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# Climate finance in the renewable energy sector in Africa

## To what extent can it help combat global warming while stimulating economic development? – Analysis of Morocco

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Academic year 2023-2024
Dissertation for the master of Business Engineering specialising in Financial Engineering
Daytime schedule

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# Declaration

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**1. Rephrasing sentences:** After generating his own texts, the author asked the AI to reformulate some of them to improve their flow.

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By signing this declaration, we affirm that the content of this master's thesis reflects our original work, augmented by the responsible use of AI.

Coline Botspoel, 5 August 2024 in Assesse

Botspoel

## Abstract

In recent years, climate change has become a major concern. Indeed, numerous global agreements have been adopted to reduce CO2 emissions, the main greenhouse gas responsible for global warming. However, while reduction targets are well established, emissions are quite unevenly distributed. Africa, as a very minor emitter, is particularly vulnerable to the consequences.

On the same continent, many initiatives are being undertaken to meet the Paris Agreement targets by 2030. Through climate finance, some countries are receiving funds or accessing various types of financing that enable them to develop projects aimed at mitigating the effects of climate change or improving adaptation, notably by investing in renewable energy. However, although the funding received is significant for the beneficiary countries, its distribution across the continent is highly inequitable, despite a considerable energy potential.

This study aims to analyse, using a quantitative approach with linear regression models, the impact of climate finance invested in renewable energy in Africa on both CO2 emission reductions and the continent's economic development. The goal is to understand to what extent climate finance in renewables can mitigate the effects of global warming while transforming Africa's energy potential into tangible economic benefits.

## Acknowledgements

*The completion of this thesis was made possible through the support, guidance, and presence of several people, to whom I would like to extend my gratitude.*

*First, I would like to thank my supervisor, Professor Bertrand Candelon, for his invaluable advice and guidance, as well as for his responsiveness and availability, which have been crucial in the completion of this thesis.*

*Next, I would like to thank my parents, Michaël and Delphine, as well as my grandmother, for their unwavering support throughout my journey and for helping me reach this point.*

*I would also like to thank Karen Bloomer for dedicating her time to reviewing this thesis.*

*Finally, I am especially grateful to my friends and family, whose support, encouragement, and assistance were significant in completing the writing of this thesis.*

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## Abbreviations and Acronyms

| | |
|---|---|
| **AF** | Adaptation Fund |
| **AFD** | *Agence Française de Développement* (French Development Agency) |
| **AfDB** | African Development Bank |
| **B&C** | Baseline and Credit |
| **BFI** | Bilateral Financial Institutions |
| **C&T** | Cap and Trade |
| **CAT Bond** | Catastrophe Bond |
| **CIF** | Climate Investments Funds |
| **CO2** | Carbon Dioxide |
| **COP** | Convention of the Parties |
| **CPI** | Climate Policy Initiative |
| **CTF** | Clean Technology Funds |
| **ERPA** | Emissions Reductions Payment Agreements |
| **ETS** | Emissions Trading Schemes |
| **GBP** | Green Bond Principles |
| **GCF** | Green Climate Fund |
| **GDP** | Gross Domestic Product |
| **GEF** | Global Environment Facility |
| **GHG** | Greenhouse Gas |
| **IBDR** | International Bank for Reconstruction and Development |
| **IEA** | International Energy Agency |
| **IMF** | International Monetary Fund |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IPP** | Independent Power Producer |
| **IRENA** | International Renewable Energy Agency |
| **JICA** | Japan International Cooperation Agency |
| **KfW** | German Development Bank |
| **LDC(F)** | Least Developed Countries (Fund) |
| **MASEN** | Moroccan Agency for Sustainable Energy |

| | |
|---|---|
| **MDB** | Multilateral Development Bank |
| **Mt CO2** | Million Tonnes of CO2 |
| **NDC** | Nationally Determined Contributions |
| **NGO** | Non Governmental Organisation |
| **OECD** | Organisation for Economic Co-operation and Development |
| **ONEE** | *Office National de l'Électricité et de l'Eau potable* (National Agency for Electricity and Water) |
| **SPV** | Special Purpose Vehicles |
| **SUR** | Seemingly Unrelated Regression |
| **tCO2/Capita** | tonnes of CO2 per Capita |
| **UNDP** | United Nations Development Programme |
| **UNECA** | United Nations Economic Commission for Africa |
| **UNEP** | United Nations Environment Programme |
| **UNESCWA** | United Nations Economic and Social Commission for Western Asia |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **VIF** | Variation Inflation Factor |
| **WB** | World Bank |

# I. Introduction

## 1. Context of the study

Africa is particularly vulnerable to the impacts of climate change. Despite contributing very little to global greenhouse gas emissions (Statista, 2023), the continent is disproportionately affected by these effects. Several sectors, particularly agriculture, which is crucial for the livelihood of many populations, are severely impacted by changing weather conditions, especially extreme and unpredictable ones (*Agence Française de développement* [AFD], 2023). These challenges make it difficult for countries to adapt without adequate resources (Meattle, Balm, Dobrovich, & Guzmán, 2022a).

Climate finance, defined as local, national, or international financial flows intended to fund projects that aim to mitigate or adapt to the impacts of climate change (United Nations Framework Convention on Climate Change [UNFCCC], n.d.-a), emerges as a key concept to help African countries face these challenges (Meattle et al., 2022a). The continent also possesses significant energy potential, particularly in renewable energy, which could be harnessed to achieve their Nationally Determined Contributions (NDCs) and the goals of the Paris Agreement (International Renewable Energy Agency and African Development Bank [IRENA & AfDB], 2022).

## 2. Problem statement

While climate finance appears to be a crucial concept for achieving the goals that African countries have committed to, it also seems to be quite limited, which poses obstacles to meeting these commitments. Indeed, despite significant energy potential in terms of renewable energy, the continent as a whole struggles to attract sufficient funding (Meattle et al., 2022a). Furthermore, the available funds are often poorly distributed, leaving the most vulnerable countries without the resources needed to invest in sustainable solutions (Meattle et al., 2022b). Therefore, the aim of this study is to analyze the impact of the funding received by certain African countries and their investment in renewable energy, focusing on two main aspects:

1. The fight against climate change through the reduction of carbon dioxide (CO2) emissions.
2. The economic development of the recipient countries.

The study aims to evaluate the impact of investments in renewable energy funded by climate finance on economic development and CO2 emissions in Africa. We seek to understand to what extent these investments can mitigate the effects of climate change and how well these efforts align with the objectives of international agreements. Although Africa's energy potential is huge, hundreds of millions of Africans still lack access to electricity, raising the question of whether investments in sustainable energy can truly transform this potential into tangible economic benefits. The goal is to demonstrate, potentially and optimally, that these investments can have positive impacts on $CO_2$ emissions and economic development. By attempting to prove the effectiveness of these investments, we hope to encourage increased financial assistance to these nations in need, while emphasizing the essential role of both public and private sectors in this process.

### 3. Methodology

The study is divided into several parts, each aiming to address a specific aspect of the issue: the introduction, the theoretical and quantitative sections, and the conclusion.

The introduction aims to present the context of the study, the motivations behind choosing this topic, the issue being addressed, the organisation of the research, and finally, the difficulties encountered.

The second part, which constitutes the literature review, includes several chapters: an introduction to the context of climate change in Africa, an exploration of climate finance and its tools, and an overview of the renewable energy sector. The latter includes an analysis of the climate finance received by the sector. For the sections on climate finance and renewable energy, comparisons are drawn between global dynamics and those specific to Africa. Finally, the literature review concludes with an in-depth analysis of the case of Morocco, aiming to explore the mechanisms implemented in the renewable energy sector, the received funding, as well as existing projects and their observable impacts on $CO_2$ emissions and the country's economic development.

The quantitative section is the core of this thesis, as it includes performing multiple linear regressions based on econometric models and analysing their results. ***Chapter 6*** presents our data, explains their collection and preparation, and details the statistical tests used as well as the theory underlying multiple linear regression. ***Chapter 7*** discusses the results of our analyses, while ***Chapter 8*** focuses on testing the hypothesis, highlighting the limitations of the study, and offering recommendations.

Finally, the conclusion provides a summary of the research and its results, while presenting our personal opinion on the issues addressed.

### 4. Difficulties encountered

During the completion of this work, several difficulties were encountered. These concerned mainly the availability of data as well as their temporality, due to the relatively recent nature of the topic of climate change. Additionally, it is important to consider that our results might be biased by unobservable variables that are not constant over time, and that the dependent variable chosen to represent the economic development of countries (i.e., GDP) may not capture all the important dimensions necessary to illustrate this factor. Finally, we would like to mention that the selection of countries for our panel data focuses on those with significant investments in renewable energy and greater utilisation of climate finance mechanisms compared to most countries in Africa. Therefore, the sample does not reflect the entire continent but aims to demonstrate the potential of renewable energy financing when extended to other countries.

# II. Literature Review

## Chapter 1: Africa’s global warming context

### 1.1. Area covered

For the purposes of this report, the term “Africa” refers to the African continent as a whole, encompassing all 55 member countries. The analysis of climate finance and renewable energy sector in this region will therefore be based on data on a continental scale to provide a global perspective on the challenges and obstacles to which Africa is facing in general. However, in some cases, more targeted information may be provided on individual countries (African Union, n.d.).

### 1.2. Minimum contribution for maximum impact

#### 1.2.1. Africa’s greenhouse gas emissions

Between 2000 and 2021, CO2 emissions in Africa varied between 3.4% and 3.9% of global emissions (Statista, 2023). In 2021, the amount of CO2 emitted in Africa was around fourteen times less than that emitted by the Asia-Pacific region in the same year (Statista, 2024). Worldwide, more than half of all emissions come from China, India and the United States only (Global Carbon Atlas, 2023).

In terms of sectors and activities, Africa's emissions are primarily due to the combustion of fossil fuels such as oil, coal and natural gas, particularly for electricity production. Industry and transportation also account for a significant portion of the continent's emissions (International Energy Agency [IEA], n.d.-a). At the end of COP27, it emerged that the main sources of these emissions were also due to deforestation and poor land-use practices (African Development Bank [AfDB], 2022).

Africa's emissions can be largely attributed to a few key countries. Chief among these is South Africa, the country with the highest per capita emissions on the continent (IEA, n.d.-a). South Africa’s emissions are due mainly to its heavy dependence on coal. Additionally, since 2024, Libya has been Africa's leading oil producer (Pellissier, 2024), resulting in significant CO2 emissions from this activity. Conversely, the countries with the lowest emissions are the Democratic Republic of Congo, Somalia and the Central African Republic (AJLabs, 2023).

#### 1.2.2. The reasons for its vulnerability

According to Edmond Totin, an Intergovernmental Panel on Climate Change (IPCC)[1] expert and coordinator, the major source of Africa's vulnerability to climate change is its lack of adaptation and resilience. On the one hand, the effects of climate change are having a direct

[1] “The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.”, according to the IPCC organisation itself.

impact on agriculture, which is a very important sector for the continent. However, for years now, harvests have been declining because Africans do not have the capacity or the means to adapt to these changes. On the other hand, diseases such as malaria are appearing in regions where they have never been seen before, regions that do not always provide medical centres adapted to this type of pathology or able to deal efficiently with the situation, with the result that those affected cannot be properly treated. Mr Totin also raised the issue of infrastructure, explaining that if many countries suffer from floods, this is often because the drainage systems are not adapted or not well maintained (Hutton, 2022).

#### 1.2.3. Direct impacts on the continent and its population

According to the French Development Agency (AFD), the continent is warming faster than the global average and this is already having a number of consequences. These include an increase in high temperatures and in the frequency and duration of heatwaves, a drop in rainfall, a decline in flora, fauna and ecosystems, an increase in tree and coral mortality, as well as a significant reduction in economic growth.

In North Africa, temperatures could rise by 4°C in summer and 2.5°C in winter by 2100. Moreover, from +2.7°C (i.e. potentially in 2060), the flow of rivers in this region could fall by more than 30%. In West Africa, the number of days per year with temperatures above 40.6°C could rise from 60 days today to 196 days, or more than half the year. If global temperatures reach +4.4°C, the number of days with potentially lethal heat conditions could rise to between 250 and 350 days a year, with irreversible repercussions for excess mortality, agriculture, healthcare systems and economic growth.

Another major consequence is the rise in sea levels. By 2100, sea levels could have risen by 30 centimetres at best, or one metre at worst. This would lead to very high risks of erosion, saline intrusion into freshwater or even groundwater, more severe flooding and, above all, possible submersions.

Finally, global warming will also lead to changes in ecosystems. In this case, several sectors, such as agriculture, fishing and livestock farming, will be affected. Many terrestrial and marine species are also doomed to disappear because of climatic conditions incompatible with their own survival. In addition, most of the coral on the eastern coast would be destroyed. AFD strongly believes that these impacts are underestimated, as they do not take into account the interactions between species, which could be vital for some of them and therefore lead to the extinction of many more (AFD, 2023).

# Chapter 2: Climate Finance

## 2.1. Definition

According to the United Nations Framework Convention on Climate Change (UNFCCC) and to the United Nations Development Programme (UNDP), climate finance is local, national or international, bilateral or multilateral financing provided by either public or private sources. It includes a range of financial instruments such as grants, donations, green bonds, shareholdings, debt swaps and guarantees. The aim of these resources is to combat climate change by mitigating it, by trying to promote adaptation and also by strengthening the resilience of certain countries or regions to its impact (UNFCCC, n.d.-a).

Whereas a bilateral fund refers to a fund set up by one organisation or government to provide financial assistance to another institution for a clearly defined purpose (in this case, for projects to address global warming), a multilateral fund is set up by several countries or by an organisation grouping together several countries, such as the United Nations. Multilateral funds make it possible to support a larger majority of regions and/or countries, depending on the goal being promoted (Rawal, n.d.).

Multilateral funds providing aid to developing countries include among others the Green Climate Fund (GCF) and the Global Environment Facility, which will be presented later in this report (UNFCCC, n. d.-a).

Climate finance is a key element in the fight against global warming, as it enables countries to finance the objectives of the Paris Agreement, and thus to move towards a low-carbon economy (United Nations Development Programme Climate Promise [UNDP Climate Promise], 2023a). According to the Organisation for Economic Co-operation and Development (OECD), the World Bank and the United Nations Environment (2018), USD 6.9 trillion a year is needed until 2030 to meet the current objectives.

In this context, it is important to understand that climate finance falls within a broader framework of financial categories. It is therefore essential to make a distinction between **Sustainable**, **Green** and **Climate finance**. Sustainable finance encompasses all financial methods that consider social, economic, environmental and governmental concerns, while green finance only considers the environmental aspect. In contrast, climate finance is a subset of green finance that is reserved exclusively for initiatives that directly contribute to global warming adaptation or mitigation and to strengthening resilience. Climate finance is therefore a sub-entity of green finance, which is itself a sub-entity of sustainable finance. Appendix 1 contains a classification chart which shows the differences between the various types of finance (Forstater, M., & Zhang, N. N., 2016).

### 2.2. International Climate Agreements and Regulatory Policies

In 1987, the Montreal Protocol was negotiated and ratified by all 197 United Nations member states. The aim of this agreement was to protect the ozone layer by banning the production and consumption of substances that damage it, such as chlorofluorocarbons. The protocol came into force in 1989 (European Union law, 2019). To date, 99% of these substances have been destroyed thanks to this protocol (Maizland, 2023).

In 1972, the United Nations Conference on the Human Environment was held in Stockholm, where the United Nations Environment Programme (UNEP) was established. This conference was among the first to highlight the environment as a major global issue, producing several action plans and declarations aimed at promoting more rational environmental management (Chasek, 2020).

In 1992, one of the most important Earth Summits took place in Rio de Janeiro. This conference resulted in a number of climate change agreements, including the UNFCCC (Maizland, 2019).

In 1995, the first Conference of the Parties (COP) was held in Berlin, bringing together the States that had signed the UNFCCC for annual meetings (UNFCCC, n.d.-b).

In 1997, COP3 was held in Kyoto, Japan, and gave rise to one significant Climate Treaty. The Kyoto Protocol requires countries to take measures to reduce their greenhouse gas (GHG) emissions to a level equal to or lower than their 1990 levels. However, the treaty does not require developing countries such as India and China to comply with these measures and the USA has never even ratified the Protocol (Maizland, 2019). It also gave rise to the carbon market, which will be discussed in a later section (Maizland, 2023).

In 2015, 196 countries signed the Paris Agreement during COP21, which was held in the French capital. Experts consider it to be one of the most important climate agreements ever concluded. The primary objective of this agreement is to keep global temperatures below +2°C. To achieve this, it requires the 196 countries (emerging or not) to set themselves targets for greenhouse gas emissions, known as Nationally Determined Contributions (NDCs) (Maizland, 2019). Another objective of this agreement is to be climate or carbon neutral, which means that the amount of GHG emitted must be equal to the amount of GHG absorbed. Ultimately, only three countries are not officially part of the agreement: Iran, Libya and Yemen (Maizland, 2023).

### 2.3. Climate finance architecture

#### 2.3.1. Local, National vs Trans-National financing

Funding for climate change can come from national, international, or local sources. Local climate assets, municipal government funding or money for local climate adaption are examples of local financing. National funds come from national banks or the national government. Lastly, Trans-National financing refers to international financial sources or global climate financing organisations such as the UNFCCC's funds, for example (Africa Policy Research Institute, 2022).

### 2.3.2. Public financing

#### 2.3.2.1. Multilateral

Organisations like the Multilateral Development Banks (MDBs) and other international funds given to developing nations in the form of grants, loans or equity investments are examples of multilateral public funds. Developed countries' financial involvement in multilateral entities is also included (Africa Policy Research Institute, 2022).

## III. Organisations

**The International Monetary Fund (IMF)** is a global financial organisation with 190 member countries. Its main goals are to provide economic advice and financial support through loans and assistance (International Monetary Fund [IMF], 2022a). While combating climate change is not its primary mission, the IMF recognises its role in helping members address this issue. To this end, it has introduced several initiatives, such as offering tools and training for incorporating climate challenges into national strategies. It also established the Resilience and Sustainability Trust (RST) to provide affordable long-term financing for climate resilience and other external shocks, such as pandemics. In 2022, Barbados became the first country to receive RST support, amounting to USD 183 million (IMF, 2022b).

Established in 2008, the **Climate Investment Funds (CIF)** is a global multilateral financial partnership designed to provide competitive financing to low- and middle-income countries to address their current and future climate-related needs. CIF collaborates with some MDBs, such as the African Development Bank, to offer financial resources and expertise for large-scale projects through two main funds: the Strategic Climate Fund (SCF) and the Clean Technology Fund (CTF) (AfDB, 2024).

The **World Bank (WB)** was founded after World War II as the International Bank for Reconstruction and Development (IBRD). Today, the World Bank is owned by 187 countries and comprises five institutions, each with its assigned objectives, collectively known as the World Bank Group. In the realm of climate financing, the organisation is a pioneer among developing countries. By 2021, it had allocated USD 26 billion for climate-related initiatives. The World Bank has also developed various mechanisms and instruments to assist countries in combating climate change (World Bank Group, 2012). Here are a few of these :

(1) **Concessional Financing:** This refers to a form of financing that offers low-interest (and often long-term) loans, enabling emerging countries to receive financial support for

projects aimed at enhancing their resilience to and adaptation to global warming (World Bank Group, 2021a).

(2) **Emissions Reductions Payment Agreements (ERPA)**: ERPAs are contractual agreements signed between the World Bank Group and a government or company in a developing country, which present a project aimed at reducing the country's carbon emissions. After being measured, these emissions are turned into carbon credits (one carbon credit is equivalent to one tonne of CO2, which can either be sold if the company has avoided emitting a credit, or must be purchased by a company that has exceeded its emissions (Gupta, 2011)). The World Bank will buy these carbon credits through the ERPA, and over a period typically lasting between five and ten years, will provide payments on a regular basis based on outcomes that have been disclosed and validated (World Bank Group, 2021b).

(3) **Green Loans**: Similar to green bonds, green loans require the funds they provide to be strictly limited to environmentally beneficial projects. However, they differ from green bonds in that the former often include larger sums and are available on the public market, whereas the latter represent smaller sums and are typically concluded in the private sector. Because of the high transaction costs, green bond issuance is not always feasible in developing countries, where green loans are especially appealing for smaller projects (World Bank Group, 2021c).

**IV. Multilateral funds under the UNFCCC**

The specialised climate funds include a series of **operational entities established by the UNFCCC**. Here are a few of them :

(1) **Global Environment Facility (GEF)** : The GEF is an assembly of funds that work together to provide financing for projects addressing global environmental challenges such as biodiversity loss, climate change and pollution. It comprises 186 member countries, along with various stakeholders including civil society, indigenous peoples, women and youth (Global Environment Facility, n.d.). The GEF often receives guidance from the COP and contributes to achieving the objectives of the Paris Agreement (UNFCCC, n.d.-a).

(2) **Green climate fund (GCF)** : The GCF is an entity operating under the aegis of the UNFCCC and supporting the Paris Agreement. Its objective is to finance projects aimed at mitigating GHG emissions and helping countries adapt to the impacts of climate change. This financing can take the form of grants, concessional loans or paid-in capital, and is managed by the World Bank, which acts as trustee (Schalatek, 2024).

(3) **Adaptation Fund (AF)** : The AF is a financial mechanism established under the Kyoto Protocol and the UNFCCC to support developing countries in adapting to climate change.

It receives funding from various donations and a portion of the revenue from the Clean Development Mechanism (CDM) (Climate Funds Update, 2021).

#### 2.3.2.2. Bilateral

As previously said, a bilateral fund is a fund established by one government or organisation to give resources to another government or organisation for a specific goal (Rawal, n. d.-b). In the climate finance context, three notable Bilateral Financial Institutions (BFIs) are the *Agence Française de Développement* (AFD), the German Development Bank (KfW) and the Japan International Cooperation Agency (JICA). Each of these institutions has made significant contributions to climate adaptation and mitigation projects that align with their climate goals and the Paris Agreement (AFD, n.d.; KfW Development Bank, n.d.; Japan International Cooperation Agency, 2022).

### 2.3.3. Private financing

**I. Participative financing**

Participative financing, or crowdfunding, is a financing system that involves raising funds from multiple investors through a website. The various forms of participatory financing include equity-based crowdfunding, loans and donations (Abu Amuna, 2019).

**II. Green bonds**

Green bonds are bonds issued by public, private or multilateral entities exclusively to finance projects with a positive environmental impact, such as the construction of wind or solar farms, enhancements in energy efficiency and advances in clean transportation (Municipal Securities Rulemaking Board, 2018).

These bonds follow the Green Bond Principles (GBP) established by the International Capital Market Association (ICMA), which define four key principles : Use of Funds, Project Selection and Evaluation Process, Management of Funds and Reporting. The principles aim to ensure greater transparency for investors as regard the use of funds (International Capital Market Association, 2021).

**III. Catastrophe Bonds**

The catastrophe bond (CAT bond) is a bond issued by insurance or reinsurance companies offering a high yield, often higher than that of traditional bonds, but with a high risk in return. These companies issue these bonds through Special Purpose Vehicles (SPVs), legally distinct entities created for this purpose. The objective of CAT bonds is to protect against financial losses caused by natural disasters.

Investors who purchase these bonds receive periodic interest payments. If a natural disaster occurs, investors may lose some or all of their investment, depending on the terms of the CAT bond contract. This allows insurance companies to spread the risks associated with natural disasters. If no disaster occurs during the term of the bond, investors recover their entire initial investment. CAT bonds are collateralised, which means that they are guaranteed and eliminate counter-party risk, ensuring that funds are available in the event of a disaster (Polacek, 2018).

#### 2.3.4. Public and Private financing

**I. Public-Private Partnerships (PPP)**

A Public-Private Partnership (PPP) is a long-term contract between a public entity (such as a government) and a private entity. The project's operation, construction or funding may be handled by a private company, depending on the contract. Furthermore, the risk is transferred, in whole or in part, from the public entity to the private entity, depending on the type of contract as well (Iossa, Spagnolo & Vellez, 2007).

**II. Carbon Pricing**

Carbon pricing is another means used to try to reduce or limit the emissions produced by companies around the world. There are two policies available: taxation and Emissions Trading Schemes (ETS). The aim of these two methods is to determine a cost for each tonne of $CO_2$ emitted into the atmosphere, thereby encouraging companies to adopt greener practices (Black, Parry & Zhunussova, 2022).

Taxation is relatively easy to introduce and can take the form of a tax on fuels or on products with a high carbon content. Regarding emissions trading, there are two main approaches: Cap and Trade (C&T) and Baseline and Credit (B&C).

C&T involves imposing a limit on $CO_2$ emissions by companies in specific sectors. These emission allowances are either allocated free of charge or purchased by the company. If a company emits less than its quota, it can sell the excess on the market. If it emits more, it must buy additional allowances to compensate for the excess. A company that fails to comply with its emissions limit is subject to penalties.

For B&C, there is no mandatory limit. A baseline is defined, representing the number of tonnes of emissions that a company produces over a given period, as a reference. If the company emits less than this baseline, it receives credits that it can sell on the market. If it exceeds the baseline, it can buy credits on the market (Brohé, Eyre & Howarth, 2009).

**III. Debt Swaps**

A Debt Swap involves a government having some or all of its sovereign debt forgiven or restructured in return for committing to allocate equivalent or smaller funds to specific initiatives, such as those related to health, environmental conservation, or climate action. This strategy can take various forms and may involve third-party participation, such as NGOs, in what are known as third-party swaps. In these cases, third parties can purchase a portion of the debt and choose to cancel it or offer more favorable repayment terms, in return for the government's commitment to specific projects. There are two main types of debt swaps linked to sustainable development, each with specific goals in combating global warming : Debt-for-Nature swaps, which focus on environmental protection, and Debt-for-Climate swaps, which are designed to fund climate change mitigation and adaptation efforts in return for debt reduction (Climate Action Network, 2023).

### 2.4. Global landscape of international Climate Finance

In 2021 and 2022, USD 1.27 trillion was invested in climate initiatives. In comparison, during the same period, USD 7 trillion was invested in fossil fuels, and USD 11.7 trillion was mobilised for emergency measures related to COVID-19 in 2020. Between 2016 and 2020, Asia was the largest recipient of climate finance, followed by Africa and Latin America (*Figure 1*).

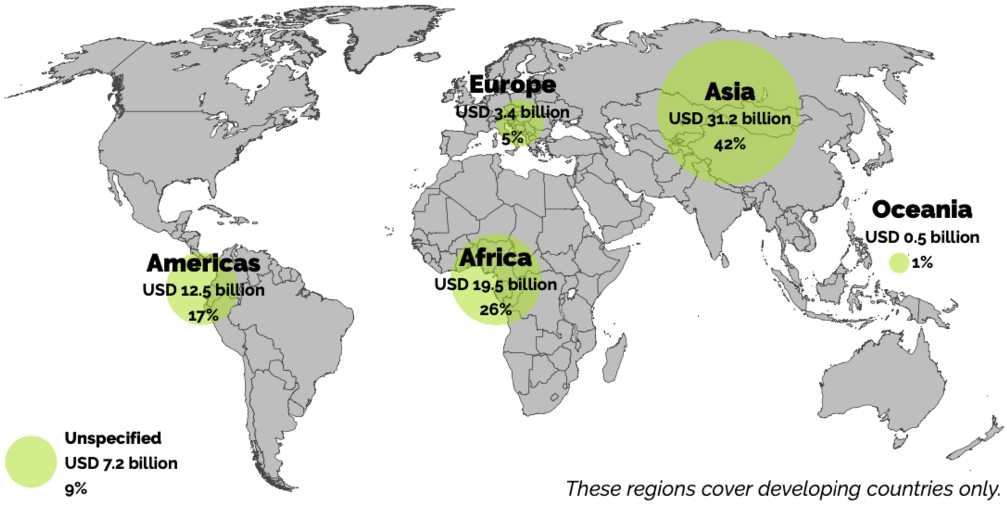


***Figure 1****: Geographical breakdown of climate financing for developing countries between 2016 and 2020. Available at: OECD, 2022.*

These investments are relatively evenly split between the public and private sectors, with USD 640 billion and USD 625 billion invested by each respectively. The use of these funds can contribute to mitigation projects, adaptation projects, or both. In 2021 and 2022, 91% of the funds were allocated to mitigation projects, leaving only USD 63 billion for adaptation projects, compared with USD 1.2 trillion for mitigation.

Among the mitigation projects, the renewable energy sector is the most financed with USD 510 billion annually, followed by the transport sector with USD 334 billion. However, these amounts are still far too low when you consider that spending on fossil fuels is almost three times higher every year. Financing for projects with dual benefits (mitigation and adaptation) reached USD 51 billion in 2021/2022 (Buchner et al., 2023).

In recent years, climate-related spending has not yet exceeded the USD 2 trillion per annum mark. However, in the average scenario, the climate finance needed until 2030 stood at USD 9 trillion yearly. Thereafter, from 2031 to 2050, the estimated needs jump to over USD 10 trillion each year. This implies that to avoid the worst impacts of climate change, the current level of climate finance must increase at least five-fold annually, according to the Climate Policy Initiative (CPI).

Finally, according to the European Commission, funds allocated to developing countries are often given in the form of loans, which only adds to the debt problems in these countries. In addition, complicated application procedures and a lack of institutional capacity make it difficult for LDCs and Small Island Developing States (SIDS) to obtain financing. Transparency in the allocation of cash is another major issue; money is going to programmes that are not focused solely on combating climate change. Among other things, it is imperative to raise additional money from the private sector to close the current gaps in climate funding in order to overcome these obstacles (Jensen L. & Roniger J., 2023).

# Chapter 3: Climate Finance in Africa

Climate finance in Africa exists within a context of significant financial needs to address the challenges of climate change. To achieve this, it requires substantial funding, which, unfortunately, is currently far too low to meet the NDCs. Indeed, while African countries need to mobilize approximately USD 2.5 trillion between 2020 and 2030, climate finance flows, both domestic and international, totaled only USD 30 billion in 2020, representing just 12% of the required amount (Meattle et al., 2022a).

## 3.1. The current state of climate investments

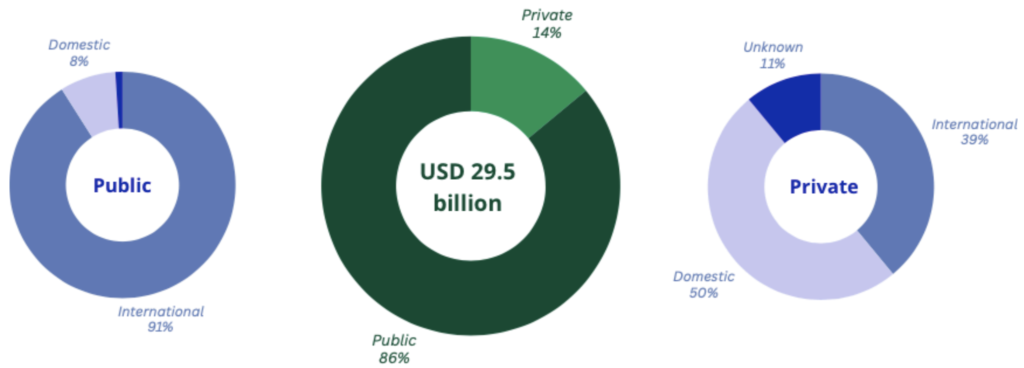


***Figure 2**: Breakdown of climate finance by sector.*
*Data for this chart were sourced from Climate Policy Initiative.*

Annual spending on climate finance in Africa for 2019 and 2020 is equivalent to around USD 29.5 billion, according to the CPI. However, to meet the targets of the NDCs, the continent would need USD 277 billion. Most of this expenditure involves the public sector, which accounts for no less than 86%, and its funding comes mainly from international sources (see *Figure 2*). Among the projects financed, renewable energies attracted the most funding, particularly solar and wind power projects.

Over these two years, Multilateral DFIs contributed about USD 11.5 billion, followed by governments with USD 6.4 billion and then Bilateral DFIs with USD 5.3 billion. The Multilateral Climate Funds, meanwhile, contributed only USD 1 billion for the whole continent, most of which was financed by the Green Climate Fund (GCF).

While funding exists and is progressing on the continent, it is important to note that the distribution of funds is not necessarily equitable. Ten countries alone hold more than half of the funds: Egypt, Morocco, Nigeria, Kenya, Ethiopia, South Africa, Mozambique, Côte d'Ivoire, Tunisia, and Ghana, in descending order of funds allocated (Meattle et al., 2022b).

## 3.2. Types of investment and projects financed

Africa has a good balance between adaptation and mitigation funding, which is not always the case in other countries that focus more on mitigation. Given Africa's vulnerability, it is crucial to focus on adaptation. In 2022, funding amounted to USD 11.4 billion for adaptation, USD 14.6 billion for mitigation, and USD 3.2 billion for dual-benefit projects, with USD 0.3 billion for projects whose category is unknown. However, to achieve the NDC targets, USD 66 billion needs to be mobilised for adaptation, USD 183 billion for mitigation and USD 28 billion for dual-benefit projects, each year (Meattle et al., 2022b).

### 3.2.1. Mitigation projects

Mitigation projects are mainly directed towards renewable energies (59%), and more specifically towards solar energy generation projects and wind turbines. The energy sector even accounts for 29% (USD 9.4 billion) of total climate finance spending in Africa, but this is still short of the USD 133 billion the continent needs to meet its targets. Loans are the most common means of financing mitigation projects (Meattle et al., 2022b).

The wind farm at Lake Turkana in Kenya is an example of a mitigation project in Africa. The AfDB provided most of the funding for it, and its goal is to generate 300 MW of wind power for the nation's grid—just over 20% of Kenya's existing electricity production capacity (AfDB - MapAfrica, 2024).

### 3.2.2. Adaptation projects

Funding for adaptation projects focuses mainly on agriculture, forestry and land use (AFOLU). This sector plays a crucial economic and social role, which is why it receives particular attention. These funds are mainly obtained via subsidies (46%) and low-cost loans (30%) (Africa Policy Research Institute, 2022).

For example, West Africa Coastal Areas (WACA) is a programme set up by the World Bank to lessen the hazards that both natural and man-made factors pose to the western coastal zone of the continent and to enhance resource management there. WACA mobilises funds to tackle erosion, flooding, etc., with the main aim of improving adaptation to global warming (West Africa Coastal Area, n.d.).

# Chapter 4: Renewable energy sector in Africa

## 4.1. Definition

According to the International Energy Agency (IEA), renewable energies are natural resources whose use poses no risk of depletion, unlike fossil fuels, which take a very long time to regenerate and emit large quantities of $CO_2$ when burned. As well as being more economical, renewable energies are also more widely accessible around the world (IEA, 2023a). As the International Renewable Energy Agency (IRENA) puts it, renewables are "Energy that doesn't run out!" (International Renewable Energy Agency [IRENA], 2021, p.3).

The sun, wind, water and biomass are some of the natural elements that provide renewable energy. Here is an overview of the main technologies :

One of the least expensive forms of energy is **solar energy**, which employs solar panels to convert sunlight into thermal or electrical energy. Because of the rate at which light is captured by the Earth, it is the most abundant form of energy. Solar panels last for thirty years on average.

The **wind**'s kinetic **energy** is used by wind turbines to generate electrical power. These places can be located offshore (in the sea) or onshore (on land).

The earth's heat can be harnessed using **geothermal energy** to produce electricity. This technology has been in use for more than a century.

**Hydroenergy** generates electricity by utilising the movement of water, often using dams or reservoirs. This method also frequently provides additional benefits, such as flood prevention and drinkable water supply (United Nations, n.d.). Even though hydroelectricity is one of the main sources of energy production, its development (specifically for large projects) may have a negative environmental effect (it can damage the biosphere and have an impact on the land-use practices of local communities). Consequently, it is important to find a balance between the benefits this technology can bring, and the damage it can cause (IRENA, 2024).

The energy of the oceans and waves is used as **marine energy** to generate heat or electricity. Although these technologies are still in their infancy, there is more than enough theoretical energy potential to meet the world's energy needs.

Lastly, **bioenergy**, which utilises organic materials like wood and carbon, is primarily used in rural areas for lighting and culinary purposes. Even though bioenergy releases $CO_2$, it does so at a lower rate than fossil fuel energy. However, its use needs to be restricted to prevent significant deforestation or excessive changes to land use (United Nations, n.d.).

## 4.2. Focus on Africa

As already mentioned, Africa is particularly vulnerable to the consequences of global warming (AFD, 2023). Investing in renewable energies is therefore imperative, in order to mitigate or even reduce these effects. At present, about 600 million Africans have no access to electricity, and 970 million have no access to clean cooking fuels. This undoubtedly explains why the continent has the lowest level of modern energy per capita, but according to the IEA, this trend could be reversed in the future (IEA, 2023a).

Furthermore, Africa still relies heavily on fossil fuels : in 2018, biofuels and waste were the leading source of primary energy used on the continent, followed by oil, coal and natural gas. In 2020, installed renewable energy capacity was equivalent to just over 50 GigaWatt (GW), with the energy mix largely driven by hydropower, followed by solar and wind. For decades, Africa has been taking advantage of its rivers to produce hydropower (IRENA & AfDB, 2022), which accounts for 24% of total capacity electricity generation on the continent (IRENA, 2024).

In the future, solar energy will play a central role in the continent's energy mix, with sufficient potential to cover 80% of new electricity generation capacity by 2030 (Appendix 2) (IRENA & AfDB, 2022). In addition, 12 countries have pledged to achieve zero net emissions by 2050, but these targets require substantial funding. Doubling investment before 2030 is crucial, especially as costs in Africa can be two to three times higher than in other regions, not to mention the often unfavourable policies and regulations that make access to finance even more difficult (IEA, 2023a ; IEA, 2023b).

Consequently, although the continent has great energy potential, this remains difficult to exploit without better access to finance. Nevertheless, the AfDB is no longer financing fossil fuel projects and has already released funds for renewable energy projects in Kenya and Morocco via the Sustainable Energy Fund for Africa (SEFA). Other initiatives, such as the Alliance for Green Infrastructure in Africa (AGIA), are also supporting the development of green infrastructure on the continent (IEA, 2023b).

### 4.2.1. Investments trends

Between 2000 and 2020, USD 60 billion was invested in renewable energies in Africa[2]. However, this amount only represents 2% of the total investment received by the continent over the same period (IRENA & AfDB, 2022). Between 2010 and 2020, most of this amount was mobilised, i.e. USD 55 billion, with annual peaks in investment when major projects were deployed in Egypt, Morocco and Kenya in particular. From 2019 onwards, investment fell drastically, dropping by more than 30% in the space of three years.

[2] These data come from Bloomberg New Energy Finance (BNEF), which does not take into account data from large-scale hydropower (i.e. more than 50MW).

As far as the distribution of this investment is concerned, it would appear to be rather uneven. Three countries alone are estimated to have received more than two-thirds of the financing linked to renewable energies, while over the period from 2010 to 2020, 37% of the financing was dedicated to a total of 33 countries, including some of the least developed on the continent. According to IRENA, this difference is largely due to the fact that countries that are more advanced in terms of policies and regulatory frameworks have easier access to financing, as their profile is more attractive to investors (IRENA, 2024).

Between 2010 and 2020, Africa's investments in geothermal, solar and wind energy represented 14%, 7% and 3% respectively of global investments. However, the amounts of this funding tend to show a reverse trend : over the same period, USD 18 billion was spent on solar PV, USD 17 billion on onshore wind and USD 9 billion on solar thermal, and only USD 200-300 million was spent annually on bioenergy, geothermal and small-scale hydropower combined (IRENA & AfDB, 2022).

By 2020, **public investment** accounted for only 14% of direct investments related to renewable energy in Africa. However, it plays a critical role in the Sub-Saharan region of the continent, since most of the countries lack access to financing due to riskier macroeconomic factors (IRENA, 2024). International donors as well as governments and financial institutions are the main sources of public funding. Between 2010 and 2019, 54 active donors (bilateral or not), including China, France, Germany, MDBs and DFIs, raised no less than USD 43 billion, or 85% of the continent's public funding. A significant role is also played by investment funds, some of which are mentioned in Appendix 4 as examples of the projects they support. Debt and grants are the most commonly used types of financing, accounting for 86% and 11% of total public investment respectively. Concessional loans and risk mitigation instruments have also become more popular, but to a lesser extent than debt and grants.

However, a major issue is that there is a significant discrepancy between commitments and actual disbursements. The data provided above are predicated on investor pledges rather than project financial closure. This indicates that, to some extent, due to issues with coordination, obstacles, or restricted access, the promised funds are not always paid out on time (IRENA & AfDB, 2022).

Since 2000, Independent Power Producers, or IPPs, have represented USD 61 billion in financing for all energies combined, and have increased installed electricity generation capacity by 14 GW on the continent (IRENA & AfDB, 2022). These are private entities that own or operate facilities to produce electricity, which they sell to utilities, governments, or directly to consumers (United States Energy Information Administration, n. d.). Because they account for a third of total investments made for this purpose, the MDBs and DFIs play a significant role in financing IPPs by providing loans or subsidies associated with technical assistance for businesses.

Finally, off-grid technology refers to systems that generate electricity from renewable sources, aiming to extend access to remote populations not connected to the public power grid (Rouse, 2014). According to ITPEnergised, expanding off-grid networks is crucial in Sub-Saharan Africa, as it has the potential to significantly reduce the number of people without electricity by providing underserved communities with reliable power. This could also have economic benefits, as well as improving healthcare services and education for citizens (ITPEnergised, 2019). Between 2010 and 2020, more than 60% of the financing for these infrastructures came from the private sector (with investors mainly from Europe, North America and Oceania), in the form of shares and loans (IRENA & AfDB, 2022).

#### 4.2.2. Environmental impacts

On average, fossil fuel production generates emissions of around 0.6515 kgCO2e/kWh, with coal being the fuel that emits the most greenhouse gases. By comparison, renewable energies emit an average of 0.0195 kgCO2e/kWh, 33 times less than fossil fuels, and geothermal energy emits the most CO2 per kWh (Dkhissi, 2024). In Africa, the electricity and heat sector emits the most, accounting for 55.9% of the continent's total emissions in 2021 (IEA, n.d.-a). If Africa wants to reduce its carbon footprint, it is therefore important to turn to sustainable energy production through renewable energies. A number of countries, including the Democratic Republic of Congo (DRC), Mozambique, Niger and Tunisia, have already shown a strong commitment to these technologies, aiming, among other things, to multiply their installed electricity capacity using renewable energies or to combat the deforestation faced by their land (UNFCCC, 2023). As an example, the Noor Ouarzazate project in Morocco has avoided one million tonnes of GHG emissions annually since its creation (AfDB, 2020).

#### 4.2.3. Impact on economic development

If the objective of +1.5°C (maximum) is achieved, impacts on the continent's economic (and social) development should be observed between now and 2050. According to IRENA, Gross Domestic Product (GDP) will increase by 6.4%, and the number of jobs should reach eight million, i.e. four times more jobs than in 2022. Furthermore, an increase in renewable energy in Africa would considerably reduce imports of fossil fuels and the resulting price volatility, which could then be used to invest in other projects (IRENA & AfDB, 2022). According to the United Nations Economic Commission for Africa (UNECA), investments in renewable energies could enable African countries to participate in carbon markets, allowing them to earn revenue from the CO2 emissions they have avoided or reduced, which could then be reinvested. However, it is crucial to prevent a vicious cycle where excessive pursuit of carbon credits in Africa leads to higher global emissions. If credits are used inefficiently, other regions might increase their emissions, thereby negating the intended environmental benefits (United Nations Economic Commission for Africa, 2024).

One concrete example is the creation of the Noor Ouarzazate complex in Morocco (already referred to in the previous point), supported by the African Development Bank. This infrastructure, one of the world's biggest solar installations, was already capable of supplying electricity to two million Moroccans in 2020. Jobs have been created, but the project has also been able to support smaller local businesses, such as a restaurant, which has seen its turnover soar since the arrival of Noor. Finally, the complex also supports young people by offering them training ; a young man was able to take part in a welding course, which enabled him to set up his own business. The investment therefore has real economic potential for Africa, in addition to its initial objective of reducing greenhouse gas emissions (AfDB, 2020).

# Chapter 5: Analysis of the renewable energy sector in Morocco

Morocco is a country located in the northern part of Africa, covering an area of 446 550 square kilometres (World Bank Group Open Data, n.d.-a). Its capital is Rabat, and the country has approximately 38 million inhabitants (World Bank Group Open Data, n.d.-b). In recent years, Morocco has experienced a significant evolution in its energy mix, marked by a notable improvement in the renewable energy sector. A prominent example of this transition is the Noor Ouarzazate project, frequently cited, a solar complex that illustrates Morocco's commitment to renewable energies (AfDB, 2020). This country therefore constitutes an excellent case study to analyse the effects that climate finance can have on renewable energies within the country as well as on the continent.

## 5.1. Nationally Determined Contributions

As a reminder, NDCs are targets set by countries under the Paris Agreement, which they commit to achieving and implementing in the short or medium term to reach the global goal of limiting the increase in global temperature to 1.5°C or, in the worst case, not exceeding +2°C compared to pre-industrial levels. The implementation of these targets is detailed in the NDC reports submitted by each country, outlining how they plan to reduce their GHG emissions (UNDP Climate Promise, 2023b).

Regarding Morocco, the country has clearly defined adaptation and mitigation targets. The targets related to renewable energy are primarily considered in mitigation projects, which will be examined in depth. Indeed, Morocco aims to reduce its GHG emissions by 18.3% by 2030, and this percentage could reach up to 45.5% if the country benefits from international funding (referred to as unconditional action if the country can finance and implement the project itself, and conditional action if it requires external aid to be realised). If they aim to achieve a nearly 46% reduction in emissions, the total costs are estimated at USD 38.8 billion to implement 61 actions, conditional or unconditional, across various sectors. Nine of these 61 projects were implemented before 2020 in the energy and agriculture sectors.

Electricity production alone accounts for eight actions, of which only two are unconditional (Appendix 3 lists the various projects and their costs). This means that most actions related to electricity generation have already been or should soon be implemented. The country aims for 52% of installed electric power to be produced from renewable energy sources. This would involve 20% solar energy, 20% wind energy, and 12% hydropower. Finally, Morocco also aims to reduce its energy consumption by 20% by 2030. This would mean reducing energy consumption in various sectors, such as industry, transport, agriculture and maritime fishing (Moroccan Government, 2021).

## 5.2. Energy policies

### 5.2.1. Institutions

Energy policies and regulations in Morocco are managed by several institutions: the Ministry of Energy, Mines and Sustainable Development, the Moroccan Agency for Energy Efficiency, the Moroccan Agency for Sustainable Energy (MASEN), the Institute for Research into Solar and Renewable Energies (IRESEN) and the National Agency for Electricity and Water (ONEE). They each have distinct roles in overseeing and implementing energy strategies, ensuring efficiency, and promoting sustainable development (IEA, 2019).

### 5.2.2. Supporting schemes

There are numerous financing programmes, often with the support of the institutions mentioned above, which encourage companies to invest in renewable energy in Morocco. Here are some notable examples:

**1. EPC Contracts:** The Moroccan government uses Engineering, Procurement and Construction (EPC) contracts allowing ONEE to commission turnkey projects. The contractor delivers the project to ONEE once it is operational, following a Build, Transfer and Operate (BTO) scheme. This means that the contractor builds the facility, transfers it to ONEE, and then continues to operate it.

**2. Independent Power Producers (IPPs):** Since 1994, *Law 2-94-503* has allowed private investors to generate electricity. ONEE buys this electricity through Power Purchase Agreements (PPAs), using a Build, Own, Operate and Transfer (BOOT) scheme. The IPPs, primarily active in wind energy, receive investments in the form of concessional loans from private and public sources, both domestic and international (IEA, 2019).

**3. MASEN's Innovative Approach:**

- For large-scale solar projects:

  MASEN is responsible for securing concessional or non-concessional loans from MDBs and International Financial Institutions (IFIs). These MDBs receive backing from the Moroccan government, which provides guarantees to secure the investments. The Solar

Energy Investment Fund (SIE), the Hassan II Fund, and ONEE contribute capital to MASEN, which means that they invest funds into MASEN directly.

In tender processes, MASEN appoints developers who, with the support of commercial banks, establish a Special Purpose Company (SPC) to implement the project. The SPC holds 75% of the project's shares, while MASEN retains 25%. In return, the SPC is required to repay its debt to MASEN.

MASEN purchases the electricity produced by the SPC under an initial Power Purchase Agreement (PPA). Ultimately, ONEE buys the electricity from MASEN through a secondary PPA (United Nations Economic and Social Commission for Western Asia [UNESCWA], 2018).

The following diagram provides a detailed overview of the financing structure for solar projects in Morocco:

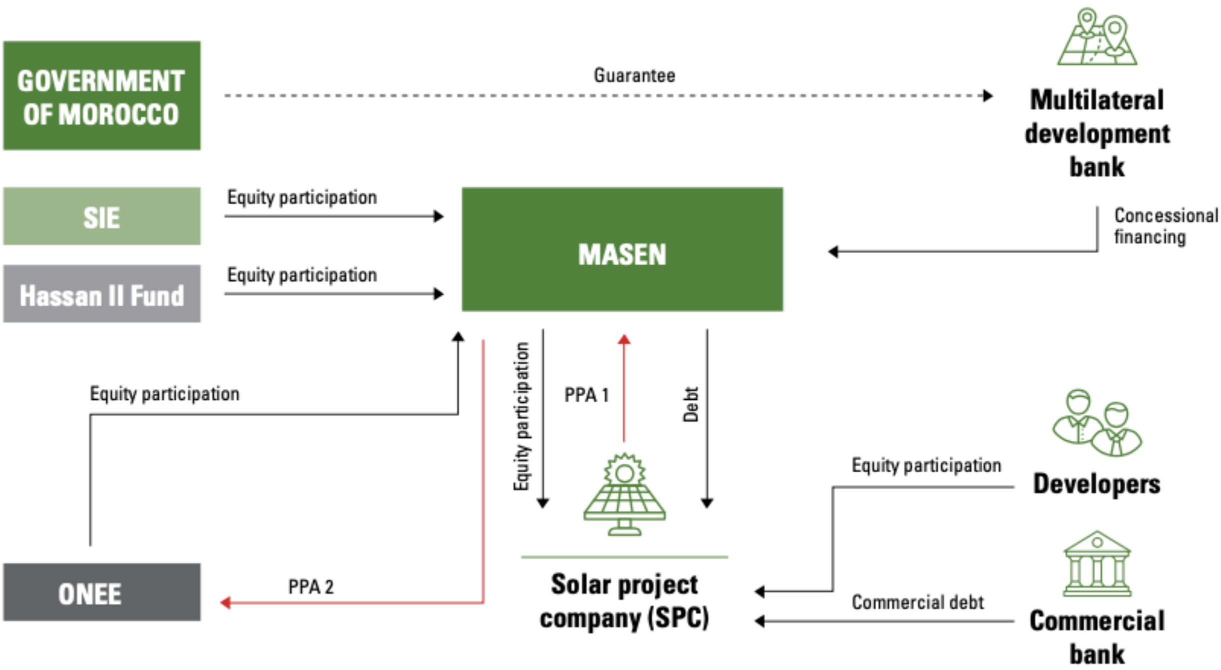


***Figure 3**: Chart of procedures for large-scale wind projects.*
*Chart available at [Case study on Policy Reforms to promote Renewable Energy in Morocco](), p.35.*

- For large-scale wind projects:

In this case, ONEE, the Solar Energy Investment Fund (SIE) and the Hassan II Fund have a direct equity stake in the Wind Project Company (WPC), collectively holding 35%. The developer selected through the tender process holds the remaining 65% of the WPC. ONEE raises funds through concessional loans from Multilateral Development Banks (MDBs). A Power Purchase Agreement (PPA) is signed directly between the WPC and ONEE, without involving MASEN, with ONEE purchasing the electricity produced by the project directly (UNESCWA, 2018).

**4. Local content and industrial development:** This approach encourages renewable energy projects to collaborate with local businesses, provided it remains cost-effective. The goal is to build a domestic renewable energy industry that can be relied upon and to foster job creation. For example, MASEN tenders often set a target of 30% local content (IEA, 2019).

### 5.3. Existing projects and their financing

Noor Ouarzazate is a solar complex with a total installed capacity of 580 MW. Currently, the facility provides electricity to over one million Moroccans.

The Noor Ouarzazate complex consists of four solar power plants, each distinguished by the technology used : Noor I and II employ cylindrical parabolic mirrors, Noor III is a solar power tower, and Noor IV is a hybrid photovoltaic plant. Together, these plants produce about 1.9 MWh of electricity and reduce $CO_2$ emissions by 888 540 tons annually. The complex is set to expand further with Noor Midelt I, which plans to combine photovoltaic and concentrated solar power technologies to achieve an installed capacity of 800 MW, making it one of the most advanced solar complexes in the world (ESFC Investment Group, n.d.). The project is scheduled for completion on 31 December 2025 (AfDB - MapAfrica, n.d.).

For the Noor project, ACWA Power was chosen as the main developer and holds approximately 70% of the project company (SPC). MASEN also holds a 25% stake. To finance its participation, MASEN benefits from subsidies from various financial institutions. The four Noor projects have been largely financed by MDBs, such as the World Bank through the CTF, the AfDB, the AFD, the European Investment Bank (EIB) and the KfW, which have lent funds to MASEN to support these projects (Global Infrastructure Hub, 2018). A more detailed version of the financing for Noor I is available in Appendix 5.

Many programmes concerning solar power plants are also being implemented throughout the rest of the country, again with the assistance of MASEN. In fact, MASEN issued the first green bonds on the Moroccan market in 2017, amounting to 1.15 billion Moroccan dirhams, or USD 118 million. These bonds notably helped finance the Noor Laayoune and Noor Boujdour projects (Chestney, 2017).

Since 2014, the Tarfaya wind farm, one of the largest in Africa, has also been in operation. It has an installed capacity of approximately 300 MW. The electricity produced is then purchased through a PPA by ONEE. This installation alone prevents the emission of 800,000 tons of $CO_2$ annually (Nareva, n.d.). There is therefore a substantial range of renewable energy projects in Morocco. The CIF has already contributed to two projects with an approved amount of USD 149.75 million (Climate Investment Funds, n.d.). The GCF has provided funding for twelve projects amounting to USD 265.6 million, several of which are related to renewable energy (Green Climate Fund, n.d.).

## III. Research question and hypothesis

Now that we have closely analysed the current situation in Africa in the face of global warming, conducted a review of climate finance and investments directed towards renewable energies on the continent and more specifically in Morocco, and finally, addressed their impact on economic development and CO2 emissions, we can formulate a pertinent research question and hypothesis.

The **research question**, based on these analyses, is formulated as follows :

**To what extent can climate finance in the renewable energy sector help combat global warming while stimulating economic development in Africa?**

*Analysis of Morocco*

In the first part of the literature review, the goal was to demonstrate the extent of Africa's vulnerability to the effects of global warming and to underscore the urgency of taking measures to address it (AFD, 2023). In the second part, we presented climate finance and its current presence in Africa across all sectors. We then specifically analysed the renewable energy sector and reviewed the trends in investments in this field. These sections highlighted the fact that, despite the recognised urgency of investing in renewable energy in African countries for environmental, economic, and even social reasons, investments remain insufficient to meet the targets set by the Paris Agreement (IEA, 2023b). Nevertheless, numerous initiatives have been implemented and have already increased the installed energy production capacity across the continent in many countries, and more specifically in Morocco. In the final point of this section, we examined the expected or already proven ecological and economic impacts of climate investments in such infrastructures. It was found that these projects have already managed to reduce greenhouse gas emissions to some extent (UNFCCC, 2023), and that the economic sector is likely to benefit positively from the creation of renewable energy infrastructure, with an anticipated increase in GDP in the coming years. Based on all this information, we have formulated the following hypothesis :

**Climate finance in renewable energies in Africa contributes to combating global warming by reducing CO2 emissions and stimulates economic development on the African continent.**

The objective of the subsequent part of this report is to conduct a quantitative study aimed at confirming or refuting our hypothesis. This study will be based on data from four different countries, each a pioneer and promising player in renewable energy: Morocco, Egypt, Kenya and Ethiopia.

# IV. Quantitative study

## Chapter 6: Objectives and methodology

### 6.1. Purpose of the study

The primary objective of this study is to assess the impact of investments in renewable energy funded by climate finance on economic development and CO2 emissions in Africa.

There are several reasons for undertaking this analysis. Firstly, as previously mentioned, Africa is particularly vulnerable to the effects of global warming on various levels, including environmental and public health (Hutton, 2022). Therefore, we aim to understand the extent to which investments in renewable energy can mitigate these effects and how well these efforts align with the goals of international agreements.

Additionally, although Africa's energy potential is huge (IRENA & AfDB, 2022), hundreds of millions of Africans still lack access to electricity (IEA, 2023b). This situation raises the question of whether investments in sustainable energy can truly convert this potential into tangible economic benefits. Through this study, we seek to evaluate whether such investments can reconcile environmental objectives with economic advantages.

Ultimately, the goal is to demonstrate that these investments have a significant positive impact on CO2 emissions and economic development, thereby making a compelling case for supporting poorer countries that struggle to attract funding. By proving the effectiveness of these investments, we aim to encourage increased financial assistance to those nations in need.

To conduct this study, we will estimate two models:

- The first involves using economic development, as measured by Gross Domestic Product (GDP), to determine whether investments in renewable energy actually contribute to the economic growth of the continent.
- The second model is similar to the first but focuses specifically on assessing the impacts on CO2 emissions.

We will adopt a methodology based on econometric models to identify the relationships between investments in sustainable energy and the two aspects mentioned above. The duration of the available data for analysing the models is somewhat limited. Indeed, the first international treaty to set legally binding targets, the Kyoto Protocol, was adopted in 1997 (Maizland, 2023). Furthermore, the impacts of investments on the studied variables do not manifest immediately, and energy infrastructures may take time to become fully operational. We have therefore opted for annual data covering the period from 2000 to 2020, due to the limited availability of official data beyond this period.

This data limitation has led us to use panel data to estimate our models. Panel data are datasets that can record information on multiple entities (called individuals) over successive periods of time. They thus combine both their temporal and cross-sectional aspects (Macé, 2013). In our case, the entities are four countries: Morocco, Kenya, Egypt and Ethiopia. To estimate our two models, we will use multiple linear regression models specifically designed for panel data. For each of our models, we seek to determine whether there is a causal relationship between our explanatory variables (to be presented in section 6.2) and (1) economic development, and (2) CO2 emissions. Finally, we will conduct statistical tests to ensure that our estimations are not biased, thereby guaranteeing the relevance and accuracy of our results. These models will be executed using RStudio, a programming language for statistical calculations (R Core Team, 2024).

### 6.2. Description of the databases used

To carry out this study, we opted for the analysis of temporal data, which we collected from official database platforms such as the World Bank, the International Energy Agency (IEA), the International Labour Organisation Statistics (ILOSTAT), the United States Energy Information Administration (EIA) and Our World in Data[3].

Moreover, as previously explained, we chose to collect data for four different countries (i.e., Morocco, Egypt, Kenya and Ethiopia) to create a panel data model. The selection of these countries was driven by their significant energy potential and existing renewable energy projects within their territories.

It is important to note that the relationships between investments in energy, CO2 emissions, and GDP are not direct. We therefore had to select variables that are affected, either directly or indirectly, by these investments and that could potentially influence CO2 emissions and GDP. The variables we selected, along with the justification for our choices, are detailed in the following *Table 1*. In addition, you will note that we do not have a variable for the amount of investment in renewable energy per year as such. This information was either not available at all on the official databases, or was only available from 2017 onwards, which did not correspond to our research period.

[3] Although Our World in Data is not an official database platform as such, it does rely on official databases. The dataset we have downloaded from this site is sourced from the U.S. Energy Information Administration (2023) and the Energy Institute - Statistical Review of World Energy (2024).

| Variable | Type | Unit of measurement | Description | Justification* | Source |
|---|---|---|---|---|---|
| **$CO_2$ emissions** | Dependent | $tCO_2$/Capita | "$CO_2$ emissions from fuel combustion in the energy sector. " (IEA, n.d.-b). | The choice of $CO_2$ emissions as the dependent variable for assessing efforts to combat climate change is justified by the fact that $CO_2$ is one of the primary greenhouse gases responsible for global warming (Jensen & Roniger, 2023). As they are directly influenced by energy sources (IEA, n.d.-c), $CO_2$ emissions serve as a relevant indicator for measuring the effectiveness of investments in renewable energy in reducing emissions and, consequently, in addressing climate change. | IEA |
| **GDP** | Dependent | Current USD | "GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars." (World Bank Group Open Data, n.d.-c). | The choice of GDP as an indicator of a country's economic development is justified by the fact that it reflects the overall economic activity and performance of a country, while being a standard and widely recognised measure for assessing economic growth and development (Fernando, Boyle & Rathburn, 2024). By analysing GDP variations, we aim to evaluate the impact of investments in renewable energies on the overall economic health of a country. | World Bank |
| **Electricity access** | Independent | % of population | "Access to electricity is the percentage of population with access to electricity. Electrification data are collected from industry, national surveys and international sources." (World Bank Group Open Data, n.d.-d). | An increase in access to electricity through investments in renewable energy in Africa is expected to positively impact GDP by boosting productivity. At the same time, it should allow $CO_2$ emissions to remain stable or even decrease despite the increased access. | World Bank |
| **Electricity capacity (renewables)** | Independent | Million kW | Includes renewable energy sources such as hydroelectricity, geothermal, wind, biomass and waste, solar, tide and fuel cell in order to produce electricity (United States Energy Information Administration, n.d.). | Increasing investments in renewable energy should significantly expand the installed capacity for renewable energy production, which would reduce dependence on fossil fuels and consequently lower $CO_2$ emissions. Additionally, a larger renewable energy capacity can decrease energy imports, reducing the country's exposure to price volatility and freeing up financial resources, which could have a positive impact on GDP. | US EIA |

| Variable | Type | Unit of measurement | Description | Justification* | Source |
|---|---|---|---|---|---|
| **Energy imports** | Independent | TeraJoule TJ | Net energy imports of total energy supply (IEA, n.d.-d). | An increase in investments in renewable energy should enhance the country's energy production capacity, thereby reducing its dependence on energy imports. Additionally, by meeting more of its own energy needs, the country would be less vulnerable to fluctuations in energy prices, which could be beneficial for its economy. | IEA |
| **Share of modern renewables in final energy consumption** | Independent | % | This is the share of renewables in the final energy consumption of a country, excluding traditional uses of biomass (IEA, n.d.-e). | Increasing investments in renewable energy should significantly boost the share of these renewables in final energy consumption. This shift would reduce dependence on fossil fuels, thereby lowering CO2 emissions. Moreover, a higher share of modern renewables in energy consumption can decrease energy imports, reduce exposure to price fluctuations, and free up financial resources, which could positively impact GDP. | IEA |
| **Average energy consumption** | Independent | kWh per capita | The variable represents primary energy use per person. Primary energy is the energy available before transformation, such as coal or oil. It includes efficiency losses and end-use needs (heating, transportation and electricity) (Our World in Data, 2024). | Increasing investments in renewable energy should improve energy access, which might lead to a rise in average energy consumption per capita. While this could negatively impact CO2 emissions, a sufficiently high share of renewables in the energy mix might mitigate this increase. Nonetheless, this improvement in energy access and consumption is expected to be favourable for GDP. | Our World in Data |
| **Unemployment rate** | Independent | % | "The unemployment rate conveys the number of persons who are unemployed as a percent of the labour force (i.e., the employed plus the unemployed)", considering all men and women over the age of 15 (ILOSTAT, 2024). | Increasing investments in renewable energy should create new jobs in the construction, installation, and maintenance of energy infrastructure. This is expected to reduce the unemployment rate and, consequently, benefit GDP. However, the impact of the unemployment rate on CO2 emissions is difficult to measure accurately. | ILOSTAT |

***Table 1***: *Description and justification of the databases used in the quantitative study*

*The justifications for our choice of variables are based on our hypothesis, which supports the idea that investment in renewable energies can help combat global warming by reducing the continent's CO2 emissions, while at the same time stimulating its economic development. This is also inspired by the analyses presented in sections **4.2.2** and **4.2.3** during the review of the renewable energy sector in Africa.

### 6.3. Description of the statistical test bases

Since the data used in our study are panel data, it is crucial to note that some tests are not compatible with this type of data. We have taken this into account and used tests specifically adapted for panel data.

#### 6.3.1. Multiple linear regression

Multiple linear regression aims to establish causal relationships between a dependent variable and several explanatory variables. These variables are linearly related according to the following equation (Robert, 2024):

(1) $$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

Where y is the dependent variable, $x_1$ and $x_2$ are the independent variables and $\beta_0$ is the intercept. $\beta_1$ and $\beta_2$ are the coefficients that determine the intensity and direction of the effect of a one-unit increase in the associated independent variable on the dependent variable y and $\varepsilon$ is the error term (Cabannes, 2008).

Usually, regressions are conducted with a single entity observed over a time dimension *t*. This means that we observe a dependent variable *y* and explanatory variables $x_1$ and $x_2$ at different points in time for a single group or sample (Shumway & Stoffer, 2006).

In contrast, with panel data, we have two dimensions: a time dimension *t* and an individual dimension *i*. In other words, we observe multiple individuals over time. This dual dimension allows us to analyse not only changes over time but also differences between individuals. Therefore, equation (1) becomes:

(2) $$y_{it} = (\beta_0)_{it} + (\beta_1 x_1)_{it} + (\beta_2 x_2)_{it} + \varepsilon_{it}$$

Where *i* represents the individual and *t* represents time.

Finally, the specificity of regression using panel data lies in the modelling of the error term $\varepsilon_{it}$. Indeed, the error term can be defined as follows :

(3) $$\varepsilon_{it} = u_i + v_t + w_{it}$$

Where $u_i$ is constant and depends only on individual *i*, $v_t$ depends only on the time dimension *t* and $w_{it}$ is a random cross term.

Depending on the assumption about the components of the error term $\varepsilon_{it}$, the model can be estimated in various ways. In our case, we will estimate a model with fixed effects, which assumes that $u_i$ and $v_t$ are continuous, non-random effects that modify only the value of the constant $\beta_0$ in equation (1) based on the individual (Cabannes, 2008).

Multiple linear models are based on several assumptions to ensure the validity of the results obtained. These assumptions include the existence of a linear relationship between the dependent variable and the independent variables, that the model residuals follow a normal distribution, that they are homoscedastic, and that they exhibit no autocorrelation or multicollinearity (Quebec Centre for Biodiversity Science, 2023). Tests have been conducted to verify these assumptions in our model. They are described in the following sections.

### 6.3.2. Stationarity test

In time series analysis, stationarity is a crucial assumption that must be respected to ensure accurate and reliable results. Stationarity means that the statistical properties of the time series (variance, mean, and autocorrelation) remain constant over time (Tate, 2023). To test for stationarity, we use the Levin-Lin-Chu (2002) test, utilising the *purtest()* function, which performs unit root testing for panel data. The presence of a unit root in the data indicates that it is non-stationary. The $H_0$ of the test states that the data are non-stationary (RDocumentation, n.d.-a). If this hypothesis is not rejected, we must differentiate the data to make them stationary (Tate, 2023).

### 6.3.3. Granger causality test

Granger causality is a concept that allows establishing predictive relationships between time series data. If a variable $x$ is identified as Granger causal for a variable $y$, it means that past values of $x$ (at time $t-1$ or earlier lags) help predict the values of $y$ at time $t$. Granger causality tests whether past values of one variable provide useful information for forecasting future values of another variable (Seth, 2007). The Granger test is based on the null hypothesis that the variable is not Granger causal.

### 6.3.4. Test for normality of residuals

One of the underlying assumptions of multiple linear regression is that the residuals of the model follow a normal distribution. This normal distribution is characterised by a skewness of 0 and a kurtosis of 3. In other words, for the residuals to follow a normal distribution, these conditions must be met. To test this assumption, we use the Jarque-Bera test, which assesses the skewness $S$ and kurtosis $K$ coefficients under the null hypothesis that the residuals are normally distributed (i.e., $H_0$: $S = 0$ and $K = 3$).

Jarque-Bera test follows the following equation (Khefacha, 2022) :

(4)
$$JB = \frac{n-k}{6}(S^2 + \frac{(K-3)^2}{4})$$

Where $n$ is the number of observations, $k$ is the number of independent variables (equal to 0 except if the data comes from the residuals of a linear regression), $S$ is the skewness coefficient of the residuals, and $K$ is their kurtosis.

#### 6.3.5. Multicollinearity test

Multicollinearity occurs when some of the independent variables in a model are correlated with each other, which means that they influence each other. The absence of multicollinearity is therefore an important condition for the estimation of models. To verify this, we will use the Variance Inflation Factor (VIF), which allows us to determine the extent to which the variance of a variable's coefficient is impacted by potential linear relationships with other variables. VIF values of 1 indicate no collinearity. Some authors suggest that multicollinearity should be a concern starting from a VIF of 2.5, while others recommend worrying only from a VIF of 5 (Larmarange, 2024).

#### 6.3.6. Cross-sectional dependence test

Cross-sectionality is frequently observed in panel data models. It is thought to be due in particular to the presence of unobservable factors which affects the error term and therefore the reliability of the analyses. It is therefore important to check this in order to avoid bias in the results obtained (De Hoyos & Sarafidis, 2006).

#### 6.3.7. Error autocorrelation test

Autocorrelation of residuals is a common issue in time series data. It occurs when errors at time *t* are correlated with errors at other time points. This temporal dependence introduces biases in the variance estimates of the residuals, which can make coefficient estimates less precise and affect the validity of the regression results (Penn State - Stat Online, n. d.). To check our models, we use the Breusch-Godfrey test for panel data. This test allows us to verify the presence of serial correlation in the model residuals, with the null hypothesis being that there is no autocorrelation of the residuals (RDocumentation n.d.-b).

#### 6.3.8. Heteroscedasticity test

Finally, as previously discussed, it is crucial to check for heteroscedasticity in a model, which means examining whether the variance of its residuals remains constant over time. The presence of heteroscedasticity suggests that the model may be mis-specified. This could imply that important variables are missing from the model, or that the relationship between the dependent and independent variables is not correctly specified. To address this issue, one common approach is to transform some variables into logarithms or explore other transformations to stabilise the variance of the residuals (Bock, 2018 ; Williams, 2020). To check our models, we use the Breusch-Pagan test which tests the null hypothesis that the errors are homoscedastic (RDocumentation, n.d.-c).

### 6.4. Data preparation

First, the databases were imported into RStudio[4]. Next, they were cleaned to ensure that each variable for each country had 21 data points, ranging from 2000 to 2020. Subsequently, the

[4] The full code is available in Appendix 6

data were combined by country and then assembled into a panel data frame, named *pdata* in the RStudio code (Appendices 7, 8 and 9 contain three summary tables of all the variables used and their names, as well as their values between 2000 and 2020).

It is important to note that seasonality is an important and frequently observed factor in time series data. It is characterised by recurring fluctuations at specific times of the year, across different years. These variations can be due to seasonal effects such as climate or institutional decisions. It is crucial to account for seasonality to avoid biases in future analyses (LinkedIn, 2023). However, detecting seasonality requires infra-annual data, which is not applicable in our case since our time series are annual (Statistics Canada, 2015). Therefore, this characteristic has not been studied in our analysis.

To stabilise variance (Tiplica, 2022) and normalise our data (Della Vedova, 2022), we decided to apply logarithmic transformations to some of our variables (i.e. CO2 emissions, GDP, Renewable Capacity, Share Renew, Electricity access and Imports). This step is crucial to meet the assumptions of autocorrelation and error normality, ensuring that our results are unbiased. Subsequently, we also analysed the stationarity of our data. Stationarity is a necessary prerequisite for conducting multiple linear regression. To test this, we used the Levin-Lin-Chu test, which is specific to panel data. Some of our data were non-stationary, so we decided to apply differencing. First-order data differentiation works as follows (Statistics Globe, 2020) :

(5) $$y'_t = y_t - y_{t-1}$$

After a first-order differentiation, some of our datasets were still not stationary (i.e. the *p-value* was still above the rejection threshold of 0.05). We therefore had to apply a second-order differencing:

(6) $$\begin{aligned} y''_t &= y'_t - y'_{t-1} \\ &= (y_t - y_{t-1}) - (y_{t-1} - y_{t-2}) \end{aligned}$$

After two rounds of differencing, all our data were found to be stationary. Therefore, we decided to use our panel data with a second-order differencing for our models[5]. A summary table of the stationarity test results, conducted after the first and second differentiation, is available in Appendix 10.

Before estimating our models, we also tested for multicollinearity between our variables using the *vif()* function. The results of these tests are provided in Appendix 11. Since all VIF values are very close to 1, we can conclude that there is no significant multicollinearity among our

[5] It is important to note that differencing was performed on the data for each country, given that we are working with a panel. As a result, we now have 19 observations per variable instead of the initial 21.

variables. Typically, multicollinearity is a concern when the VIF is 2.5 or higher (Larmarange, 2024).

Finally, we performed the Granger causality test using the *pgrangertest()* function in RStudio, which allows us to conduct this test for panel data. We first tested each independent variable individually on the dependent variables *CO2_capita* and *GDP*. It turned out that only one independent variable is Granger causal for both dependent variables: *renew_capacity* (see Appendix 12 for the test results for each variable), which implies that the past values of *renew_capacity* are somehow capable to explain actual values of the CO2 emissions and the GDP per capita.

# Chapter 7: Results and interpretation

## 7.1. Descriptive analysis of databases

Before proceeding to the analysis of our multiple linear regressions, we will first conduct a descriptive analysis of our datasets. This will involve calculating key statistics such as means and variances, and then examining graphical trends for each country. Additionally, we will compare these trends across countries to gain a comprehensive understanding of the data.

The *Table 2* presents the means of all variables by country (except for electricity access). The main takeaway from this table is that Morocco and Egypt have higher means in almost all variables, while Ethiopia shows relatively low values compared to these two countries. Kenya, on the other hand, falls in between, with data sometimes closer to those of Ethiopia and therefore lower, and sometimes closer to those of Morocco and Egypt, but never exceeding them.

| | CO2_emissions | GDP | energy_cons_capita | share_renew | renew_capacity | imports | unemployment_rate |
|---|---|---|---|---|---|---|---|
| Unit | tCO2/capita | Current USD/capita | kWh/capita | % | Million kW | TJ | % |
| **Egypt** | 1.88338095 | 2233.9036 | 9594.9194 | 2.596190 | 3.579105 | 564940.0 | 10.468286 |
| **Ethiopia** | 0.08004762 | 413.8771 | 542.7318 | 1.961429 | 1.938114 | 114975.3 | 2.680571 |
| **Kenya** | 0.26504762 | 1094.7186 | 1637.8470 | 2.973333 | 1.198862 | 189490.2 | 3.127190 |
| **Morocco** | 1.42242857 | 2789.0636 | 5733.1275 | 8.019524 | 1.874442 | 696152.0 | 10.131143 |

***Table 2****: Mean for each variable by country (except elec_access)*

What we can observe is that average per capita consumption in Egypt is significantly higher than in Ethiopia, at about 9595 vs 543 kWh/capita. This is also reflected in CO2 emissions per capita, which are on average over 23 times higher in Egypt than in Ethiopia. Regarding the share of renewables in final energy consumption, Morocco leads with an average of 8%, significantly higher than all the others.

Examining the percentage of access to electricity in these countries (*Table 3*) reveals a particularly alarming finding. In 2020, just over half of the Ethiopian population had access to electricity, and only 71.5% of the Kenyan population. In contrast, in Egypt and Morocco, almost the entire population has had access to electricity for several years now. This largely explains the differences in averages we have observed between the countries.

| | **elec_access (% of population)** | |
|---|---|---|
| | **Minimum** | **Maximum** |
| **Egypt** | 97.4 | 100.0 |
| **Ethiopia** | 10.2 | 51.1 |
| **Kenya** | 15.2 | 71.5 |
| **Morocco** | 69.8 | 100.0 |

***Table 3****: Minimum and maximum percentages of access to electricity by country*

The following graph (*Figure 4*) shows the evolution of the dependent variables that we are studying. It can be seen that, unsurprisingly, Kenya and Ethiopia exhibit lower CO2 emissions with a more stable trend over the 20-year period. In contrast, emissions in Egypt and Morocco increase more or less continuously, with declines starting from 2017 to 2020 for Egypt and from 2019 for Morocco.

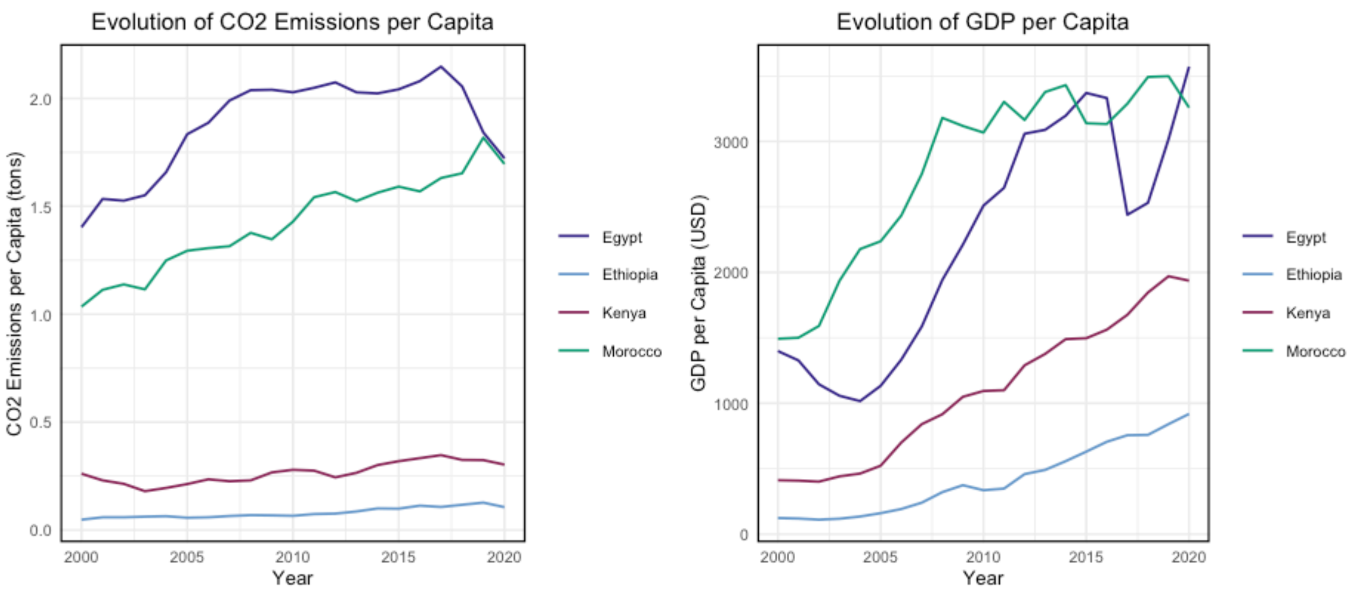


***Figure 4****: Trend graphs for the dependent variables studied*

On the other hand, GDP per capita appears to increase continuously for Morocco, Ethiopia and Kenya. In Egypt, however, while GDP per capita saw significant growth between 2004 and 2015, it experienced a notable decline shortly after 2016 before rising again. Charts showing changes in the independent variables are available in Appendices 13.1 to 13.6.

## 7.2. Multiple Linear Regression models and statistical tests results

### 7.2.1. Multiple Linear Regressions

As previously explained, the purpose of our study is to test the hypothesis that investments in renewable energy help combat climate change by reducing CO2 emissions, while also stimulating economic development in Africa. To do this, we used the Seemingly Unrelated Regression (SUR) method, introduced by Zellner in 1962, utilising the *systemfit()* package in RStudio. SUR is a method that involves estimating a system of equations simultaneously, taking into account the possible correlation between the error terms of each equation. This method is particularly relevant for panel data, as it accounts for potential cross-sectional dependence between the errors of the individuals, which in our case are the four countries ; i.e. Morocco, Kenya, Egypt and Ethiopia (Moon & Perron, 2006 ; RDocumentation, n.d.-d).

It is widely acknowledged that individuals have characteristics unique to them that can influence the results obtained in the regression. The fixed effects for individuals capture unobserved effects that impact the error term, and thus the regression estimations. The goal is therefore to check for these effects to obtain reliable results (Torres-Reyna, 2007). Consequently, we decided to include fixed effects for individuals in our model, as time-fixed effects are often negligible or absent (Cabannes, 2008).

To account for these unobservable individual effects, we created and included dummy variables in our models. These binary variables allowed us to manually incorporate fixed effects into our regressions. Dummies were therefore created for each country, except for one, to avoid multicollinearity among the variables (Rathore, 2020).

For the multiple linear regressions, we decided to retain all our variables, whether they are Granger causal or not. This choice is based on the fact that we tested each variable individually for Granger causality. We believe that it is still possible that some variables, in combination with others, could influence our dependent variables.

Model 1, for which we used second-order differencing, is presented as follows:

$$
\begin{aligned}
CO2\_capita'' = \beta_0 &+ \beta_1(elec\_access)'' \\
&+\beta_2(share\_renew)'' + \beta_3(imports)'' \\
&+\beta_4(energy\_cons\_capita)'' \\
&+\beta_5(renew\_capacity)'' + \beta_6(unemployment\_rate)'' \\
&+\beta_{7,8,9}(country\_dummy\_vars) + \epsilon
\end{aligned} \tag{7}
$$

After running this regression in RStudio, we obtained a set of results that are available in *Figure 5*. What interests us in particular are the coefficients of the independent variables. The

"Estimate" column shows, for each variable, how many units the dependent variable (here, CO2 emissions) increases or decreases on average in response to a one-unit increase in the corresponding independent variable. The "Pr(>|t|)" column indicates whether this change has a statistically significant impact on the dependent variable *y* (Torres-Reyna, 2010).

SUR estimates for 'eq1' (equation 1)

Model Formula: CO2_capita ~ elec_access + share_renew + imports + energy_cons_capita + renew_capacity + unemployment_rate + countryEthiopia + countryKenya + countryMorocco

Coefficients:

| | Estimate | Std. Error | T-value | Pr(>|t|) | |
|---|---|---|---|---|---|
| (Intercept) | -5.91047e-04 | 1.74120e-02 | -0.03394 | 0.97302354 | |
| elec_access | 4.11270e-03 | 4.69039e-02 | 0.08768 | 0.93039363 | |
| share_renew | -1.60998e-01 | 6.82730e-02 | -2.35816 | 0.02133783 | * |
| imports | 2.54404e-01 | 6.66572e-02 | 3.81661 | 0.00030093 | *** |
| energy_cons_capita | 1.19664e-04 | 3.49752e-05 | 3.42139 | 0.00107366 | ** |
| renew_capacity | -1.05734e-01 | 5.70714e-02 | -1.85266 | 0.06840331 | . |
| unemployment_rate | -8.61850e-03 | 1.10214e-02 | -0.78198 | 0.43702412 | |
| countryEthiopia | -1.50322e-02 | 2.46097e-02 | -0.61082 | 0.54341447 | |
| countryKenya | 1.83752e-03 | 2.46198e-02 | 0.07464 | 0.94073029 | |
| countryMorocco | 3.65597e-03 | 2.45784e-02 | 0.14875 | 0.88220650 | |

---

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.075521 on 66 degrees of freedom
Number of observations: 76 Degrees of Freedom: 66
SSR: 0.376423 MSE: 0.005703 Root MSE: 0.075521
Multiple R-Squared: 0.409703 Adjusted R-Squared: 0.329208

***Figure 5**: Multiple linear regression results for Model 1*

In Model 1, the results highlight three variables with a significant influence on CO2 emissions: *share_renew*, *imports* and *energy_cons_capita*.

For a one-unit increase in *share_renew*, *imports* and *energy_cons_capita*, we observe an average decrease in CO2 emissions of 0.1610 units, and increases of 0.2544 and 0.0001 units, respectively. With a wider rejection threshold of 7%, changes in the *renew_capacity* variable also affect CO2 emissions, reducing them by 0.1057 units. This is consistent with the expectation that an increase in the share of renewable energy and in the total renewable energy capacity should reduce CO2 emissions. Conversely, an increase in average energy consumption per capita and imports would lead to higher CO2 emissions, although the impact of *energy_cons_capita* is relatively smaller.

Another important measure is the R-Squared. The R-Squared (or $R^2$) is a key metric that indicates the percentage of the variance in the dependent variable that is explained by the independent variables in the model. However, it tends to increase simply with the number of variables included in the model, even if these variables are not truly relevant, which can lead to misleading estimates. For a more accurate assessment, it is better to refer to the Adjusted R-Squared (or Adjusted $R^2$), which corrects for this tendency by taking into account the number of variables in the model (Akossou, 2013). In our analysis, the Adjusted R-Squared indicates that 32.92% of the variation in CO2 emissions per person is explained by the model. While this suggests that the model accounts for a notable portion of the variation, it also implies that there is still a substantial amount of variability in CO2 emissions that is not captured by the model.

The second model is defined as follows:

(8)
$$\begin{aligned} GDP'' = {} & \beta_0 + \beta_1(elec\_access)'' \\ & + \beta_2(share\_renew)'' + \beta_3(imports)'' \\ & + \beta_4(energy\_cons\_capita)'' \\ & + \beta_5(renew\_capacity)'' \\ & + \beta_6(unemployment\_rate)'' \\ & + \beta_{7,8,9}(country\_dummy\_vars) + \epsilon \end{aligned}$$

*Figure 6* below allows us to analyse the results obtained after performing the regression. We observe that none of the variables appear to explain the model. This means that changes in the chosen independent variables cannot account for changes in GDP per capita. The $R^2$ value confirms this information.

```
SUR estimates for 'eq2' (equation 1)
Model Formula: GDP ~ elec_access + share_renew + imports +
        energy_cons_capita + renew_capacity + unemployment_rate +
        countryEthiopia + countryKenya +  countryMorocco

Coefficients:
                      Estimate     Std. Error   T-value    Pr(>|t|)
(Intercept)         1.19582e-02   2.54941e-02   0.46906    0.64057
elec_access        -6.53315e-02   6.86754e-02  -0.95131    0.34492
share_renew        -6.21545e-02   9.99635e-02  -0.62177    0.53623
imports             5.68505e-02   9.75977e-02   0.58250    0.56222
energy_cons_capita  3.71790e-06   5.12098e-05   0.07260    0.94234
renew_capacity      3.12509e-02   8.35625e-02   0.37398    0.70962
unemployment_rate  -1.64168e-02   1.61373e-02  -1.01733    0.31271
countryEthiopia    -2.29689e-03   3.60329e-02  -0.06374    0.94937
countryKenya       -1.35091e-02   3.60477e-02  -0.37476    0.70904
countryMorocco     -1.26138e-02   3.59870e-02  -0.35051    0.72707
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.110575 on 66 degrees of freedom
Number of observations: 76 Degrees of Freedom: 66
SSR: 0.806978 MSE: 0.012227 Root MSE: 0.110575
Multiple R-Squared: 0.042693 Adjusted R-Squared: -0.087849
```

***Figure 6****: Multiple linear regression results for Model 2*

### 7.2.2. Statistical tests results

*Table 4* below presents the results of the statistical tests conducted for each model. These tests are crucial for enhancing the reliability of the results obtained from our regressions. We used RStudio to perform these tests, utilising the functions mentioned in the table. The tests were conducted to verify the cross-sectional dependence, normality, homoscedasticity and autocorrelation of the model residuals.

| | | **Model 1** | | **Model 2** | |
|---|---|---|---|---|---|
| ***Test*** | | **p-value** | **Decision** | **p-value** | **Decision** |
| ***pcdtest()*** | **$H_0$**: No cross sectional dependence | 0.4041 | Accept $H_0$ | 0.2604 | Accept $H_0$ |
| ***jarque.bera.test()*** | **$H_0$**: Residuals are normally distributed | 0.7055 | Accept $H_0$ | 0.08944 | Accept $H_0$ |
| ***bptest()*** | **$H_0$**: Homoscedasticity | 0.4887 | Accept $H_0$ | 0.2245 | Accept $H_0$ |
| ***pbgtest()*** | **$H_0$** :No serial correlation in errors | 0.1948 | Accept $H_0$ | 0.1183 | Accept $H_0$ |

***Table 4****: Results of statistical tests on the residuals of the two models*

Regarding the statistical test results, it appears that all the assumptions necessary for conducting a regression analysis without bias are met. Specifically, the residuals of both models are normally distributed, homoscedastic and free from serial correlation and cross-sectional dependence. Therefore, we can confidently rely on the results obtained from both models. We conclude that the variation in CO2 emissions is influenced by the variables share_renew, energy_cons_capita and imports, with *renew_capacity* also having an impact, but to a lesser extent compared to the other three variables. In contrast, GDP does not seem to be influenced by any of the variables.

---

# Chapter 8: Discussion

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## 8.1. Evaluating results against the hypothesis

Given the results obtained, we can reconsider our hypothesis: "Climate finance in renewable energy in Africa contributes to combating global warming by reducing CO2 emissions and stimulates economic development on the African continent.".

Regarding the first model, which examines the first part of this hypothesis, we can partly confirm that increasing climate finance in renewable energy contributes to reducing CO2 emissions and therefore mitigates the impact of global warming. The increase in renewable energy infrastructure in Africa, particularly through the involvement of MDBs, funds, and international organisations, seems to have a positive impact on CO2 emissions. That makes sens, as the increase in the share of clean energy available contributes to reducing greenhouse gas emissions. Moreover, investments in renewable energy tend to reduce energy imports, which has a direct and negative impact on CO2 release. This trend is observed in Egypt, where energy imports have significantly decreased in recent years, and in Morocco, where they remain relatively stable (see Appendix 13.5). However, given the value of $R^2$, it is important to bear in mind that the majority of CO2 emissions are not explained by the variables we have chosen.

Even though some countries do not yet have full electricity access for their entire population, this access has been steadily increasing year by year. This increase is a potential factor leading to a rise in per capita energy consumption, and, according to our analysis, it also implies a rise in CO2 emissions. However, the role of renewable infrastructure seems to be significant as it helps mitigate these increases across the continent. These results are very encouraging, as they demonstrate that efforts at both the national and international levels are proving effective. If African countries could benefit from more funding, the results could improve further.

Regarding the second part of the hypothesis, which examines whether investments in renewable energy, in addition to making a positive contribution to combating global warming, are capable of stimulating economic development on the continent, the results obtained are not very promising. Although infrastructure development is expected to increase employment, improve access to education, and strengthen healthcare (AfDB, 2020), the data indicate that investments in renewable energy do not have a significant effect on economic development in Africa. This situation is concerning, as in a context where balancing economic and environmental sustainability is crucial, results showing that these two goals are not compatible could restrict the development of policies favouring renewable energy and, to some extent, discourage major energy sector players from making greener decisions.

In conclusion, our analyses confirm that climate finance in renewable energy infrastructure has an impact on reducing CO2 emissions, thus contributing to the fight against global warming. However, we were unable to confirm the hypothesis that these investments would stimulate economic development. It is important to note that, while climate finance in renewable energy does not seem to stimulate economic development, it does not slow it down either. This lack of a negative effect is a significant point to consider.

### 8.2. Study limitations

Although our analysis provides valuable information, it is important to recognise that the study has a number of limitations:

#### A. Data availability and delayed effects of investments on dependent variables

Firstly, the availability of relevant data was a significant limitation. Our primary objective was to evaluate how climate finance in renewable energies contributes to combating climate change and stimulating economic development. Ideally, we would have verified this hypothesis using a variable that represents the amount of climate investment in renewable energies per year for each country. However, time series data spanning the period from 2000 to 2020 for these specific details were not available online. Additionally, there are numerous funds and international organisations that contribute to these investments. Finding a comprehensive source that aggregated the amounts from all these funds together did not prove possible. We therefore had to rely on available variables that are potentially impacted by these investments and that could also potentially influence our dependent variables. This indirect approach reduces the directness and potentially the reliability of our conclusions, as the variables used may not perfectly capture the effects of climate finance on renewable energy investments.

Moreover, climate investments take years to have measurable impacts on GHG emissions as well as GDP. The time required to construct and operationalise energy infrastructures means that their impact on emissions may not be fully captured within our study period, which ended in 2020. Consequently, some recently built facilities might not have had enough time to influence our data and, therefore, our hypotheses. Economic development stimulated by these investments, such as job creation, improved access to education, and enhanced healthcare, often takes several years to materialise and be reflected in GDP growth too. Therefore, the short-term data available may not adequately reflect the potential long-term economic benefits of renewable energy investments. Additionally, we chose not to use data prior to 2000 because significant international agreements, such as those leading to the Kyoto Protocol, only began to take shape in the early 2000s. This marked the period when countries first started to adopt formal obligations regarding greenhouse gas emissions and therefore also marked the beginning of an interesting period for our study (Maizland, 2023).

**B. Choice of GDP as the variable representing the economic development**

The choice of GDP as the dependent variable was driven by its status as a widely recognised measure for assessing economic growth and development (Fernando et al., 2024). However, it is important to acknowledge that GDP might not encompass all the relevant dimensions of economic development necessary for this study. As a result, relying solely on GDP may limit the ability to fully assess the comprehensive impact of renewable energy investments on economic development.

**C. Unmeasured impacts**

In our analysis, we incorporated fixed effects in the regression models to account for unobserved variables that are constant over time within each country. This approach helps check for time-invariant factors that might otherwise bias the results. However, it is important to note that this methodology does not account for unobserved variables that are not constant over time, such as corruption or political instability, which could have a significant impact on the dependent variables in our regression models.

**D. Representativeness of the selected sample**

In this study, the focus was on African countries that have already received significant climate financing and have integrated these funds into renewable energy projects. This approach aimed to examine the tangible impact of these investments on CO2 emissions and economic development by concentrating on contexts where the effects are already observable. However, this selection presents a significant limitation in terms of generalising the results. By excluding poorer countries that do not attract sufficient investments and lack the resources to develop renewable infrastructures, the conclusions may not necessarily reflect the situation across the entire African continent.

Nevertheless, it is crucial to emphasise that the study also aims to demonstrate that the efforts made are yielding results. Specifically, it shows that the energy policies of countries already receiving financing are effective in reducing CO2 emissions, even though the impact on economic development was not significant. By highlighting these successes, the study seeks to encourage the implementation of similar energy policies and attract public investments to less developed countries. Such investments could enable poorer nations, which cannot afford to develop such infrastructure on their own, to benefit from renewable energy among other advantages. Consequently, although the studied sample studied is limited, it does illustrate the potential for expanding investments and policies to less advantaged contexts.

### 8.3. Suggestions for future improvements

In conclusion, we have several suggestions for future research concerning the impact of climate finance in renewable energy in Africa. The findings of this study prompt us to move beyond our initial framework and suggest several avenues for improvement.

Firstly, the conclusions drawn from our models indicate that climate finance in renewable energy in Africa does not have a significant impact on the economic development of the analysed countries. However, as mentioned in our limitations, the dependent variable that we chose to represent economic development -GDP- may not be capable of capturing all the dimensions that could be influenced by these investments. Therefore, it could be beneficial to integrate a broader set of indicators into the model to better represent the economic development of the countries.

To achieve this, a composite index could be created, aimed at consolidating multiple indicators into a single measure (Chakrabartty, 2017). This index could include variables such as employment rates, poverty levels, access to education, healthcare, and more. Such an approach would also make it possible to observe the impacts on social development as well.

Additionally, we would advise conducting a regional assessment focusing on specific countries or areas to understand how energy policies and other country-specific factors influence the financing received. For instance, we know that ten countries in Africa received more than half of the climate investments (Meattle et al., 2022b). Analysing these countries could provide a basis for understanding the successful strategies and conditions that attract significant funding. This approach could identify strategies to assist countries struggling to attract climate finance and ensure that resources are allocated in a way that addresses the unique needs and contexts of different regions.

Furthermore, to gain a more comprehensive understanding of the impacts of climate finance on renewable energy projects, it would be beneficial to extend the temporal scope of the analysis. As more data become available over time, the long-term effects of climate investments on $CO_2$ emissions and economic development can be better captured.

Finally, we suggest exploring a wider range of independent variables. Beyond the primary variables of interest, such as emissions and GDP, it would be valuable to examine other factors to assess their direct or indirect relationships with climate finance in renewable energy. These factors could include technological advancements or improvements in energy efficiency. Incorporating these additional variables would provide a more comprehensive understanding of the diverse effects of climate finance and offer deeper insights into how it can influence sustainable, economic and social development.

## V. Conclusion

Firstly, we would like to reiterate that the objective of this study was to establish a link between climate finance investments in renewable energy and their impact on $CO_2$ emissions and the economic development of African countries. The aim of this research was to attempt to demonstrate a positive correlation between these factors, in order to show that climate finance in renewables on the continent has the potential to positively influence both the fight against climate change and the stimulation of economic development.

To achieve this, we first theoretically explored the concepts of climate finance and renewable energy, and examined these within the context of Africa. Morocco, a pioneer in the renewable energy sector on the continent, was analysed in detail to present its financing mechanisms and the projects that have already been implemented within its borders. Subsequently, we conducted a quantitative study to determine whether there is a causal relationship between investments in renewable energy in Africa and their effects on $CO_2$ emissions and economic development. Given the limited availability of data, we had to opt for variables where the impact of investments was deferred, and utilised panel data by selecting four African countries where renewable investments are significant.

Using the data we collected, we conducted two multiple linear regressions employing the SUR estimator and fixed effects. The results indicate that $CO_2$ emissions are partially influenced by climate investments in renewables, generally showing a decrease. However, economic development does not appear to be stimulated (or hindered) by these investments. Therefore, we can confirm the first part of our hypothesis, but not the second.

It therefore appears that the continent's efforts to meet the targets of the Paris Agreement are bearing fruit in terms of $CO_2$ emissions. However, we firmly believe that if access to financing for the most vulnerable African countries were facilitated, even better results could be observed. Similarly, energy policies that encourage countries to invest in renewables could play a crucial role in accelerating the energy transition and promoting sustainable development across the continent. Furthermore, while this study did not demonstrate a direct impact of renewable investments on economic development, we are convinced that these investments can have significant social impacts. Indeed, such investments can enhance access to energy across the continent, leading to numerous benefits, including improvements in education and healthcare.

Finally, we must emphasise that although our study focuses on climate finance in renewable energy, which is primarily related to mitigation goals, it is crucial to also prioritise adaptation projects in response to climate change. As Edmond Totin pointed out, the continent's greatest vulnerability to climate change lies in its difficulty to adapt (Hutton, 2022). Therefore, it is important not to overlook that, while African countries have well-established NDCs that they aim to achieve, this should not come at the expense of investment in adaptation, especially given that Africa is not among the top emitters of greenhouse gases. That said, we are confident that the continent can benefit from its mitigation projects and emission reduction goals by increasing its involvement in carbon markets, among other opportunities.

In conclusion, in a world where climate change is widely acknowledged but still inadequately addressed given its urgency, it is crucial to implement global strategies that fully leverage the potential of countries capable of making significant contributions to this fight. However, it is equally essential not to overlook the most disadvantaged regions, such as Africa, which, despite their vulnerabilities, often lack the necessary funding and resources to adapt to climate challenges. In other words, Africa has a huge potential, but this potential will remain untapped until adequate resources are mobilised. Thanks to the results of our analyses, we can hope that if appropriate measures are taken and less developed countries receive support from the public sector, we can move closer to the NDCs and the goals of the Paris Agreement. Additionally, although we have not been able to identify a significant link between renewable energies and economic development, we are convinced that such a link can be established in the coming years with the inclusion of variables that take more dimensions into account.

The emergence of climate finance, along with the involvement of national and international bodies, MDBs, and others, will undoubtedly bring us closer to global objectives. However, without intensified international cooperation and genuine changes, achieving the ambitions set forth in the Paris Agreement may, in our opinion, remain out of reach.

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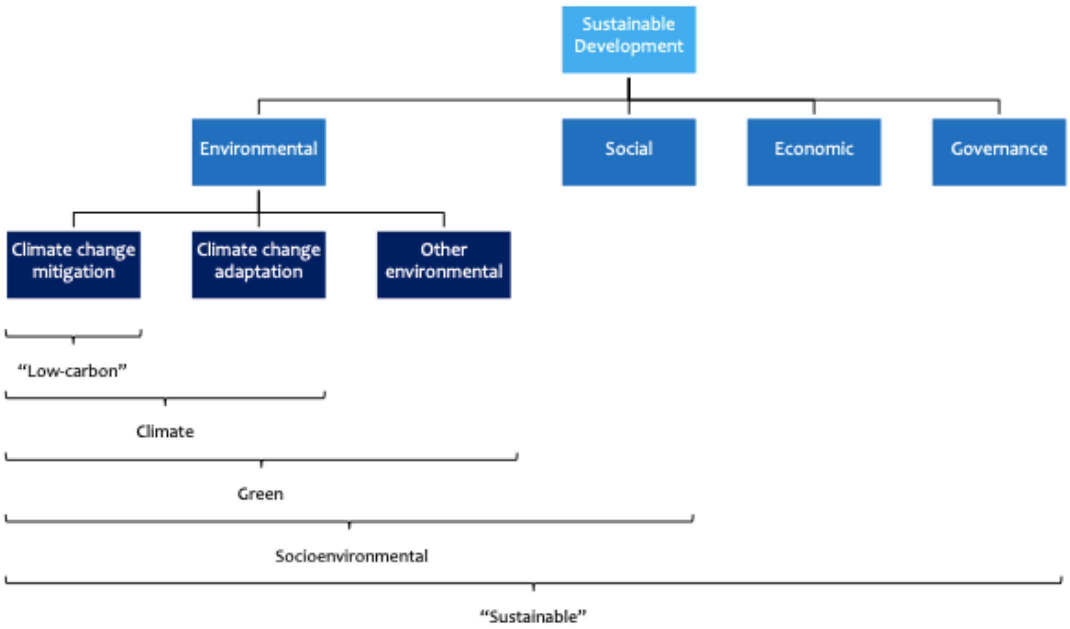
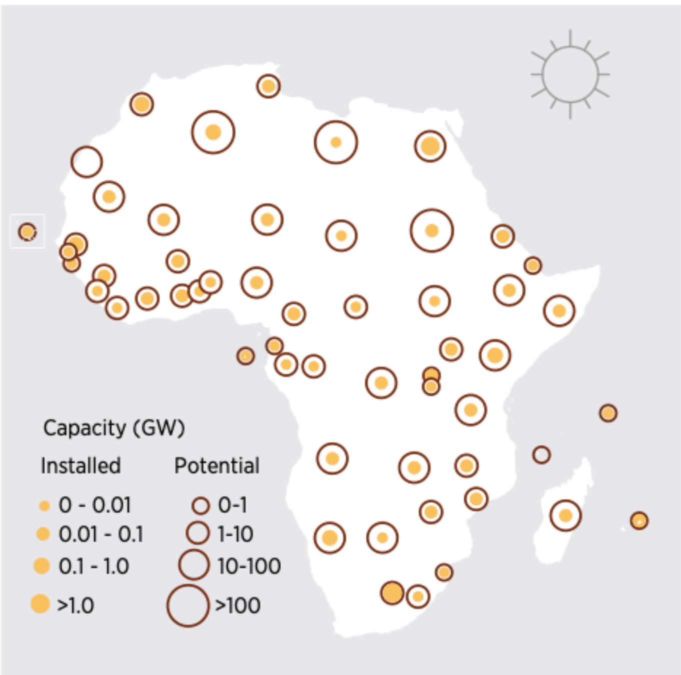
## VII. Appendices

**Appendix 1:** Difference between Climate, Green and Sustainable finance




Available at UNEP Inquiry, 2016, p.11.

**Appendix 2:** Solar PV (photovoltaic) potential and installed capacity, Africa.





Available at IRENA & AfDB , 2022, p.42.

**Appendix 3:** Mitigation action plans for electricity generation in Morocco

| N° | Secteur | Mesures | Description | Atténuation 2020-2030 (Gg CO2) | Atténuation 2030 (Gg CO2) | Coût (Millions U$) |
|---|---|---|---|---|---|---|
| 1 | Production électricité | Plan éolien national à l'horizon 2020 | Mise en place de parcs éoliens sur plusieurs sites à l'horizon 2020 pour une capacité totale de 1 467 MW. | 33 761,3 | 3 305,3 | 2 000,0 |
| 2 | | Plan solaire national à l'horizon 2020 | Mise en place de centrales solaires thermo-dynamiques à concentration et photovoltaïques sur plusieurs sites à l'horizon 2020 pour une capacité totale de 827 MW. | 15 501,7 | 1 504,6 | 2 550,0 |
| 3 | | Centrales hydrauliques à l'horizon 2020 | Centrale hydraulique : Tanafnit El Borj (Khénifra) de 40MW en plus de 40 MW de capacités micro-hydrauliques. | 1 064,4 | 102,2 | 160,0 |
| 4 | | Centrales à cycle combiné à l'horizon 2020 | Extension de 23MW de la centrale de Tahaddart. | 557,7 | 62,6 | 16,0 |
| 5 | | Centrales à cycle combiné à l'horizon 2030 | Il s'agit d'un projet d'extension de 450 MW de la centrale de Tahadart prévu en 2025. | 6 354,4 | 1 197,6 | 2 280,0 |
| 6 | | Centrales hydro-électriques à l'horizon 2030 | Mise en place de plusieurs stations de transferts d'énergie par pompage (STEP) et centrales hydroélectriques totalisant 1098 MW de capacité à l'horizon 2030. | 1 178,8 | 379,5 | 1 124,5 |
| 7 | | Plan éolien national à l'horizon 2030 | Mise en place de plusieurs centrales éoliennes sur plusieurs sites pour une capacité totale équivalente à 2180 MW à l'horizon 2030. | 55 234,8 | 10 975,2 | 2 925,0 |
| 8 | | Plan national solaire à l'horizon 2030 | Mise en place de centrales solaires thermo-dynamiques à concentration et photo-voltaïques sur plusieurs sites pour une capacité totale équivalente à 4000 MW à l'horizon 2030. | 42 003,0 | 8 458,5 | 6 026,0 |
| | | **Scénario total** | | **140 795,2** | **22 770,7** | **17 081,5** |

Available at *Moroccan Government*, 2021, p.28.

Translation in English :

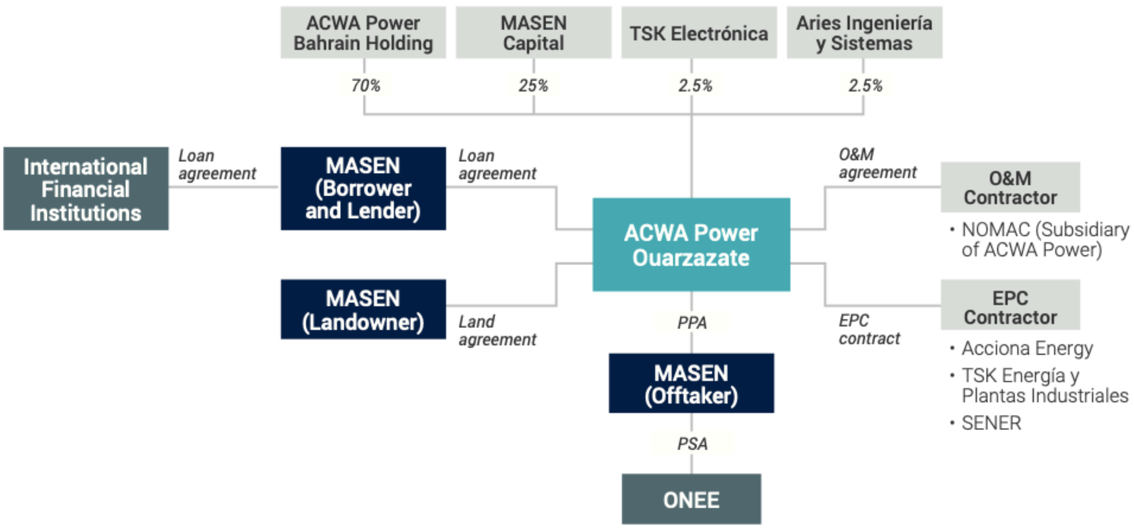
| Sector No. | | Measures | Description | Mitigation 2020-2030 (Gg CO2) | Mitigation 2030 (Gg CO2) | Cost (Millions U$) |
|---|---|---|---|---|---|---|
| 1 | Electricity production | National wind plan for 2020 | Installation of wind farms on several sites by 2020 for a total capacity of 1467 MW. | 33 761,3 | 3 305,3 | 2 000,0 |
| 2 | | National solar plan by 2020 | Installation of concentrated solar thermal power plants and photovoltaic plants on several sites by 2020 for a total capacity of 827 MW. | 15 501,7 | 1 504,6 | 2 550,0 |
| 3 | | Hydroelectric power plants by 2020 | Hydraulic power station: Tanafnit El Borj (Khénifra) of 40MW in addition to 40 MW of micro-hydraulic capacities. | 1 064,4 | 102,2 | 160,0 |
| 4 | | Combined cycle power plants by 2020 | Extension of 23MW of the power plant of Tahaddart. | 557,7 | 62,6 | 16,0 |
| 5 | | Combined cycle power plants by 2030 | This is a 450 MW extension project of the Tahadart power plant scheduled for 2025. | 6 354,4 | 1 197,6 | 2 280,0 |
| 6 | | Hydroelectric power plants by 2030 | Installation of several pumped storage energy transfer stations (PSETs) and hydroelectric power plants totaling 1098 MW of capacity by 2030. | 1 178,8 | 379,5 | 1 124,5 |
| 7 | | National wind plan for 2030 | Installation of several wind farms on several sites for a total capacity equivalent to 2180 MW by 2030. | 55 234,8 | 10 975,2 | 2 925,0 |
| 8 | | National solar plan by 2030 | Installation of concentrated solar thermal power plants and photovoltaic plants on several sites for a total capacity equivalent to 4000 MW by 2030. | 42 003,0 | 8 458,5 | 6 026,0 |
| | | Total scenario | | **140 795,2** | **22 770,7** | **17 081,5** |

**Appendix 4:** Investment funds supporting renewable energy in Africa

| Investment Funds | Projects supported |
|---|---|
| **Africa Renewable Energy Fund (AREF)** | Renewable energy projects with an installed capacity of between 5 and 50 MW. |
| **Beyond the grid Fund for Africa** | Projects to supply off-grid energy to 6 million Africans in various regions by 2025. |
| **Clean Technology Fund** | Funds provided in order to facilitate the scaling up of carbon-neutral technologies. |
| **Green Climate Fund (GCF)** | A major climate fund that has already developed 70 climate-related projects in Africa |
| **Renewable Energy Challenge Fund** | Decentralised photovoltaic projects in Uganda |
| **Sustainable Energy Fund for Africa (SEFA)** | Private funding opened up for small and medium-sized renewable energy projects. |

Information used to create this table available at *IRENA & AfDB , 2022, p.112-113*

**Appendix 5:** Main contracts for Noor I Project




Available at *Global Infrastructure HUB*, 2018, p.4.

**<u>Appendix 6:</u>** Rstudio Code for the quantitative study

*RStudio code used to obtain the results of the quantitative study.*

***#Importation of the packages*———————————————————————————**

```
install.packages("ecm")
install.packages("astsa")
install.packages("trend")
install.packages("tsoutliers")
install.packages("tis")
install.packages("ggplot2")
install.packages("ggthemes")
install.packages("nnet")
install.packages("mgcv")
install.packages("quantreg")
install.packages("systemfit")
install.packages("foreign")
install.packages("car")
install.packages("Rcpp")

library(ecm)
library(vars)
library(mFilter)
library(TSstudio)
library(tidyverse)
library(astsa)
library(car)
library(forecast)
library(tseries)
library(lmtest)
library(trend)
library(outliers)
library(EnvStats)
library(quantmod)
library(dynlm)
library(readr)
library(tsoutliers)
library(tis)
library(urca)
library(RColorBrewer)
library(corrplot)
library(ggplot2)
library(ggthemes)
library(gridExtra)
library(readr)
library(foreign)
library(systemfit)
```

***#Importation of the databases*———————————————————————————-**

***##EGYPT*————————————————————————————————-**

```
library(readr)

CO2_capita_EGY <- read_csv("EGYPT/CO2_capita_EGY.csv",
```

```
                    col_types = cols(Year = col_number(),
                                     `CO2 emissions per capita, Egypt` = col_number()))
#View(CO2_capita_EGY)

energy_cons_capita_EGY <- read_delim("EGYPT/energy_cons_capita_EGY.csv",
                           delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                                  `Primary energy consumption per capita
(kWh/person)` = col_number()),
                           trim_ws = TRUE)
#View(energy_cons_capita_EGY)

GDP_EGY <- read_delim("EGYPT/GDP_EGY.csv",
                delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                       `GDP per capita (current US$)` = col_number()),
                trim_ws = TRUE)
#View(GDP_EGY)

imports_EGY <- read_delim("EGYPT/imports_EGY.csv",
                   delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                          `Imports (TJ)` = col_number(), `Exports (TJ)` =
col_number()),
                   trim_ws = TRUE)
#View(imports_EGY)

renew_capacity_EGY <- read_delim("EGYPT/renew_capacity_EGY.csv",
                        delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                              `Renewables (million kW)` = col_number()),
                        trim_ws = TRUE)
#View(renew_capacity_EGY)

share_renew_EGY <- read_delim("EGYPT/share_renew_EGY.csv",
                      delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                            `Share of modern renewables in final energy
consumption, Egypt` = col_number()),
                      trim_ws = TRUE)
#View(share_renew_EGY)

elec_access_EGY <- read_delim("EGYPT/elec_access_EGY.csv",
                      delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                            `Access to electricity (% of population)` =
col_number()),
                      trim_ws = TRUE)
#View(elec_access_EGY)

unemployment_EGY <- read_delim("EGYPT/unemployment_EGY.csv",
                       delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                             Rate = col_number()), trim_ws = TRUE)
#View(unemployment_EGY)


##MOROCCO——————————————————————————————————————————

CO2_capita_MO <- read_delim("MOROCCO/CO2_capita_MO.csv",
                     delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                           `CO2 emissions per capita, Morocco` =
col_number()),
                     trim_ws = TRUE)
#View(CO2_capita_MO)
```

```
energy_cons_capita_MO <- read_delim("MOROCCO/energy_cons_capita_MO.csv",
                        delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                    `Primary energy consumption per capita (kWh/
person)` = col_number()),
                        trim_ws = TRUE)
#View(energy_cons_capita_MO)

GDP_MO <- read_delim("MOROCCO/GDP_MO.csv",
              delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                              `GDP per capita (current US$)` = col_number()),
              trim_ws = TRUE)
#View(GDP_MO)

imports_MO <- read_delim("MOROCCO/imports_MO.csv",
                 delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                              `Imports (TJ)` = col_number(), `Exports (TJ)` =
col_number()),
                 trim_ws = TRUE)
#View(imports_MO)

renew_capacity_MO <- read_delim("MOROCCO/renew_capacity_MO.csv",
                      delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                    `Renewables (million kW)` = col_number()),
                      trim_ws = TRUE)
#View(renew_capacity_MO)

share_renew_MO <- read_delim("MOROCCO/share_renew_MO.csv",
                    delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                  `Share of modern renewables in final energy
consumption, Morocco` = col_number()),
                    trim_ws = TRUE)
#View(share_renew_MO)

elec_access_MO <- read_delim("MOROCCO/elec_access_MO.csv",
                    delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                  `Access to electricity (% of population)` =
col_number()),
                    trim_ws = TRUE)
#View(elec_access_MO)

unemployment_MO <- read_delim("MOROCCO/unemployment_MO.csv",
                     delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                  Rate = col_number()), trim_ws = TRUE)
#View(unemployment_MO)


##KENYA———————————————————————————————————————

CO2_capita_KE <- read_csv("KENYA/CO2_capita_KE.csv",
                 col_types = cols(Year = col_number(),
                           `CO2 emissions per capita, Kenya` = col_number()))
#View(CO2_capita_KE)

energy_cons_capita_KE <- read_delim("KENYA/energy_cons_capita_KE.csv",
                        delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                    `Primary energy consumption per capita (kWh/
person)` = col_number()),
```

```
                          trim_ws = TRUE)
#View(energy_cons_capita_KE)

GDP_KE <- read_delim("KENYA/GDP_KE.csv",
               delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                    `GDP per capita (current US$)` = col_number()),
               trim_ws = TRUE)
#View(GDP_KE)

imports_KE <- read_delim("KENYA/imports_KE.csv",
                 delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                      `Imports (TJ)` = col_number(), `Exports (TJ)` =
col_number()),
                 trim_ws = TRUE)
#View(imports_KE)

renew_capacity_KE <- read_delim("KENYA/renew_capacity_KE.csv",
                      delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                          `Renewables (million kW)` = col_number()),
                      trim_ws = TRUE)
#View(renew_capacity_KE)

share_renew_KE <- read_delim("KENYA/share_renew_KE.csv",
                    delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                        `Share of modern renewables in final energy
consumption, Kenya` = col_number()),
                    trim_ws = TRUE)
#View(share_renew_KE)

elec_access_KE <- read_delim("KENYA/elec_access_KE.csv",
                    delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                        `Access to electricity (% of population)` =
col_number()),
                    trim_ws = TRUE)
#View(elec_access_KE)

unemployment_KE <- read_delim("KENYA/unemployment_KE.csv",
                     delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                        Rate = col_number()), trim_ws = TRUE)
#View(unemployment_KE)


##ETHIOPIA————————————————————————————————————

CO2_capita_ET <- read_delim("ETHIOPIA/CO2_capita_ET.csv",
                   delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                       `CO2 emissions per capita, Ethiopia` =
col_number()),
                   trim_ws = TRUE)
#View(CO2_capita_ET)

elec_access_ET <- read_delim("ETHIOPIA/elec_access_ET.csv",
                    delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                        `Access to electricity (% of population)` =
col_number()),
                    trim_ws = TRUE)
#View(elec_access_ET)
```

```
energy_cons_capita_ET <- read_delim("ETHIOPIA/energy_cons_capita_ET.csv",
                        delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                        `Primary energy consumption per capita (kWh/
person)` = col_number()),
                        trim_ws = TRUE)
#View(energy_cons_capita_ET)

GDP_ET <- read_delim("ETHIOPIA/GDP_ET.csv",
             delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                    `GDP per capita (current US$)` = col_number()),
             trim_ws = TRUE)
#View(GDP_ET)

imports_ET <- read_delim("ETHIOPIA/imports_ET.csv",
                delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                     Imports = col_number()), trim_ws = TRUE)
#View(imports_ET)

renew_capacity_ET <- read_delim("ETHIOPIA/renew_capacity_ET.csv",
                       delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                           `Renewables (million kW)` = col_number()),
                       trim_ws = TRUE)
#View(renew_capacity_ET)


share_renew_ET <- read_delim("ETHIOPIA/share_renew_ET.csv",
                     delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                         `Share of modern renewables in final energy
consumption, Ethiopia` = col_number()),
                     trim_ws = TRUE)
#View(share_renew_ET)

unemployment_ET <- read_delim("ETHIOPIA/unemployment_ET.csv",
                      delim = ";", escape_double = FALSE, col_types = cols(Year = col_number(),
                                                          Rate = col_number()), trim_ws = TRUE)
#View(unemployment_ET)


#Cleaning the data——————————————————————————————————

#install.packages("magrittr")
library(magrittr)
library(dplyr)

CO2_capita_EGY <- CO2_capita_EGY %>% select(Year, `CO2 emissions per capita, Egypt`)
CO2_capita_EGY <- subset(CO2_capita_EGY, CO2_capita_EGY$Year>=2000 &
CO2_capita_EGY$Year<=2020)

CO2_capita_KE <- CO2_capita_KE %>% select(Year, `CO2 emissions per capita, Kenya`)
CO2_capita_KE <- subset(CO2_capita_KE, CO2_capita_KE$Year>=2000 &
CO2_capita_KE$Year<=2020)

CO2_capita_MO <- CO2_capita_MO %>% select(Year, `CO2 emissions per capita, Morocco`)
CO2_capita_MO <- subset(CO2_capita_MO, CO2_capita_MO$Year>=2000 &
CO2_capita_MO$Year<=2020)

CO2_capita_ET <- CO2_capita_ET %>% select(Year, `CO2 emissions per capita, Ethiopia`)
```

```
elec_access_EGY <- elec_access_EGY %>% select(Year, `Access to electricity (% of population)`)
elec_access_EGY <- subset(elec_access_EGY, elec_access_EGY$Year>=2000 &
elec_access_EGY$Year<=2020)

elec_access_KE <- elec_access_KE %>% select(Year, `Access to electricity (% of population)`)
elec_access_KE <- subset(elec_access_KE, elec_access_KE$Year>=2000 &
elec_access_KE$Year<=2020)

elec_access_MO <- elec_access_MO %>% select(Year, `Access to electricity (% of population)`)
elec_access_MO <- subset(elec_access_MO, elec_access_MO$Year>=2000 &
elec_access_MO$Year<=2020)


energy_cons_capita_EGY <- subset(energy_cons_capita_EGY,
energy_cons_capita_EGY$Year>=2000 & energy_cons_capita_EGY$Year<=2020)

energy_cons_capita_KE <- subset(energy_cons_capita_KE, energy_cons_capita_KE$Year>=2000 &
energy_cons_capita_KE$Year<=2020)

energy_cons_capita_MO <- subset(energy_cons_capita_MO, energy_cons_capita_MO$Year>=2000
& energy_cons_capita_MO$Year<=2020)


GDP_EGY <- subset(GDP_EGY, GDP_EGY$Year>=2000 & GDP_EGY$Year<=2020)

GDP_KE <- subset(GDP_KE, GDP_KE$Year>=2000 & GDP_KE$Year<=2020)

GDP_MO <- subset(GDP_MO, GDP_MO$Year>=2000 & GDP_MO$Year<=2020)


imports_EGY <- imports_EGY %>% select(Year, `Imports (TJ)`)
imports_EGY <- subset(imports_EGY, imports_EGY$Year>=2000 & imports_EGY$Year<=2020)

imports_KE <- imports_KE %>% select(Year, `Imports (TJ)`)
imports_KE <- subset(imports_KE, imports_KE$Year>=2000 & imports_KE$Year<=2020)

imports_MO <- imports_MO %>% select(Year, `Imports (TJ)`)
imports_MO <- subset(imports_MO, imports_MO$Year>=2000 & imports_MO$Year<=2020)


renew_capacity_EGY <- subset(renew_capacity_EGY, renew_capacity_EGY$Year >=2000 &
renew_capacity_EGY$Year<=2020)

renew_capacity_KE <- subset(renew_capacity_KE, renew_capacity_KE$Year >=2000 &
renew_capacity_KE$Year<=2020)

renew_capacity_MO <- subset(renew_capacity_MO, renew_capacity_MO$Year >=2000 &
renew_capacity_MO$Year<=2020)


share_renew_EGY <- share_renew_EGY %>% select(Year, `Share of modern renewables in final
energy consumption, Egypt`)

share_renew_KE <- share_renew_KE %>% select(Year, `Share of modern renewables in final energy
consumption, Kenya`)

share_renew_MO <- share_renew_MO  %>% select(Year, `Share of modern renewables in final
energy consumption, Morocco`)
```

```
#Panel data model creation——————————————————————————

#Combine all the data in one data frame

data_MO <- data.frame(year=2000:2020, country="Morocco", CO2_capita_MO$`CO2 emissions per capita, Morocco`, elec_access_MO$`Access to electricity (% of population)`, GDP_MO$`GDP per capita (current US$)`, energy_cons_capita_MO$`Primary energy consumption per capita (kWh/person)`, imports_MO$`Imports (TJ)`, share_renew_MO$`Share of modern renewables in final energy consumption, Morocco`, renew_capacity_MO$`Renewables (million kW)`, unemployment_MO$Rate)

data_EGY <- data.frame(year=2000:2020, country="Egypt", CO2_capita_EGY$`CO2 emissions per capita, Egypt`, elec_access_EGY$`Access to electricity (% of population)`, GDP_EGY$`GDP per capita (current US$)`, energy_cons_capita_EGY$`Primary energy consumption per capita (kWh/person)`, imports_EGY$`Imports (TJ)`, share_renew_EGY$`Share of modern renewables in final energy consumption, Egypt`, renew_capacity_EGY$`Renewables (million kW)`, unemployment_EGY$Rate)

data_KE <- data.frame(year=2000:2020, country="Kenya", CO2_capita_KE$`CO2 emissions per capita, Kenya`, elec_access_KE$`Access to electricity (% of population)`, GDP_KE$`GDP per capita (current US$)`, energy_cons_capita_KE$`Primary energy consumption per capita (kWh/person)`, imports_KE$`Imports (TJ)`, share_renew_KE$`Share of modern renewables in final energy consumption, Kenya`, renew_capacity_KE$`Renewables (million kW)`, unemployment_KE$Rate)

data_ET <- data.frame(year=2000:2020, country="Ethiopia", CO2_capita_ET$`CO2 emissions per capita, Ethiopia`, elec_access_ET$`Access to electricity (% of population)`, GDP_ET$`GDP per capita (current US$)`, energy_cons_capita_ET$`Primary energy consumption per capita (kWh/person)`, imports_ET$Imports, share_renew_ET$`Share of modern renewables in final energy consumption, Ethiopia`, renew_capacity_ET$`Renewables (million kW)`, unemployment_ET$Rate)

#Rename the columns
colnames(data_MO) <- colnames(data_EGY) <- colnames(data_KE) <- colnames(data_ET) <- c("year", "country", "CO2_capita", "elec_access", "GDP", "energy_cons_capita", "imports", "share_renew", "renew_capacity", "unemployment_rate")

#Combine the data of the 3 countries
data <- rbind(data_MO, data_EGY, data_KE, data_ET)

#Panel Data
library(plm)
pdata <- pdata.frame(data, index = c("country", "year"))


#Descriptive analysis————————————————————————————

#install.packages(c("psych", "corrplot"))
library(plm)
library(ggplot2)
library(dplyr)
library(psych)
library(corrplot)

#Overall statistical summary
summary(data)

#Statistical summary by country
summary <- pdata %>%
  group_by(country) %>%
```

```
  summarise(
    across(c(CO2_capita, elec_access, GDP, energy_cons_capita, imports, share_renew,
renew_capacity, unemployment_rate),
           list(mean = ~ mean(., na.rm = TRUE),
                sd = ~ sd(., na.rm = TRUE),
                min = ~ min(., na.rm = TRUE),
                max = ~ max(., na.rm = TRUE)))
  )

print(summary)

#Plots
library(ggplot2)
library(ggthemes)
library(gridExtra)

palette_bleue <- c("#332288", "#6699cc", "#882255", "#009e73")

CO2plot <- ggplot(data, aes(x = year, y = CO2_capita, color = country)) +
  geom_line(linewidth = 0.7) +
  labs(title = "Evolution of CO2 Emissions per Capita", x = "Year", y = "CO2 Emissions per Capita
(tons)") +
  scale_color_manual(values = palette_bleue) +
  theme_minimal() +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.title = element_blank(),
    legend.key.size = unit(1.5, "lines"),
    panel.border = element_rect(color = "black", fill = NA, size = 1)
  )

# GDP per capita
GDPplot <- ggplot(data, aes(x = year, y = GDP, color = country)) +
  geom_line(linewidth=0.7) +
  labs(title = "Evolution of GDP per Capita", x = "Year", y = "GDP per Capita (USD)") +
  scale_color_manual(values = palette_bleue) +
  theme_minimal() +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.title = element_blank(),
    legend.key.size = unit(1.5, "lines"),
    panel.border = element_rect(color = "black", fill = NA, size = 1)
  )

grid.arrange(CO2plot, GDPplot, ncol = 2)

#Electricity access
elec_access_plot <- ggplot(data, aes(x = year, y = elec_access, color = country)) +
  geom_line(linewidth = 0.7) +
  labs(title = "Access to Electricity (% of population)", x = "Year", y = "Access to Electricity (%)") +
  scale_color_manual(values = palette_bleue) +
  theme_minimal() +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.title = element_blank(),
    legend.key.size = unit(1.5, "lines"),
    panel.border = element_rect(color = "black", fill = NA, size = 1)
  )
```

```
#Energy consumption per capita
energy_cons_capita_plot <- ggplot(data, aes(x = year, y = energy_cons_capita, color = country)) +
  geom_line(linewidth = 0.7) +
  labs(title = "Primary Energy Consumption per Capita", x = "Year", y = "Energy Consumption per
Capita (kWh/person)") +
  scale_color_manual(values = palette_bleue) +
  theme_minimal() +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.title = element_blank(),
    legend.key.size = unit(1.5, "lines"),
    panel.border = element_rect(color = "black", fill = NA, size = 1)
  )

#Share of renewable in final consumption
share_renew_plot <- ggplot(data, aes(x = year, y = share_renew, color = country)) +
  geom_line(linewidth = 0.7) +
  labs(title = "Share of Modern Renewables in final Energy Consumption", x = "Year", y = "Share of
Renewables (%)") +
  scale_color_manual(values = palette_bleue) +
  theme_minimal() +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.title = element_blank(),
    legend.key.size = unit(1.5, "lines"),
    panel.border = element_rect(color = "black", fill = NA, size = 1)
  )

#Renewable capacity
renew_capacity_plot <- ggplot(data, aes(x = year, y = renew_capacity, color = country)) +
  geom_line(linewidth = 0.7) +
  labs(title = "Renewable Capacity", x = "Year", y = "Renewable Capacity (million kW)") +
  scale_color_manual(values = palette_bleue) +
  theme_minimal() +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.title = element_blank(),
    legend.key.size = unit(1.5, "lines"),
    panel.border = element_rect(color = "black", fill = NA, size = 1)
  )

#Imports
imports_plot <- ggplot(data, aes(x = year, y = imports, color = country)) +
  geom_line(linewidth = 0.7) +
  labs(title = "Imports", x = "Year", y = "Imports (TJ)") +
  scale_color_manual(values = palette_bleue) +
  theme_minimal() +
  theme(
    plot.title = element_text(hjust = 0.5),
    legend.title = element_blank(),
    legend.key.size = unit(1.5, "lines"),
    panel.border = element_rect(color = "black", fill = NA, size = 1)
  )

#Unemplyment rate
unemploy_plot <- ggplot(data, aes(x = year, y = unemployment_rate, color = country)) +
  geom_line(linewidth = 0.7) +
```

```
 labs(title = "Unemployment rate", x = "Year", y = "Unemployment (%)") +
 scale_color_manual(values = palette_bleue) +
 theme_minimal() +
 theme(
   plot.title = element_text(hjust = 0.5),
   legend.title = element_blank(),
   legend.key.size = unit(1.5, "lines"),
   panel.border = element_rect(color = "black", fill = NA, size = 1)
 )


grid.arrange(elec_access_plot, energy_cons_capita_plot, share_renew_plot,
renew_capacity_plot,imports_plot, unemploy_plot,  ncol = 3)


#LOG Transformation————————————————————————

pdata$renew_capacity <- log(pdata$renew_capacity)
pdata$share_renew <- log(pdata$share_renew)
pdata$elec_access <- log(pdata$elec_access)
pdata$imports <- log(pdata$imports)
pdata$CO2_capita <- log(pdata$CO2_capita)
pdata$GDP <- log(pdata$GDP)


#Stationarity————————————————————————————

#First diff()
d_pdata <- pdata

for (col in names(pdata)[-c(1, 2)]) {
  d_pdata[[col]] <- ave(pdata[[col]], pdata$country, FUN = function(x) c(NA, diff(x)))
}

d_pdata <- d_pdata[complete.cases(d_pdata), ]
d_pdata <- pdata.frame(d_pdata, index = c("country", "year"))

#Second diff()
d2_pdata <- pdata

for (col in names(pdata)[-c(1, 2)]) {
  d2_pdata[[col]] <- diff(diff(pdata[[col]]), differences = 1)
}

#Delete NAs generated by the differenciation
d2_pdata <- d2_pdata[complete.cases(d2_pdata), ]
d2_pdata <- pdata.frame(d2_pdata, index = c("country", "year"))


##CO2_capita——————————————————————————————

test_result <- purtest(pdata$CO2_capita, test = "levinlin", lags=5)
test_result
#Stationary


##GDP———————————————————————————————————
```

```
test_result_GDP <- purtest(pdata$GDP, test = "levinlin", lags=5)
test_result_GDP

test_result2_GDP <- purtest(d_pdata$GDP, test = "levinlin", lags=5)
test_result2_GDP
#Stationary after one diff


##Elec_access————————————————————————————————

test_result_elec_access <- purtest(pdata$elec_access, test = "levinlin", lags=5)
test_result_elec_access

test_result_elec2_access <- purtest(d_pdata$elec_access, test = "levinlin", lags=5)
test_result_elec2_access
#stationary after one diff()


##Renew capacity————————————————————————————————

test_result_renew_capacity <- purtest(pdata$renew_capacity, test = "levinlin", lags=5)
test_result_renew_capacity

test_result2_renew_capacity <- purtest(d_pdata$renew_capacity, test = "levinlin", lags=5)
test_result2_renew_capacity

test_result3_renew_capacity <- purtest(d2_pdata$renew_capacity, test = "levinlin", lags=5)
test_result3_renew_capacity
#Stationary after 2 diff()


##Imports————————————————————————————————

test_result_imports <- purtest(pdata$imports, test = "levinlin", lags=5)
test_result_imports

test_result2_imports <- purtest(d_pdata$imports, test = "levinlin", lags=5)
test_result2_imports
#Stationary after one diff()


##Energy cons per capita————————————————————————————————

test_result_energy_cons<- purtest(pdata$energy_cons_capita, test = "levinlin", lags=5)
test_result_energy_cons

test_result2_energy_cons <- purtest(d_pdata$energy_cons_capita, test = "levinlin", lags=5)
test_result2_energy_cons

test_result3_energy_cons <- purtest(d2_pdata$energy_cons_capita, test = "levinlin", lags=5)
test_result3_energy_cons
#Stationary after 2 diff()


##Share renew————————————————————————————————

test_result_share_renew <- purtest(pdata$share_renew, test = "levinlin", lags=5)
test_result_share_renew
```

```
test_result_share2_renew <- purtest(d_pdata$share_renew, test = "levinlin", lags=5)
test_result_share2_renew

test_result_share3_renew <- purtest(d2_pdata$share_renew, test = "levinlin", lags=5)
test_result_share3_renew
#Stationary after 2 diff()


##Unemployment

test_result_unemployment <- purtest(pdata$unemployment_rate, test = "levinlin", lags=5)
test_result_unemployment

test_result2_unemployment <- purtest(d_pdata$unemployment_rate, test = "levinlin", lags=5)
test_result2_unemployment
#Stationary after one diff()

#As renew capacity, share_renew and energy cons per capita need 2 diff(), that's what we will use for our models.


#Granger Causality

pgrangertest(CO2_capita~elec_access, data = d2_pdata) #NO
pgrangertest(CO2_capita~share_renew, data = d2_pdata) #NO
pgrangertest(CO2_capita~energy_cons_capita, data = d2_pdata) #NO
pgrangertest(CO2_capita~imports, data = d2_pdata) #NO
pgrangertest(CO2_capita~renew_capacity, data = d2_pdata) #YES
pgrangertest(CO2_capita~unemployment_rate, data = d2_pdata) #NO

pgrangertest(GDP~elec_access, data = d2_pdata) #NO
pgrangertest(GDP~share_renew, data = d2_pdata) #NO
pgrangertest(GDP~energy_cons_capita, data = d2_pdata) #NO
pgrangertest(GDP~imports, data = d2_pdata) #NO
pgrangertest(GDP~renew_capacity, data = d2_pdata) #YES
pgrangertest(GDP~unemployment_rate, data = d2_pdata) #NO


#Multicollinearity

#Transformation in lm() because vif() doesn't support plm()
CO2 <- lm(CO2_capita ~ elec_access + share_renew + imports + energy_cons_capita +
renew_capacity + unemployment_rate, data = d2_pdata)

GDP <- lm(GDP ~ elec_access + share_renew + imports + energy_cons_capita + renew_capacity +
unemployment_rate, data = d2_pdata)

library(car)
vif(CO2) #<5 OK
vif(GDP) #<5 OK


#DUMMIES

library(dummy)

#Creation of dummies froc countries
```

```
country_dummies <- model.matrix(~ country - 1, data = d2_pdata)

#Adding dummies to dataframe
d2_pdata <- cbind(d2_pdata, country_dummies[, -1])

country_dummy_vars <- colnames(country_dummies)[-1]

#Adding dummies to formula
eq1_formula <- as.formula(paste("CO2_capita ~ elec_access + share_renew + imports +
energy_cons_capita + renew_capacity + unemployment_rate +", paste(country_dummy_vars,
collapse = " + ")))
eq2_formula <- as.formula(paste("GDP ~ elec_access + share_renew + imports +
energy_cons_capita + renew_capacity + unemployment_rate +", paste(country_dummy_vars,
collapse = " + ")))

eq1 <- as.formula(eq1_formula)
eq2 <- as.formula(eq2_formula)
```

***#SUR MODEL***

```
library(systemfit)

sur_model1 <- systemfit(list(eq1 = eq1), method = "SUR", data = d2_pdata)
sur_model2 <- systemfit(list(eq2 = eq2), method = "SUR", data = d2_pdata)

summary(sur_model1)
summary(sur_model2)

#Calculation of the residuals
resid_sur_model1 <- residuals(sur_model1)
resid_sur_model2 <- residuals(sur_model2)
```

***###CO2***

```
#Getting residuals/country
resid_sur_model1 <- as.data.frame(resid_sur_model1)
resid_sur_model1$country_year <- rownames(resid_sur_model1)

library(tidyr)
resid_sur_model1 <- separate(resid_sur_model1, country_year, into = c("country", "year"), sep =
"-")
resid_sur_model1$year <- as.numeric(resid_sur_model1$year)


#Residuals^2 for testing homoscedasticity
residuals_squared_model1 <- resid_sur_model1$eq1^2
d2_pdata$residuals <- residuals_squared_model1

#Regressing the residuals on the same independant variables
auxiliary_model <- lm(residuals ~ elec_access + share_renew + imports + energy_cons_capita +
renew_capacity + unemployment_rate, data = d2_pdata)
```

***###GDP***

```
#Getting residuals/country
```

```
resid_sur_model2 <- as.data.frame(resid_sur_model2)
resid_sur_model2$country_year <- rownames(resid_sur_model2)

resid_sur_model2 <- separate(resid_sur_model2, country_year, into = c("country", "year"), sep =
"-")
resid_sur_model2$year <- as.numeric(resid_sur_model2$year)

#Residuals^2
residuals_squared_model2 <- resid_sur_model2$eq2^2
d2_pdata$residuals2 <- residuals_squared_model2

#Regressing the residuals on the same independant variables
auxiliary_model2 <- lm(residuals2 ~ elec_access + share_renew + imports + energy_cons_capita +
renew_capacity + unemployment_rate, data = d2_pdata)
```

**##Normality of the residuals**——————————————————————————

```
library(tseries)
resid1 <- resid_sur_model1$eq1
resid2 <- resid_sur_model2$eq2

jarque.bera.test(resid1) #pval= 0.7055
jarque.bera.test(resid2) #pval= 0.08944
```

**##Homoscedasticity**——————————————————————————————-

```
bp_test <- bptest(auxiliary_model)
bp_test #Homosc, pval = 0.4887

bp_test2 <- bptest(auxiliary_model2)
bp_test2 #homosc, pval = 0.2245
```

**##Autocorrelation**——————————————————————————————

```
###CO2
residuals_data <- d2_pdata

#Adding lags to residuals
residuals_data$residuals_lag1 <- lag(residuals_data$residuals, k = 1)

bg_model <- lm(residuals ~ residuals_lag1 + elec_access + share_renew + imports +
energy_cons_capita + renew_capacity + unemployment_rate, data = residuals_data)
bgtest(bg_model, order = 1) #pvalue= 0.1948

###GDP
#Adding lags to residuals
residuals_data$residuals2_lag1 <- lag(residuals_data$residuals2, k = 1)

bg_model2 <- lm(residuals2 ~ residuals2_lag1 + elec_access + share_renew + imports +
energy_cons_capita + renew_capacity + unemployment_rate, data = residuals_data)
bgtest(bg_model2, order = 1) #pvalue=  0.1183
```

***##Cross section dependence———————————————————————————————***

```
pdata_resid_model1 <- pdata.frame(resid_sur_model1, index = c("country", "year"))

pdata_resid_model2 <- pdata.frame(resid_sur_model2, index = c("country", "year"))

# Test CD for Model 1
cd_test_model1 <- pcdtest(pdata_resid_model1$eq1, test = "cd")
print(cd_test_model1) #C0.4041

# Test CD for Model 2
cd_test_model2 <- pcdtest(pdata_resid_model2$eq2, test = "cd")
print(cd_test_model2) #0.2604
```

**The following Appendices have been produced using code outputs (from the code available in Appendix 6).**

**Appendix 7:** Names chosen for the variables in the RStudio Code

| Variable | Variable name in the code |
|---|---|
| **CO2 emissions per capita** | *CO2_capita* |
| **GDP per capita** | *GDP* |
| **Energy imports** | *imports* |
| **Average energy consumption per capita** | *energy_cons_capita* |
| **Share of modern renewables in final energy consumption** | *share_renew* |
| **Electricity access** | *elec_access* |
| **Renewable energy capacity** | *renew_capacity* |
| **Unemployment rate** | *unemployment_rate* |

**Appendix 8:** Names chosen for the panel databases

| Initial name | first-order differentiation | Second-order differentiation |
|---|---|---|
| *pdata* | *d_pdata* | *d2_pdata* |

**Appendix 9:** Data values for each variable and for each country from 2000 to 2020

| Country | Year | CO2_capita | GDP | elec_access | energy_cons_capita | imports | share_renew | renew_capacity | unemployment_rate |
|---|---|---|---|---|---|---|---|---|---|
| **Egypt** | 2000 | 1.403 | 1398.8598 | 97.7 | 7965.8477 | 201309 | 3.46 | 2.946100 | 8.980 |
| | 2001 | 1.534 | 1327.0965 | 97.4 | 8143.8460 | 149956 | 3.47 | 2.814500 | 9.260 |
| | 2002 | 1.526 | 1144.5324 | 97.5 | 8202.8900 | 129259 | 2.95 | 2.881600 | 10.010 |
| | 2003 | 1.551 | 1056.9372 | 98.8 | 8503.9930 | 137030 | 3.02 | 2.881600 | 10.910 |

| Country | Year | CO2_capita | GDP | elec_access | energy_cons_capita | imports | share_renew | renew_capacity | unemployment_rate |
|---|---|---|---|---|---|---|---|---|---|
| | 2004 | 1.658 | 1016.2539 | 97.8 | 8798.1490 | 169274 | 3.03 | 2.952600 | 10.320 |
| | 2005 | 1.834 | 1133.1055 | 99.4 | 8844.9420 | 289221 | 2.60 | 3.000600 | 11.049 |
| | 2006 | 1.887 | 1332.3394 | 99.0 | 9136.1450 | 306428 | 2.52 | 3.050600 | 10.490 |
| | 2007 | 1.990 | 1586.4729 | 98.4 | 9542.5830 | 320070 | 2.72 | 3.209700 | 8.800 |
| | 2008 | 2.038 | 1941.9000 | 99.8 | 9921.1670 | 344593 | 2.58 | 3.267900 | 8.517 |
| | 2009 | 2.040 | 2212.2181 | 98.9 | 10077.9010 | 462213 | 2.31 | 3.298000 | 9.087 |
| | 2010 | 2.028 | 2509.7720 | 99.4 | 10258.8760 | 535975 | 2.13 | 3.442000 | 8.757 |
| | 2011 | 2.049 | 2645.6225 | 99.4 | 10555.7520 | 561752 | 2.28 | 3.452000 | 11.849 |
| | 2012 | 2.074 | 3059.1354 | 99.7 | 10739.8130 | 603405 | 2.17 | 3.452000 | 12.597 |
| | 2013 | 2.028 | 3088.8908 | 99.9 | 10422.9030 | 684050 | 2.21 | 3.452000 | 13.154 |
| | 2014 | 2.023 | 3196.8614 | 99.8 | 10063.2705 | 881660 | 2.28 | 3.452000 | 13.105 |
| | 2015 | 2.042 | 3370.3824 | 99.3 | 9988.4380 | 1086579 | 2.24 | 3.667000 | 13.052 |
| | 2016 | 2.080 | 3331.6125 | 100.0 | 10324.9060 | 1322915 | 2.08 | 3.691000 | 12.450 |
| | 2017 | 2.147 | 2439.9673 | 100.0 | 10519.2230 | 1182266 | 1.99 | 3.802000 | 11.767 |
| | 2018 | 2.055 | 2531.2001 | 100.0 | 10327.1420 | 983378 | 2.12 | 4.793000 | 9.855 |
| | 2019 | 1.842 | 3017.2583 | 100.0 | 9951.8960 | 887600 | 3.06 | 5.689500 | 7.851 |
| | 2020 | 1.722 | 3571.5569 | 100.0 | 9203.6250 | 624807 | 3.30 | 5.965500 | 7.974 |
| **Ethioipia** | 2000 | 0.048 | 122.9617 | 12.7 | 287.9912 | 46163 | 1.29 | 0.406800 | 3.502 |
| | 2001 | 0.059 | 119.2619 | 10.2 | 304.5467 | 50518 | 1.28 | 0.478800 | 3.174 |
| | 2002 | 0.059 | 110.4609 | 11.9 | 303.8467 | 52416 | 1.35 | 0.478800 | 3.061 |

| Country | Year | CO2_capita | GDP | elec_access | energy_cons_capita | imports | share_renew | renew_capacity | unemployment_rate |
|---|---|---|---|---|---|---|---|---|---|
| | 2003 | 0.062 | 117.8602 | 13.5 | 319.2207 | 55964 | 1.37 | 0.512900 | 3.002 |
| | 2004 | 0.064 | 134.5425 | 15.2 | 331.6574 | 59275 | 1.43 | 0.722900 | 2.771 |
| | 2005 | 0.057 | 160.0768 | 14.0 | 370.1885 | 66026 | 1.51 | 0.722900 | 2.497 |
| | 2006 | 0.059 | 191.7513 | 18.6 | 394.9136 | 73440 | 1.56 | 0.722900 | 2.346 |
| | 2007 | 0.065 | 240.3480 | 20.3 | 424.8531 | 84174 | 1.56 | 0.722900 | 2.344 |
| | 2008 | 0.069 | 320.8611 | 22.0 | 432.3203 | 91209 | 1.48 | 0.722900 | 2.333 |
| | 2009 | 0.068 | 373.8940 | 23.7 | 434.6404 | 92469 | 1.51 | 1.442900 | 2.331 |
| | 2010 | 0.066 | 335.4385 | 25.5 | 468.2621 | 94572 | 1.75 | 1.901700 | 2.299 |
| | 2011 | 0.074 | 348.0013 | 23.0 | 514.2451 | 103690 | 1.87 | 2.080100 | 2.274 |
| | 2012 | 0.076 | 458.5509 | 29.0 | 557.1035 | 112643 | 2.07 | 2.080900 | 2.255 |
| | 2013 | 0.086 | 490.7925 | 30.8 | 632.6332 | 129839 | 2.22 | 2.224300 | 2.251 |
| | 2014 | 0.100 | 557.5341 | 27.2 | 697.6292 | 150160 | 2.28 | 2.230100 | 2.364 |
| | 2015 | 0.099 | 630.3126 | 29.0 | 715.4247 | 157234 | 2.46 | 2.618900 | 2.450 |
| | 2016 | 0.113 | 705.6175 | 42.9 | 807.2398 | 179813 | 2.64 | 2.649000 | 2.566 |
| | 2017 | 0.107 | 755.7526 | 44.3 | 794.9772 | 189719 | 2.65 | 4.366100 | 2.678 |
| | 2018 | 0.117 | 758.2977 | 44.8 | 823.5834 | 208578 | 2.96 | 4.450900 | 2.825 |
| | 2019 | 0.127 | 840.4496 | 48.0 | 921.9911 | 229948 | 2.94 | 4.450900 | 2.945 |
| | 2020 | 0.106 | 918.6526 | 51.1 | 860.0999 | 186632 | 3.01 | 4.712800 | 4.024 |
| **Kenya** | 2000 | 0.261 | 411.8214 | 15.2 | 1478.9890 | 172172 | 1.56 | 0.772500 | 2.876 |
| | 2001 | 0.230 | 408.3606 | 17.0 | 1460.3776 | 161764 | 2.36 | 0.772600 | 2.868 |

| Country | Year | CO2_capita | GDP | elec_access | energy_cons_capita | imports | share_renew | renew_capacity | unemployment_rate |
|---|---|---|---|---|---|---|---|---|---|
| | 2002 | 0.214 | 401.0924 | 18.9 | 1429.8123 | 130916 | 2.84 | 0.775600 | 2.903 |
| | 2003 | 0.180 | 441.3914 | 16.0 | 1321.4634 | 113870 | 2.83 | 0.775600 | 2.860 |
| | 2004 | 0.195 | 462.6182 | 22.6 | 1380.1080 | 147267 | 2.90 | 0.845500 | 2.836 |
| | 2005 | 0.213 | 522.7768 | 24.5 | 1454.5236 | 140689 | 2.72 | 0.845600 | 2.739 |
| | 2006 | 0.235 | 699.3997 | 26.4 | 1549.1115 | 149197 | 2.62 | 0.845600 | 2.678 |
| | 2007 | 0.226 | 840.1916 | 28.3 | 1513.0850 | 149300 | 2.85 | 0.845600 | 2.650 |
| | 2008 | 0.230 | 915.9989 | 30.3 | 1449.5537 | 161551 | 2.70 | 0.905800 | 2.752 |
| | 2009 | 0.267 | 1049.1218 | 23.0 | 1537.1414 | 180236 | 2.15 | 0.971900 | 2.813 |
| | 2010 | 0.279 | 1093.6396 | 19.2 | 1622.7236 | 185363 | 2.49 | 1.027900 | 2.793 |
| | 2011 | 0.275 | 1099.3155 | 36.2 | 1633.5077 | 195964 | 2.65 | 1.029100 | 2.706 |
| | 2012 | 0.244 | 1289.7808 | 38.1 | 1575.0422 | 179399 | 3.04 | 1.083600 | 2.686 |
| | 2013 | 0.265 | 1376.8292 | 40.1 | 1620.4467 | 186047 | 3.24 | 1.095600 | 2.764 |
| | 2014 | 0.301 | 1489.9197 | 36.0 | 1655.0222 | 212080 | 3.14 | 1.266800 | 2.768 |
| | 2015 | 0.319 | 1496.6536 | 41.6 | 1911.9027 | 233830 | 3.70 | 1.563000 | 2.763 |
| | 2016 | 0.333 | 1562.0766 | 53.1 | 1966.5875 | 247165 | 3.67 | 1.631700 | 2.757 |
| | 2017 | 0.347 | 1675.9884 | 55.8 | 1939.6578 | 263810 | 3.28 | 1.673800 | 3.540 |
| | 2018 | 0.325 | 1845.7834 | 61.2 | 2047.2719 | 261691 | 3.80 | 2.059800 | 4.284 |
| | 2019 | 0.324 | 1970.0801 | 69.7 | 1946.3412 | 263991 | 3.87 | 2.085900 | 5.014 |
| | 2020 | 0.303 | 1936.2508 | 71.5 | 1902.1184 | 242993 | 4.03 | 2.302600 | 5.621 |
| **Morocco** | 2000 | 1.035 | 1492.3771 | 69.8 | 4113.6670 | 475154 | 8.52 | 1.227300 | 13.580 |

| Country | Year | CO2_capita | GDP | elec_access | energy_cons_capita | imports | share_renew | renew_capacity | unemployment_rate |
|---|---|---|---|---|---|---|---|---|---|
| | 2001 | 1.113 | 1500.3634 | 71.6 | 4386.6230 | 531729 | 8.52 | 1.227600 | 12.460 |
| | 2002 | 1.138 | 1590.4873 | 73.3 | 4439.7236 | 496201 | 8.41 | 1.228300 | 11.590 |
| | 2003 | 1.115 | 1936.0902 | 75.1 | 4397.9960 | 487984 | 9.08 | 1.327500 | 11.920 |
| | 2004 | 1.249 | 2177.7988 | 78.2 | 4946.6387 | 545173 | 11.51 | 1.328420 | 10.830 |
| | 2005 | 1.294 | 2237.5762 | 78.6 | 5301.4736 | 592370 | 9.91 | 1.329320 | 11.010 |
| | 2006 | 1.306 | 2433.2126 | 96.5 | 5340.5317 | 595985 | 8.99 | 1.330120 | 9.670 |
| | 2007 | 1.315 | 2751.4236 | 82.2 | 5226.2114 | 647003 | 8.23 | 1.391220 | 9.560 |
| | 2008 | 1.377 | 3180.1707 | 84.1 | 5694.0356 | 628423 | 7.37 | 1.392120 | 9.570 |
| | 2009 | 1.347 | 3118.1416 | 85.9 | 5486.0760 | 662152 | 7.88 | 1.519720 | 8.960 |
| | 2010 | 1.429 | 3067.8518 | 95.7 | 6005.1500 | 714584 | 8.04 | 1.561033 | 9.090 |
| | 2011 | 1.542 | 3302.4531 | 96.1 | 6222.6260 | 773153 | 6.76 | 1.595733 | 8.910 |
| | 2012 | 1.566 | 3164.0046 | 96.4 | 6249.1240 | 858464 | 6.35 | 1.596733 | 8.990 |
| | 2013 | 1.524 | 3377.6436 | 97.2 | 6330.0835 | 840237 | 7.32 | 1.836733 | 9.230 |
| | 2014 | 1.563 | 3430.5344 | 97.3 | 6336.7560 | 868678 | 7.00 | 2.143133 | 9.700 |
| | 2015 | 1.591 | 3139.2283 | 97.3 | 6368.3936 | 804286 | 7.23 | 2.307033 | 9.460 |
| | 2016 | 1.569 | 3132.9521 | 97.8 | 6361.1960 | 777807 | 7.26 | 2.416833 | 9.300 |
| | 2017 | 1.631 | 3288.5027 | 100.0 | 6580.7236 | 815991 | 6.96 | 2.538833 | 9.229 |
| | 2018 | 1.653 | 3492.6726 | 98.1 | 6730.6070 | 835178 | 7.65 | 3.271833 | 9.282 |
| | 2019 | 1.818 | 3498.5828 | 99.6 | 7267.4640 | 866316 | 7.56 | 3.271833 | 9.210 |
| | 2020 | 1.696 | 3258.2690 | 100.0 | 6610.5780 | 802323 | 7.86 | 3.521933 | 11.203 |

**Appendix 10:** p-values for Stationary Tests

| **Variable** | ***$H_0$ = Non-Stationarity****<br>***$H_1$ = Stationarity*** | | | | |
|---|---|---|---|---|---|
| | **No diff()** | **First diff()** | **Second diff** | **Results** | **Decision** |
| | ***p*-value** | ***p*-value** | ***p*-value** | | |
| CO2_capita | 0.03391 | | | I(0) | Reject $H_0$ |
| GDP | 0.8938 | 0.01610 | | I(1) | Reject $H_0$ |
| elec_access | 0.9528 | 0.0005252 | | I(1) | Reject $H_0$ |
| renew_capacity | 0.8881 | 0.9711 | 0.003231 | I(2) | Reject $H_0$ |
| imports | 0.7915 | 0.02634 | | I(1) | Reject $H_0$ |
| energy_cons_capita | 0.6712 | 0.282 | 1.405e-05 | I(2) | Reject $H_0$ |
| share_renew | 0.4237 | 0.07223 | 6.514e-07 | I(2) | Reject $H_0$ |
| unemployment_rate | 0.9783 | 0.04318 | | I(1) | Reject $H_0$ |

*Rejection threshold: 0.05

**Appendix 11:** VIF test results for multicollinearity between independent variables

| **elec_access** | **share_renew** | **imports** | **energy_cons_capita** | **Renew capacity** | **unemployment_rare** |
|---|---|---|---|---|---|
| 1.062417 | 1.076807 | 1.039519 | 1.074614 | 1.052948 | 1.079300 |

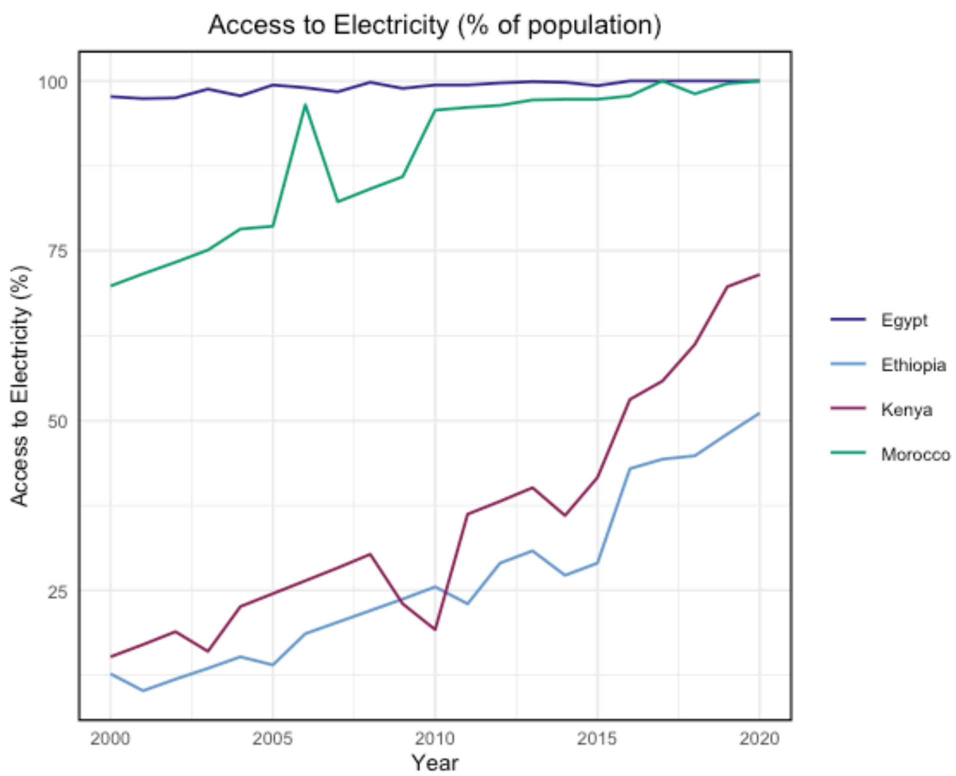
**Appendix 12:** Results of the Granger test for each independent variable, on each of the independent variables

| Variable | $H_0$ = *Non-Granger Causal** | | |
|---|---|---|---|
| | $H_1$ = *Granger Causal* | | |
| | **CO2_capita** | **GDP** | **Results** |
| | ***p*-value** | ***p*-value** | |
| elec_access | 0.6603 | 0.7915 | Reject $H_1$ |
| share_renew | 0.2565 | 0.6492 | Reject $H_1$ |
| energy_cons_capita | 0.8152 | 0.7747 | Reject $H_1$ |
| Imports | 0.8368 | 0.6643 | Reject $H_1$ |
| renew_capacity | 8.981e-07 | 0.03901 | Reject $H_0$ |
| unemployment_rate | 0.358 | 0.3663 | Reject $H_1$ |

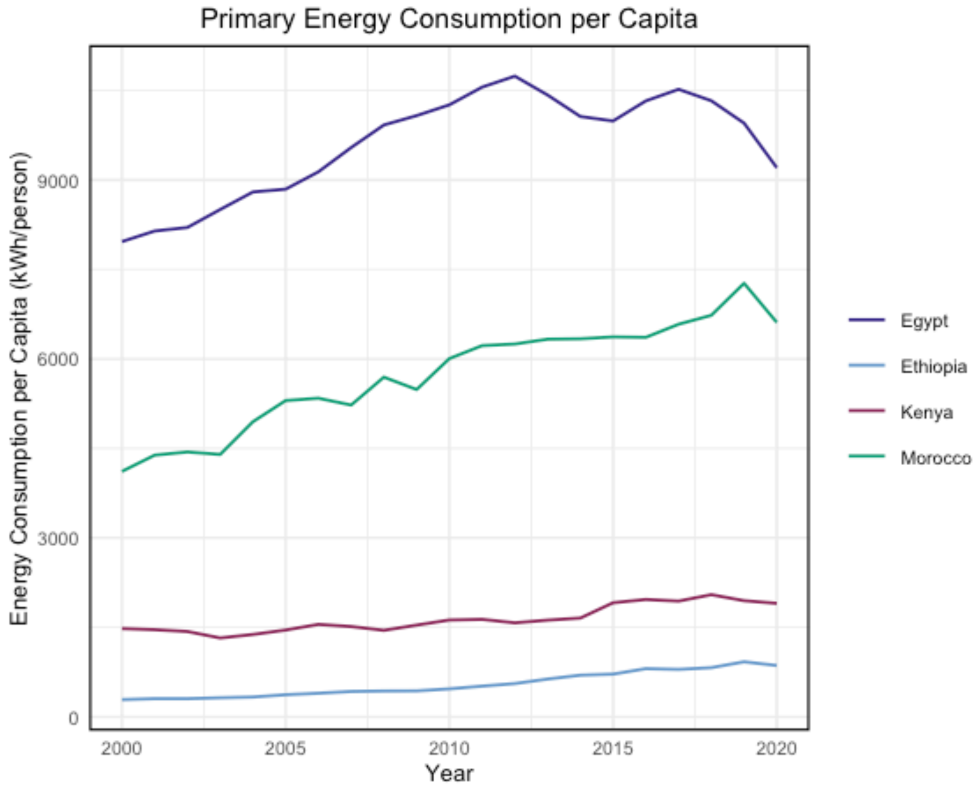
*Rejection threshold: 0.05

**Appendix 13:** Trend graphs of independent variables

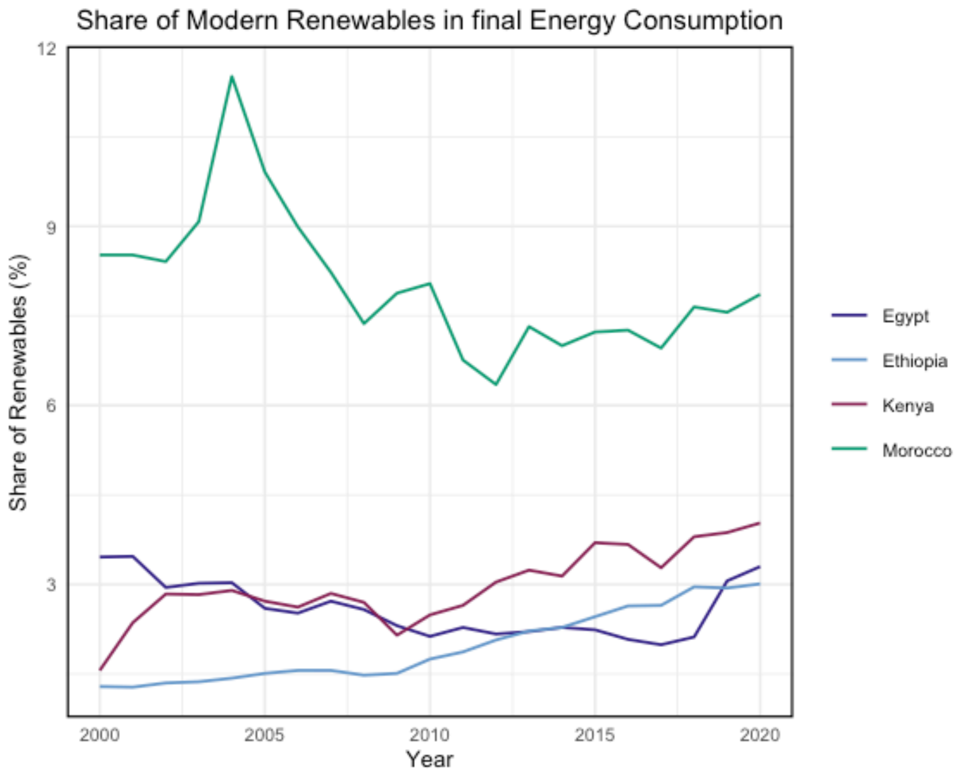
1. *Growth in access to electricity between 2000 and 2020*



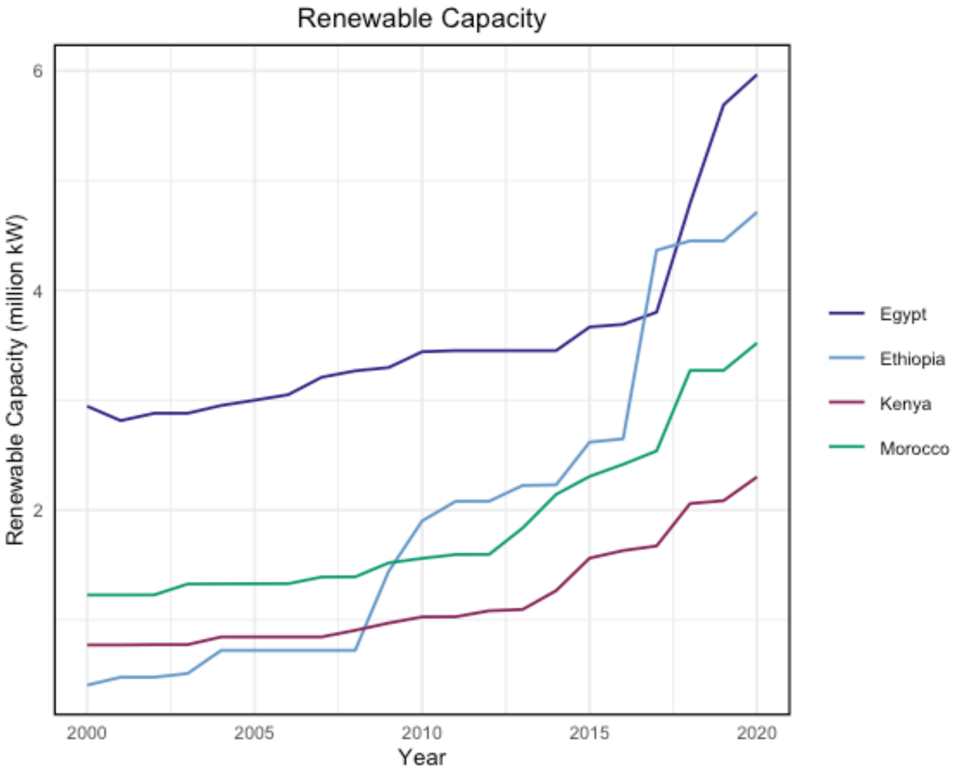
2. *Change in average energy consumption per person between 2000 and 2020*



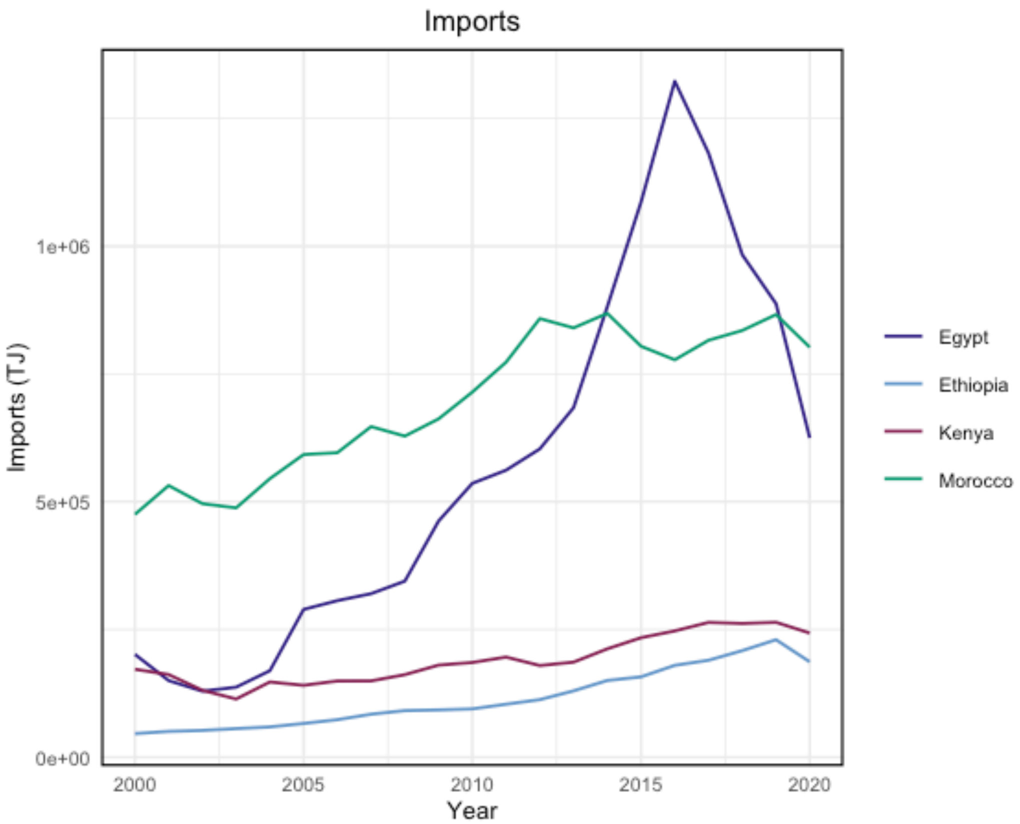

3. *Change in the share of renewable energy in final consumption between 2000 and 2020*



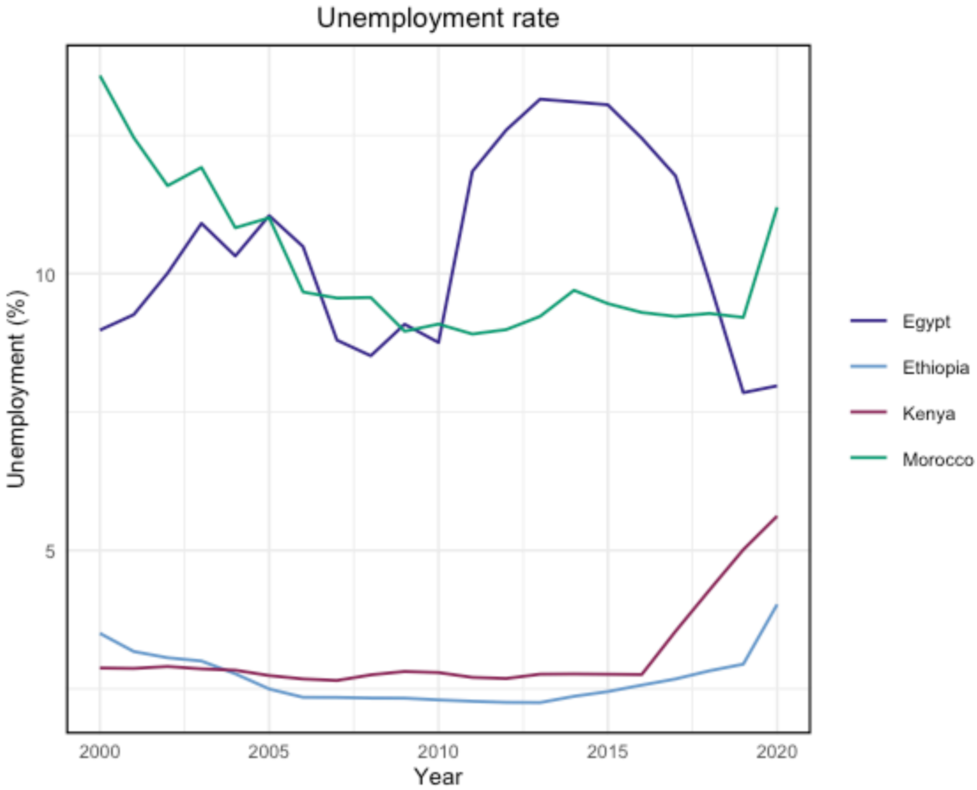
*4. Growth in renewable energy capacity between 2000 and 2020*




*5. Growth in imports between 2000 and 2020*



*6. Change in the unemployment rate between 2000 and 2020*



Abstract :

In recent years, climate change has become a major concern. Indeed, numerous global agreements have been adopted to reduce $CO_2$ emissions, the main greenhouse gas responsible for global warming. However, while reduction targets are well established, emissions are quite unevenly distributed. Africa, as a very minor emitter, is particularly vulnerable to the consequences.

On the same continent, many initiatives are being undertaken to meet the Paris Agreement targets by 2030. Through climate finance, some countries are receiving funds or accessing various types of financing that enable them to develop projects aimed at mitigating the effects of climate change or improving adaptation, notably by investing in renewable energy. However, although the funding received is significant for the beneficiary countries, its distribution across the continent is highly inequitable, despite a considerable energy potential.

This study aims to analyse, using a quantitative approach with linear regression models, the impact of climate finance invested in renewable energy in Africa on both $CO_2$ emission reductions and the continent's economic development. The goal is to understand to what extent climate finance in renewables can mitigate the effects of global warming while transforming Africa's energy potential into tangible economic benefits.

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