition. SA allows us to identify the parameters that influence each effect the most. Previous work in the literature has focused on disaggregating electricity consumption by effects. Our objective in this study, using SA, is to define the parameters influencing the effects to construct a regressive model. It is then possible for us to reconstruct the total consumption from the different regressive models. This approach is relevant for energy planning and energy scenarios.

Table 2 presents first-order indices (contribution of the main effect of the input factor to the output value) and total indices (contribution of the effect of the input factor to the output value

Table 2: E-FAST method sensitivity indices

Parameters	First order index			Total order index		
	ΔE_{int}	ΔE_{act}	ΔE_{str}	ΔE_{int}	ΔE_{act}	ΔE_{str}
ΔQ_R	-	0.976	0.323	-	0.979	0.323
ΔQ_I	-	0.020	0.613	-	0.020	0.614
ΔQ_{SME}	-	0.000	0.051	-	0.000	0.051
ΔQ_{LP}	-	0.000	0.011	-	0.000	0.011
ΔI_R	0.096	-	-	0.096	-	-
ΔI_I	0.821	-	-	0.823	-	-
ΔI_{SME}	0.078	-	-	0.078	-	-
ΔI_{LP}	0.003	-	-	0.004	-	-

taking into account its interactions with the other factors in the model). The higher its index is, the more influential the parameter.

For the variation in electricity consumption according to the activity effect (ΔE_{act}), the most influential parameter is the variation in the number of residential sector subscribers (ΔQ_R), with a total index of 0.979. The residential sector regroups the inhabitants. It has the highest concentration of subscribers. An increase in the number of residential subscribers generally reflects population growth, which leads to an extension of urban areas and of the electricity grid, thus increasing the demand for electricity. Referring to the results of the SA (Table 2), the change in consumption per subscriber in the industrial sector (ΔI_I), with a total index of 0.821, is the factor that most affects the intensity effect (ΔE_{int}), followed by the change in consumption per subscriber in the residential sector (ΔI_R). According to the JIRAMA classification, the industrial sector includes all those who subscribe to the medium-voltage/high-voltage sector, as they have the highest need per subscriber. The residential sector has the highest growth in subscribers, but the need per subscriber is low. Indeed, consumption per subscriber in Madagascar's residential sector was 1188 kWh per subscriber in 2015. With 7 people per household, the consumption of one inhabitant is approximately 170 kWh. Compared to the world average of approximately 1605 kWh per capita, this is relatively low. Future growth in the consumption per residential subscriber could result in a significant change in electricity demand. The variation in electricity consumption according to the structural effect (ΔE_{str}) is mainly influenced by the change in the number of subscribers in the industrial sector, which has a total index of 0.614 (Table 2). In this case, the structural effect, albeit of small magnitude in the period analyzed, is of great importance if one considers its causes and consequences. Indeed, it expresses the importance given to the weight of the share of subscribers in the industrial sector. A negative structural effect therefore reflects an increase in the share of subscribers in sectors with low demand per subscriber to the detriment of energy sectors. In contrast, a positive structural effect (or an increase) marks the development of the energy-intensive sector, which is the industrial sector. In other words, a negative structural effect means that a low share of energy-intensive sectors prevents the country's electricity consumption from increasing further.

Considering the results obtained above, the variation in electricity consumption according to the

effect of activity, structure and intensity are expressed by regression functions based on the identified influential parameters. The unit considered in the development of the model is the kilowatt-hour (kWh). The learning database uses 1987-2005 and the generalization database is applied to 2006-2015. The validation of the model, carried out over the period from 2006 to 2015, shows an average error range of 2% for the activity effect, 16% for the intensity effect, 11% for the structural effect and 5% for the total effect (see figure 5).

$$\Delta E_{act} = 2115 \times \Delta Q_R + 12964562 \quad (12)$$

$$\Delta E_{int} = 832.7 \times \Delta I_I + 297744.2 \times \Delta I_R - 5949865 \quad (13)$$

$$\Delta E_{str} = 1.073 \times 10^5 \times \Delta Q_I - 862.2 \times \Delta Q_R - 1.405 \times 10^7 \quad (14)$$

These reduced regression models are then used in the implementation of different projection scenarios.

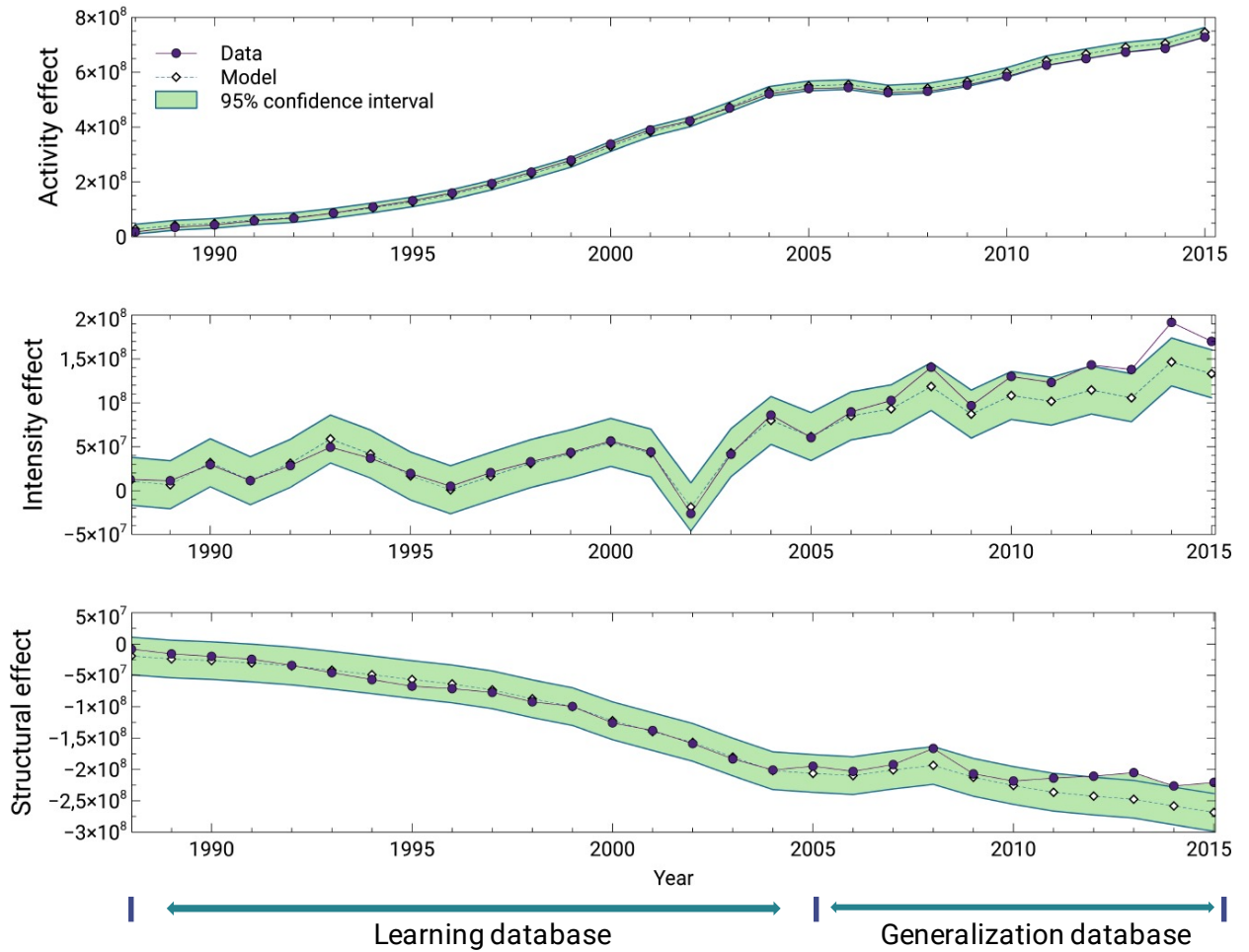


Figure 5: Validation of the reduced regressive models on the 1987-2015 period.

4.2.2. Electricity projection

As previously described in section 3.5, four scenarios were constructed for this study. The objective of the scenarios was to analyze the consequences of different energy policies in Madagascar for electricity consumption. Therefore, the assumptions were defined on the basis of the Malagasy government's energy planning objectives. The Malagasy government has included in its Act No 2017-20 [61] the necessity of using renewable sources, which aims at securing and making the electricity sector more attractive. However, no clear forecast of electricity demand is currently available. As a result, few scenarios quantifying needs exist in the literature on that country. A previous study on Madagascar proposed several scenarios for electricity consumption based only on targets for reducing greenhouse gas emissions by 2030 [11]. Three scenarios, low, medium and high, were developed in the study of [11]. Thus, the highest needs for the country defined during the simulation are 3,507 GWh by 2030.

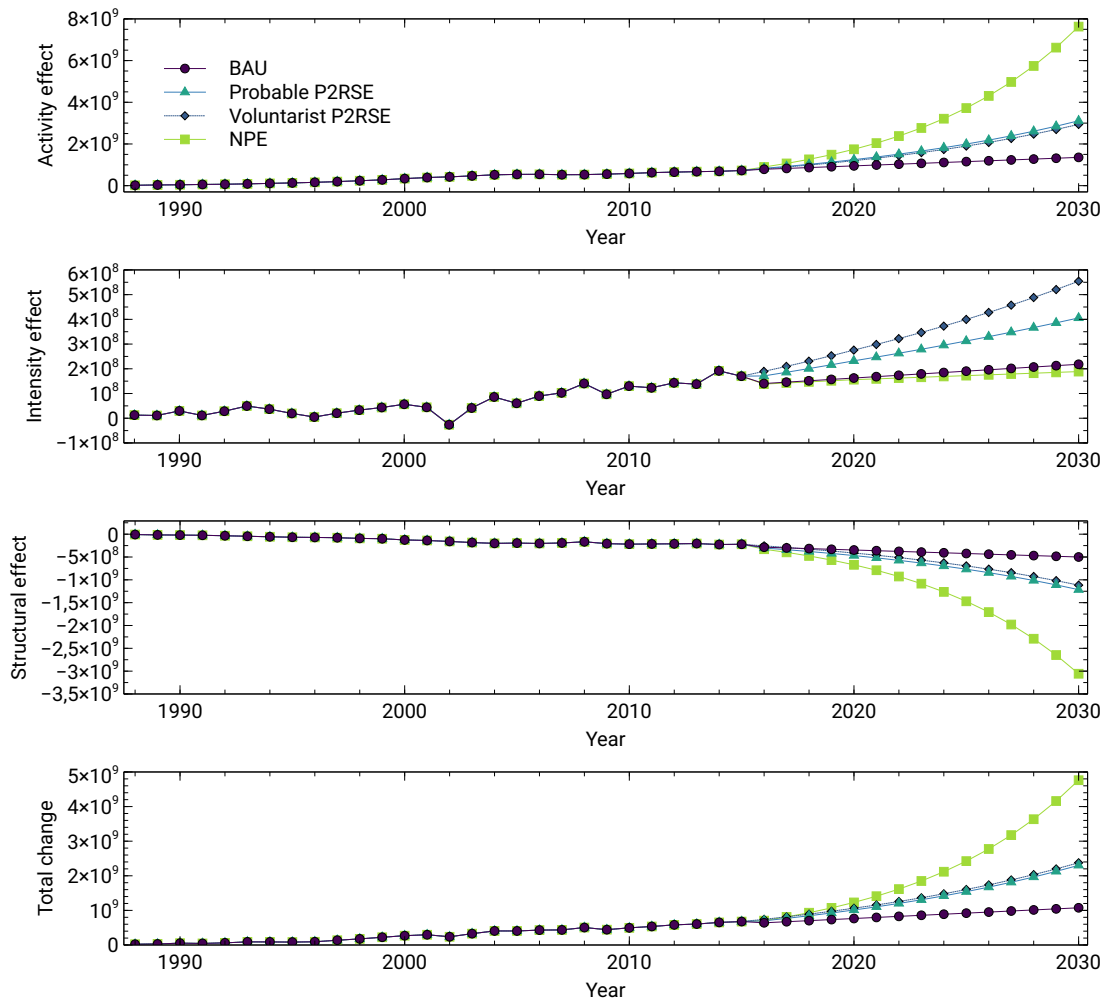


Figure 6: Evolution trend of effects in kWh according to the scenarios for 2030.

For this study, the projection is based on the metamodels obtained from the SA performed on each effect (equations 12 to 14). The results are presented in Figure 6. The projection of the evolution of electricity consumption under the BAU scenario gives results showing a general linear trend. The variation in electricity consumption from 1987 to 2030 due to the different effects (activity, structure and intensity) is estimated at 1075 GWh, which leads to a total consumption of approximately 1423 GWh in 2030, which is 50% more than in 2015. The representative lines of the projection begin to curve from the probable scenario of the P2RSE. Indeed, the projection of a 30% electrification rate in 2030 implies an increase of 2302 GWh from 1987 to 2030 for the probable scenario and 2474 GWh for the voluntarist scenario. This represents an estimated total consumption of 2650 GWh by 2030 for the probable scenario and of 2822 GWh for the voluntarist scenario, almost three times that in 2015. As soon as the electrification rate increases, electricity demand increases significantly, even if GDP increases slowly. Although the economic situation is strongly correlated with electricity consumption, for a poorly electrified territory such as Madagascar, evolution in the rate of access to electricity generates an exponential increase in demand. A comparison between the results of [62] and those of this study illustrates this case very well. Considering only a very strong economic growth rate of 10% per year, the CREAM study estimates electricity consumption of 4,719 GWh by 2030, while the NPE scenario of this analysis based only on increasing the electrification rate to 70% results in a total electricity consumption of 5110 GWh by 2030 with an increase of 4761 GWh from 1987 to 2030 (Figure 6), almost 5 times that in 2015. In terms of energy intensity, the energy efficiency policy applied by the NPE at both the industrial and residential customer levels leads to a reduction of 0.66 times the variation due to the intensity effect compared to the BAU scenario for the period of 2015 to 2030.

Moreover, even by 2030, the structure of Madagascar’s electricity consumption evolution according to established political strategies remains the same; for all established scenarios, the activity effect has the same trend as the total effect, and the structural effect follows a decreasing trend because the low share of the energy-consuming sector prevents consumption from increasing further (Figure 6). In other words, the prospective analysis of electricity demand under the considered scenarios shows that consumption will be mainly driven by residential customers. While this limits the country’s electricity consumption, the place of industrial customers must be carefully considered because the industrial sector is one of the driving forces of the economy and plays an important role in the profitability of the installed plants [63]. Households, which constitute the vast majority of consumers, have low purchasing power. The structure wherein demand is dominated by these low-income users rather than industrialists could continue to affect the profitability of operating centers.

4.2.3. Political interventions in the energy agenda

The decomposition method applied to scenario design has enlightened us on the role that political ambition can have on the different effects of electricity consumption. As shown in Figure 6, whatever the effects, the probable and voluntarist scenarios differ only slightly. Thus, considering the implications, it may be considered in the context of choosing one of the two scenarios, retaining the one that is more financially viable and easier to execute. Except for the intensity effect where the BAU and NPE scenarios merge, the NPE is quite distinct from the others in all other cases. As a result, we can see how abruptly the transition to the NPE scenario can occur. One possibility is to begin a smooth transition from one of the two P2RSE scenarios. After that, in a subsequent step, the NPE scenario could be initiated. This would imply a more gradual transformation of the economic and social systems. These findings emphasize the importance of coupling the decomposi-

tion and the scenarios, which enables us to reason about energy policy in terms of trends and test various hypotheses about energy policy across sectors of activity.

5. Conclusions

Madagascar has been trying to emerge from its least-developed country status for the past three decades. This article first provides a historical and comprehensive analysis of the electricity consumption of the island. The underlying factors affecting energy consumption in Madagascar's electricity sector over the last two decades (1987–2015) were defined using the logarithmic mean Divisia index (LMDI). Given the importance of the electricity sector to economic growth, decomposition assessments of energy use were conducted to ascertain the impact of political disruptions. Additionally, the correlation between variables affecting each sector's effects was addressed. This work then explores scenarios constructed from the regressive model based on the most influential parameters previously identified by the SA.

5.1. Main findings

- With a contribution ratio of 107.5% to the overall energy consumption change, the activity factor is responsible for a significant increase between 1987 and 2015. This value is 157.95% in the BAU scenario and 168.99% for the NPE scenario from 2015 to 2030.
- The structural factor resulted in a tremendous reduction in total energy consumption (-32.6%) and in the NPE scenario (-62.6%). The energy intensity factor substantially increased energy consumption by 25.1% (1987-2015) and 22.1% in the business-as-usual scenario.
- The trend of energy consumption is generally upward in the past and in the 2015-2030 period. In the industrial sector, the activity factor had the greatest impact on energy consumption, while energy intensity had a mixed impact on ΔE_{tot} . As this factor had a negative effect in most years, the overall change in consumption was also negative. This negative effect is roughly related to the structural effect. Thus, abrupt negative changes result from political uncertainty, which affects economic activity and, as a result, the number of industrial subscribers and the energy intensity of activities.
- By minimizing the intensity effect change to 9.87% between 2015 and 2030, the NPE scenario's total consumption increase is limited to 4084 GWh. By contrast, this amount is 398 GWh for the BAU scenario with a 22% intensity effect. This result translates into a significant increase in access to electricity.

5.2. Recommendations and policy implications

The policy implications of our main findings can be summarized as follows:

- The objective of emergence is to move from the status of a least-developed country into emerging country status. We can, therefore, expect marked economic development that will be strongly linked to an increase in electricity consumption, as shown in several comprehensive studies [64, 65]. Considering the current situation of the energy sector in Madagascar, the achievement of these objectives requires the following:
 - Initiating incentives through financial support to promote renewable energy sources.

- Securing the energy supply
- Significantly improving the distribution network
- At present, the government is focusing its efforts on energy security and decarbonization of the mix. It is necessary to include a discussion on the possible paths of future demand to anticipate production facilities. Our results can serve as a guideline for these considerations.
- Political instabilities have a negative effect on the country's structural effects and intensity. This uncertainty often hinders the sustainable development of the territory. To stabilize its economic growth and energy transition, Madagascar must pay close attention to maintaining a safe and stable political climate.

Finally, to design a roadmap for Madagascar's energy transformation, it is essential that all the effects and variables addressed in this work be integrated to consider various intermediate objectives to be achieved in the medium term. The above results suggest a strong strategic direction for national energy policy. As Madagascar has not yet completed its demographic transition, two challenges need to be addressed by stakeholders in the power system: decarbonizing the mix and satisfying a growing demand for energy. Madagascar must, therefore, decarbonize its growth, secure its electricity production and limit the growth of its energy intensity.

References

- [1] J. H. Brown, W. R. Burnside, A. D. Davidson, J. R. Delong, C. William, M. J. Hamilton, N. Mercado-silva, J. C. Nekola, J. G. Okie, H. William, J. H. Brown, W. R. Burnside, A. N. A. D. Davidson, P. John, Energetic Limits to Economic Growth, *American Institute of Biological Sciences* 61 (1) (2011) 19–26. doi:10.1525/bio.2011.61.1.7.
- [2] Y. Wolde-rufael, Energy demand and economic growth : The African experience, *Journal of Policy modeling* 27 (2005) 891–903. doi:10.1016/j.jpolmod.2005.06.003.
- [3] Y. Wolde-Rufael, Electricity consumption and economic growth: A time series experience for 17 African countries, *Energy Policy* 34 (10) (2006) 1106–1114. doi:10.1016/j.enpol.2004.10.008.
- [4] S. Abosedra, A. Dah, S. Ghosh, Electricity consumption and economic growth , the case of Lebanon, *Applied Energy* 86 (4) (2009) 429–432. doi:10.1016/j.apenergy.2008.06.011.
URL <http://dx.doi.org/10.1016/j.apenergy.2008.06.011>
- [5] W. Bank, Access to electricity (% of population) | data (2019).
URL <https://data.worldbank.org/indicator/eg.elc.accs.zs>
- [6] B. Looney, Statistical review of world energy, 2020| (2020).
- [7] L. Cozzi, T. Gould, S. Bouckart, D. Crow, T.-Y. Kim, C. McGlade, P. Olejarnik, B. Wanner, D. Wetzel, *World Energy Outlook 2020 2050* (October) (2020) 1–461.
- [8] W. Bank, World development indicators - access to electricity in least developed countries (2018).
- [9] MEH, Bilan énergétique de madagascar, Tech. rep., <http://www.energie.mg/> (2020).
- [10] P. Raghoo, D. Surroop, F. Wolf, W. Leal Filho, P. Jeetah, B. Delakowitz, Dimensions of energy security in Small Island Developing States, *Utilities Policy* 53 (2018) 94–101. doi:10.1016/j.jup.2018.06.007.
URL <http://www.sciencedirect.com/science/article/pii/S0957178717302308>
- [11] J. P. Praene, M. H. Radanielina, V. Rakotoson, L. Andriamamonjy, F. Sinama, D. Morau, Electricity generation from renewables in Madagascar : Opportunities and projections, *Renewable and Sustainable Energy Reviews* 76 (March) (2017) 1066–1079. doi:10.1016/j.rser.2017.03.125.
URL <http://dx.doi.org/10.1016/j.rser.2017.03.125>
- [12] P. A. Trotter, M. C. McManus, R. Maconachie, Electricity planning and implementation in sub-saharan africa: A systematic review, *Renewable and Sustainable Energy Reviews* 74 (2017) 1189–1209. doi:10.1016/j.rser.2017.03.001.
URL <https://doi.org/10.1016/j.rser.2017.03.001>
- [13] D. Surroop, P. Raghoo, Renewable energy to improve energy situation in african island states, *Renewable and Sustainable Energy Reviews* 88 (2018) 176–183. doi:10.1016/j.rser.2018.02.024.
URL <https://doi.org/10.1016/j.rser.2018.02.024>
- [14] M. Child, O. Koskinen, L. Linnanen, C. Breyer, Sustainability guardrails for energy scenarios of the global energy transition, *Renewable and Sustainable Energy Reviews* 91 (2018) 321–334. doi:10.1016/j.rser.2018.03.079.
URL <http://www.sciencedirect.com/science/article/pii/S136403211830176X>
- [15] J. Markard, R. Raven, B. Truffer, Sustainability transitions: An emerging field of research and its prospects, *Research Policy* 41 (6) (2012) 955–967. doi:10.1016/j.respol.2012.02.013.
URL <http://www.sciencedirect.com/science/article/pii/S004873331200056X>
- [16] A. Grubler, Energy transitions research: Insights and cautionary tales, *Energy Policy* 50 (2012) 8–16. doi:10.1016/j.enpol.2012.02.070.
URL <https://www.sciencedirect.com/science/article/pii/S0301421512002054>
- [17] M. Allen, P. Antwi-Agyei, F. Aragon-Durand, M. Babiker, P. Bertoldi, M. Bind, S. Brown, M. Buckeridge, I. Camilloni, A. Cartwright, et al., Technical summary: Global warming of 1.5° c. an ipcc special report on the impacts of global warming of 1.5° c above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (2019).
- [18] J. Köhler, F. W. Geels, F. Kern, J. Markard, E. Onsongo, A. Wiecek, F. Alkemade, F. Avelino, A. Bergek, F. Boons, L. Fünfschilling, D. Hess, G. Holtz, S. Hyysalo, K. Jenkins, P. Kivimaa, M. Martiskainen, A. McMeekin, M. S. Mühlemeier, B. Nykvist, B. Pel, R. Raven, H. Rohracher, B. Sandén, J. Schot, B. Sovacool, B. Turnheim, D. Welch, P. Wells, An agenda for sustainability transitions research: State of the art and future directions, *Environmental Innovation and Societal Transitions* 31 (2019) 1–32. doi:10.1016/j.eist.2019.01.004.
URL <http://www.sciencedirect.com/science/article/pii/S2210422418303332>
- [19] F. Robertson Munro, P. Cairney, A systematic review of energy systems: The role of policymaking in sustainable transitions, *Renewable and Sustainable Energy Reviews* 119 (2020) 109598. doi:10.1016/j.rser.2019.109598.
URL <https://www.sciencedirect.com/science/article/pii/S1364032119308068>

- [20] H. Jianchao, Z. Ruoyu, L. Pingkuo, Z. Lyuyang, A review and comparative analysis on energy transition in major industrialized countries, *International Journal of Energy Research* 45 (2) (2021) 1246–1268, [_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/er.5866](https://onlinelibrary.wiley.com/doi/pdf/10.1002/er.5866). doi:<https://doi.org/10.1002/er.5866>. URL <https://onlinelibrary.wiley.com/doi/abs/10.1002/er.5866>
- [21] N. Abas, A. Kalair, N. Khan, Review of fossil fuels and future energy technologies, *Futures* 69 (2015) 31–49. doi:10.1016/j.futures.2015.03.003. URL <https://www.sciencedirect.com/science/article/pii/S0016328715000397>
- [22] F. Dalla Longa, B. van der Zwaan, Heart of light: an assessment of enhanced electricity access in Africa, *Renewable and Sustainable Energy Reviews* 136 (2021) 110399. doi:10.1016/j.rser.2020.110399. URL <https://www.sciencedirect.com/science/article/pii/S1364032120306870>
- [23] C. Zhang, K. Zhou, S. Yang, Z. Shao, On electricity consumption and economic growth in China, *Renewable and Sustainable Energy Reviews* 76 (2017) 353–368. doi:10.1016/j.rser.2017.03.071. URL <https://www.sciencedirect.com/science/article/pii/S1364032117304045>
- [24] M. K. Nematchoua, A. Yvon, S. E. J. Roy, C. G. Ralijaona, R. Mamiharijaona, J. N. Razafinjaka, R. Tefy, 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* 24 (2019) 100748. doi:10.1016/j.est.2019.04.022. URL <https://www.sciencedirect.com/science/article/pii/S2352152X19301665>
- [25] W. N. Cowan, T. Chang, R. Inglesi-Lotz, R. Gupta, The nexus of electricity consumption, economic growth and CO2 emissions in the BRICS countries, *Energy Policy* 66 (2014) 359–368. doi:10.1016/j.enpol.2013.10.081. URL <https://www.sciencedirect.com/science/article/pii/S0301421513011087>
- [26] M. Salahuddin, K. Alam, I. Ozturk, K. Sohag, The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO2 emissions in Kuwait, *Renewable and Sustainable Energy Reviews* 81 (2018) 2002–2010. doi:10.1016/j.rser.2017.06.009. URL <https://www.sciencedirect.com/science/article/pii/S1364032117309462>
- [27] L. J. Ezzo, Y. Keho, Energy consumption, economic growth and carbon emissions: Cointegration and causality evidence from selected African countries, *Energy* 114 (2016) 492–497. doi:10.1016/j.energy.2016.08.010. URL <https://www.sciencedirect.com/science/article/pii/S0360544216311136>
- [28] J. M. Cansino, A. Sánchez-Braza, M. L. Rodríguez-Arévalo, Driving forces of Spain's CO2 emissions: A LMDI decomposition approach, *Renewable and Sustainable Energy Reviews* 48 (2015) 749–759.
- [29] T. Yang, M. Ren, K. Zhou, Identifying household electricity consumption patterns: A case study of Kunshan, China, *Renewable and Sustainable Energy Reviews* 91 (2018) 861–868. doi:10.1016/j.rser.2018.04.037. URL <https://www.sciencedirect.com/science/article/pii/S136403211830265X>
- [30] Z. Guo, K. Zhou, C. Zhang, X. Lu, W. Chen, S. Yang, Residential electricity consumption behavior: Influencing factors, related theories and intervention strategies, *Renewable and Sustainable Energy Reviews* 81 (2018) 399–412. doi:10.1016/j.rser.2017.07.046. URL <https://www.sciencedirect.com/science/article/pii/S1364032117311164>
- [31] K. R. Abbasi, J. Abbas, S. Mahmood, M. Tufail, Revisiting electricity consumption, price, and real GDP: A modified sectoral level analysis from Pakistan, *Energy Policy* 149 (2021) 112087.
- [32] H. Thomson, C. Snell, S. Bouzarovski, Health, Well-Being and Energy Poverty in Europe: A Comparative Study of 32 European Countries, *International Journal of Environmental Research and Public Health* 14 (6) (2017) 584, number: 6 Publisher: Multidisciplinary Digital Publishing Institute. doi:10.3390/ijerph14060584. URL <https://www.mdpi.com/1660-4601/14/6/584>
- [33] R. Nadimi, K. Tokimatsu, Energy use analysis in the presence of quality of life, poverty, health, and carbon dioxide emissions, *Energy* 153 (2018) 671–684. doi:10.1016/j.energy.2018.03.150. URL <https://www.sciencedirect.com/science/article/pii/S0360544218305590>
- [34] A. Kander, D. I. Stern, Economic growth and the transition from traditional to modern energy in Sweden, *Energy Economics* 46 (2014) 56–65. doi:10.1016/j.eneco.2014.08.025. URL <https://www.sciencedirect.com/science/article/pii/S0140988314002072>
- [35] G. Mutezo, J. Mulopo, A review of Africa's transition from fossil fuels to renewable energy using circular economy principles, *Renewable and Sustainable Energy Reviews* 137 (2021) 110609. doi:10.1016/j.rser.2020.110609. URL <https://www.sciencedirect.com/science/article/pii/S1364032120308935>
- [36] J. Markard, The next phase of the energy transition and its implications for research and policy, *Nature Energy* 3 (8) (2018) 628–633, number: 8 Publisher: Nature Publishing Group. doi:10.1038/s41560-018-0171-7. URL <https://www.nature.com/articles/s41560-018-0171-7>
- [37] N. Narayan, V. Vega-Garita, Z. Qin, J. Popovic-Gerber, P. Bauer, M. Zeman, The Long Road to Universal Electrification: A Critical Look at Present Pathways and Challenges, *Energies* 13 (3) (2020) 508, number: 3

Publisher: Multidisciplinary Digital Publishing Institute. doi:10.3390/en13030508.

URL <https://www.mdpi.com/1996-1073/13/3/508>

- [38] A. A. Eras-Almeida, M. A. Egado-Aguilera, What Is Still Necessary for Supporting the SDG7 in the Most Vulnerable Contexts?, *Sustainability* 12 (17) (2020) 7184, number: 17 Publisher: Multidisciplinary Digital Publishing Institute. doi:10.3390/su12177184.
URL <https://www.mdpi.com/2071-1050/12/17/7184>
- [39] A. Genave, Energy vulnerability in the Southwest Indian Ocean islands, *Journal of the Indian Ocean Region* 15 (1) (2019) 40–57, publisher: Routledge _eprint: <https://doi.org/10.1080/19480881.2019.1560760>. doi:10.1080/19480881.2019.1560760.
URL <https://doi.org/10.1080/19480881.2019.1560760>
- [40] E. Bellos, Sustainable energy development: How can the tension between energy security and energy transition be measured and managed in South Africa?, *Journal of Cleaner Production* 205 (2018) 738–753. doi:10.1016/j.jclepro.2018.08.196.
URL <https://www.sciencedirect.com/science/article/pii/S0959652618325393>
- [41] W. Bank, Population, total | data (accessed 17 January 2019).
URL <https://donnees.banquemondiale.org/indicateur/SP.POP.TOTL?locations=MG>
- [42] W. Bank, Doing business ranking (Accessed 18 Jan. 2019).
URL <http://français.doingbusiness.org/fr/rankings>
- [43] W. Bank, Access to electricity (% of population) | data (Accessed 18 Jan. 2019).
URL <https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS>
- [44] W. Bank, Gdp growth (annual %) | data (Accessed 18 Jan. 2019).
URL <https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG>
- [45] Banque Mondiale, Doing Business 2017: Egalité des chances pour tous, Banque Mondiale, 2017. doi:10.1596/978-1-4648-0948-4.
- [46] B. W. Ang, The LMDI approach to decomposition analysis : a practical guide, *Energy Policy* 33 (2005) 867–871. doi:10.1016/j.enpol.2003.10.010.
- [47] B. W. Ang, LMDI decomposition approach: A guide for implementation, *Energy Policy* 86 (2015) 233–238. doi:10.1016/j.enpol.2015.07.007.
- [48] C. Achão, R. Schaeffer, Decomposition analysis of the variations in residential electricity consumption in Brazil for the 1980-2007 period: Measuring the activity, intensity and structure effects, *Energy Policy* 37 (12) (2009) 5208–5220. doi:10.1016/j.enpol.2009.07.043.
- [49] P. A. Steenhof, Decomposition of electricity demand in China’s industrial sector, *Energy Economics* 28 (2006) 370–384. doi:10.1016/j.eneco.2006.02.006.
- [50] M. Robaina-Alves, V. Moutinho, Decomposition of energy-related GHG emissions in agriculture over 1995-2008 for European countries, *Applied Energy* 114 (2014) 949–957. doi:10.1016/j.apenergy.2013.06.059.
URL <http://dx.doi.org/10.1016/j.apenergy.2013.06.059>
- [51] R. Faivre, B. Iooss, S. Mahévas, D. Makowski, H. Monod, Analyse de sensibilité et exploration de modèles: Application aux sciences de la nature et de l’environnement, Collection Savoir-faire, Éd. Quae, 2013.
- [52] K. J. Lomas, H. Eppel, Sensitivity analysis techniques for building thermal simulation programs, *Energy and Buildings* 19 (1) (1992) 21 – 44. doi:[https://doi.org/10.1016/0378-7788\(92\)90033-D](https://doi.org/10.1016/0378-7788(92)90033-D).
URL <http://www.sciencedirect.com/science/article/pii/037877889290033D>
- [53] M. D. Morris, Factorial Sampling Plans for Preliminary Computational Experiments, *Technometrics* 33 (2) (1991) 161–174. doi:10.1080/00401706.1991.10484804.
URL <https://www.tandfonline.com/doi/abs/10.1080/00401706.1991.10484804>
- [54] A. Saltelli, S. Tarantola, K. P.-S. Chan, A Quantitative Model-Independent Method for Global Sensitivity Analysis of Model Output, *Technometrics* 41 (1) (1999) 39–56.
URL <http://www.jstor.org/stable/1270993>
- [55] A. Saltelli, S. Tarantola, F. Campolongo, Sensitivity Analysis as an Ingredient of Modeling, *Statistical Science* 15 (4) (2000) 377–395.
URL <http://www.jstor.org/stable/2676831>
- [56] M. Sobol, Sensitivity estimates for non-linear mathematical models, *MMCE* 1 (4) (1993) 407–414.
- [57] Mavethic Consulting, Projet de redressement et de restructuration du secteur de l’électricité (P2RSE) - Réactualisation des Plans de Développement des Systèmes Electriques de trois réseaux d’exploitation de la JIRAMA et de trois régions pour l’Electrification Rurale, Tech. rep., Ministère de l’énergie (2013).
- [58] MEH, Document d’étude de la politique et stratégie de l’énergie, Tech. rep., Ministère de l’énergie et des Hydrocarbures de Madagascar (aug 2015).

- [59] M. Razafindrakoto, F. Roubaud, L'énigme et le paradoxe : Economie politique de Madagascar, IRD Orstom, 2017.
- [60] H. Randriamalala, Z. Liu, Rosewood of madagascar: Between democracy and conservation, *Madagascar Conservation & Development* 5 (1) (2010) 11–22.
URL <https://www.journalmcd.com/index.php/mcd/article/view/167>
- [61] R. de Madagascar, Loi 2017- 020 portant code de l'électricité à madagascar (nov 2017).
- [62] A. Voninirina, S. Andriambeloso, Etude sur l'énergie à Madagascar, Tech. rep., CREAM (2014).
- [63] WWF, Diagnostic du secteur énergie à Madagascar, Tech. rep., WWF (2012).
- [64] U. Neelawela, E. Selvanathan, L. Wagner, Global measure of electricity security: A composite index approach, *Energy Economics* 81 (2019) 433–453. doi:10.1016/j.eneco.2019.04.009.
URL <https://doi.org/10.1016/j.eneco.2019.04.009>
- [65] A. Brew-Hammond, *Energy: The Missing Millennium Development Goal*, Springer Netherlands, 2012.