UNIVERSITY OF CAPE COAST

# ENERGY TRANSITION, HEALTH OUTCOMES AND CLIMATE VULNERABILITY IN A CHANGING WORLD

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# ENERGY TRANSITION, HEALTH OUTCOMES AND CLIMATE VULNERABILITY IN A CHANGING WORLD

BY

ERIC ATSU AVORKPO

A Thesis submitted to the Department of Economic Studies of the School of Economics, University of Cape Coast, in partial fulfilment of the requirements for the Doctor of Philosophy degree in Economics.

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# DECLARATION

## Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .................................................. Date: ..........................

Name: Eric Atsu Avorkpo

## Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: ................................... Date: ........................

Name: Dr. Godwin Kofi Vondolia

Co-Supervisor's Signature: .......................................... Date: ........................

Name: Dr. Adams Sorekuong Yakubu Adama

# ABSTRACT

The Sustainable Development Goals provide a vital framework for addressing global challenges. Notably, Target 7.2 aims to "increase substantially the share of renewable energy in the global energy mix," while Target 13.1 focuses on enhancing resilience to climate-related hazards. However, some countries may be unable to meet these targets due to the increasing devastation to the environment and public health concerns from energy consumption. This study investigates the often-neglected multifaceted relationships among energy transition, health outcomes, and climate vulnerability in a global context. Using a dataset of 150 countries from 2000 to 2021, this study examines the effects of the rate of energy transition on life expectancy, the extent to which climate vulnerability drives the rate of energy transition, and the drivers of climate vulnerability. This study uses the panel version of the Structural Equation Model, sequential dynamic linear panel data estimation, and a two-step system generalised method of moments. Air quality mediates 56.2% of the total effect of energy transition on life expectancy, while carbon dioxide emission mediates 5.68 times the total effect of energy transition. Climate readiness reduces the negative effects of climate vulnerability on energy transition, with economic readiness dominating the climate readiness component. These findings challenge the conventional notion that poorer countries pollute more by consuming fossil fuels. These results underscore the importance of enhancing air quality and reducing carbon dioxide emission through energy transition policies to improve health outcomes globally. Furthermore, the role of climate readiness in moderating the effects of climate vulnerability on energy transition emphasizes the need for comprehensive strategies that include economic, governance, and social dimensions to effectively address climate change. The findings also call for a re-evaluation of global climate policies, acknowledging the disproportionate vulnerabilities faced by lower-income countries despite their lower contributions to global pollution.

## KEYWORDS

Climate readiness

Climate vulnerability

Health outcome

Energy transition

Sequential dynamic linear panel data estimation

Structural Equation Model

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# DEDICATION

To my families.

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| | |
|---|---|
| ADF | Asymptotic Distribution-Free |
| ANZUS | Australia, New Zealand, United States |
| BENELUX | Belgium, Netherlands, Luxembourg |
| CCPI | Climate Change Performance Index |
| CCVA | Community climate vulnerability assessment |
| CGPR | Country-Specific Geopolitical Risk |
| $CO_2$ | Carbon Emission |
| CVI | Climate Vulnerability Index |
| C-VRA | climate vulnerability and risk assessment |
| EKC | Environmental Kuznets Curve |
| ESG | Economic, Social, and Governance |
| FDI | Foreign Direct Investment |
| GDP | Gross Domestic Product |
| GIS | Geographic Information Systems |
| HDI | Human Development Index |
| HIA | Health Impact Assessment |
| HPF | Health production function |
| IEA | International Energy Agency |
| IPAT | Environmental Impact, Population, Affluence, Technology |
| IPCC | Intergovernmental Panel on Climate Change |
| IRENA | International Renewable Energy Agency |
| ML | Maximum Likelihood |
| MLMV | Maximum Likelihood with Missing Values |

| | |
|---|---|
| ND-GAIN | Global Adaptation Initiative |
| Nox | Nitrogen oxides |
| OECD | Organization for Economic Co-operation and Development |
| PCSE | Panel-Corrected Standard Error |
| PM2.5 | Particulate Matter with a diameter of 2.5 micrometers or less |
| P-SEM | Panel Structural Equation Modeling, |
| SAARC | South Asian Association for Regional Cooperation |
| SDG | Sustainable Development Goal |
| SDGs | Sustainable Development Goals |
| SEDAC | Socioeconomic Data and Applications Centre |
| SIDS | Small Island Developing States |
| SO2 | Sulfur dioxide |
| STIRPAT | Stochastic Impacts by Regression on Population, Affluence, and Technology |
| TB | Tuberculosis |
| UCC | University of Cape Coast |
| UNDP | United Nations Development Programme |
| VECM | Vector Error Correction Model |
| WHO | World Health Organization |

# CHAPTER ONE

# INTRODUCTION

In a rapidly evolving global landscape, the relationships among energy transition, health outcomes, and climate vulnerability have never been more critical than now. The consequences of the global shift from fossil fuels to renewable energy sources go beyond environmental sustainability. However, it has been demonstrated that the advantages of the shift are not uniformly spread and that climate vulnerability is a significant obstacle, especially for lower-income nations (Dolezal et al., 2021; Doležal et al., 2022). Again, nations often face heightened sensitivity and exposure to climate change impacts, which could hinder their progress towards a cleaner energy future. Understanding these relationships among energy policies, health benefits, and climate resilience in a changing world is essential for crafting effective strategies that ensure a just and equitable transition.

## Background to the Study

Commitment to the 2030 Sustainable Development Goals (SDGs) represents a collective effort to address challenges to achieve a sustainable and equitable future. With the SDGs ending in 2030, the ambitious targets of several key goals, it is crucial to evaluate progress towards Goal 3 "Good Health and Well-Being", Goal 7 "Affordable and Clean Energy", and Goal 13 "Climate Action". Thus, the achievement of Target 7.2, "increase substantially the share of renewable energy in the global energy mix", Target 13.1 to "Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries" and Target 13.2 "Integrate climate change measures into national policies, strategies and planning" all rest on providing evidence for policymakers to achieve sustainable environment.

One reason for the non-achievement of these goals, according to Gu et al. (2021), is attributable to the growth in global pollution. Meanwhile, the environmental impact, population, affluence, and technology (IPAT) as explained by Chertow (2000) and Ehrlich and Holdren (1971) indicates that as the population grows, so does our impact on nature. The expansion of housing, infrastructure, and food production requires more land, water, and trees. With an increasing population, pollution and climate emissions also rise (Rehman et al., 2022), posing threats that affect all.

Global reliance on fossil fuels has resulted in a myriad of environmental and health issues. Air pollution can aggravate respiratory and cardiovascular conditions, is the burning of coal, oil, and natural gas. The World Health Organization (WHO) estimates that ambient air pollution contributed to 4.2 million premature deaths globally in 2016. Heart disease, stroke, lung cancer, chronic obstructive pulmonary disease, and acute respiratory infections in children are the main causes of death (WHO, 2018). This startling figure emphasises the urgent need to switch to sustainable energy sources.

A viable substitute is renewable energy sources such as solar power, wind, and hydropower. They lower dangerous air pollutants for human health, in addition to reducing greenhouse gas emissions. There was a strong correlation between the use of renewable energy and notable improvements in air quality. For example, US research discovered that by 2050, switching to

100% renewable energy sources might avert up to 4.5 million preventable deaths (Jacobson et al., 2018).

The relationship between energy transition and life expectancy is multilayered. Improved air quality resulting from reduced fossil fuel combustion is a direct route through energy transitions connected to life expectancy. In regions where coal is the predominant energy source, transitioning to cleaner alternatives has been associated with noticeable improvements in public health. For example, a study in China revealed that reducing coal consumption significantly decreased the incidence of respiratory and cardiovascular diseases, subsequently enhancing life expectancy (Xie et al., 2022).

The deployment of renewable energy infrastructure generates employment opportunities that indirectly influence health outcomes. The creation of jobs in the renewable energy industry has the potential to improve living standards, reduce poverty, and broaden access to healthcare. In turn, these factors contribute to a healthier population with longer life expectancy. Accordingly, the International Renewable Energy Agency (IRENA) has estimated that 12 million people will be engaged globally in the renewable energy sector in 2020. According to the report, this striking statistic is expected to increase significantly as more nations implement renewable energy legislation (IRENA & ILO, 2021).

Furthermore, there are many mechanisms through which energy transitions affect health outcomes. First, the reduction of particulate matter (PM2.5), sulphur dioxide ($SO_2$), and nitrogen oxides (NOx) plays a crucial role.

The health complications of these pollutants include lung cancer, heart ailments, and respiratory ailments. Jiying et al. (2023) and Manisalidis et al. (2020) reported that regions with higher levels of renewable energy penetration experience lower concentrations of these harmful pollutants, leading to better overall health.

Second, there are important health consequences of reducing greenhouse gas emissions to mitigate climate change (Campbell-Lendrum et al., 2023). By increasing the frequency and intensity of extreme weather events, dispersing vector-borne diseases, and jeopardising the security of food and water, climate change has become a hazard to human health (Ullah & Akhtar, 2023). Having accepted the Lancet Countdown on health and climate change, it is important that transitioning to renewable energy is necessary to combat climate change impacts which have already been realised to have severe impacts on the health of people globally (van Daalen et al., 2024). It has also been argued that investments in renewable energy often lead to economic growth and development, enhancing healthcare infrastructure and services. For instance, countries with robust renewable energy sectors tend to have better-funded healthcare systems, contributing to improved health outcomes and increased life expectancies (Zhang & Vigne, 2021).

The global shift towards sustainable energy systems has become imperative in the face of escalating climate change impacts. As the frequency and intensity of climate-related events increase, understanding the nexus between climate vulnerability and energy transition becomes crucial. Climate vulnerability refers to the susceptibility of a system to be adversely affected by climate change, encompassing sensitivity, exposure, and adaptive capacity. The heightened vulnerability of certain regions can impede their progress towards transitioning to renewable energy sources. For instance, countries with high exposure to climate risk may prioritise immediate adaptation measures over long-term energy transition investments. The Global Climate Risk Index 2020 highlights that developing nations, particularly in Asia and Africa, are disproportionately affected by climate-related disasters, thereby impacting their energy transition capabilities (Eckstein et al., 2021; Eckstein et al., 2020).

Renewable energy transition is essential for mitigating climate change; however, its pace and extent vary significantly across countries. Factors such as governance, economic readiness, and social structures play pivotal roles in shaping a country's readiness to adopt renewable energy technologies. For example, IRENA reports that countries with robust governance frameworks and economic resources have made significant strides in renewable energy adoption (IRENA, 2021). However, understanding the rate of transition to the extent that countries are becoming increasingly vulnerable to climate situations needs to be contextually understood.

The climate vulnerability and energy transition nexus tends to be multifaceted. High climate vulnerability can function as a barrier to energy transition due to the diversion of resources towards immediate adaptation needs. A study on climate vulnerability in Southeast Asia found that countries with higher vulnerability indices tend to have slower renewable energy adoption (Tan et al., 2023). This suggests that vulnerability constraints necessitate a reallocation of limited financial and human resources, hindering long-term energy transition efforts.

Climate readiness, defined as a country's ability to anticipate, prepare for, and respond to climate change, could play a crucial role in moderating the effects of climate vulnerability on energy transition. Countries with higher climate readiness are assumed to be better equipped to integrate renewable energy into their national strategies. The Climate Change Performance Index (CCPI) ranks countries based on their climate policies and actions, revealing that nations with proactive climate policies tend to have higher renewable energy shares (Burck et al., 2019). In this, three dimensions of climate readiness were discussed to include governance, economic and social readiness.

Effective governance plays a vital role in enhancing climate readiness, particularly through political stability, regulatory quality, and institutional effectiveness. Robust governance frameworks facilitate successful implementation of renewable energy policies and attract investments, thereby strengthening climate resilience. This is exemplified by countries like Denmark and Germany, which boast strong governance indicators and have achieved remarkable growth in renewable energy capacities (Alsaleh et al., 2021).

Economic readiness, a component of climate readiness characterised by financial resources and economic stability, is a critical determinant of a country's capacity to transition to renewable energy. Countries with higher economic readiness can allocate more funds towards renewable energy projects and infrastructure. The International Energy Agency (IEA) highlights that economic factors, including GDP per capita and investment in clean energy, are positively correlated with the adoption rate of renewable energy (IEA, 2023).

Social readiness is the last component, but is often neglected in the literature, involving public awareness, education, and societal support for climate change, which could moderate the impact of climate vulnerability on energy transition. Societies with higher environmental awareness and education are more likely to support and adopt renewable energy technologies. The Eurobarometer survey of the European Commission indicates that public support for renewable energy significantly influences national energy policies and transition rates (European Commission, 2019).

Recognising the effects of climate change on energy usage, pertinent energy policies are crucial for developing effective measures to prevent the negative effects of climate change and respond to them in the future. This requires a clear understanding of the factors that define climate vulnerability. Climate vulnerability is defined as the likelihood of being negatively affected by climate variability and extremes (climate vulnerability = sensitivity, exposure, and adaptive capacity).

Climate vulnerability was measured based on three attributes: exposure, sensitivity, and adaptive capability. Exposure to climate change refers to the extent to which a system is open to extreme climatic variation. Sensitivity relates to the degree to which a system is affected by climatic stimuli, whereas adaptive capacity relates to the ability of the system to lessen the effects of climate, avoid negative consequences, and recover from climatic consequences.

Many socioeconomic environment and governance factors that vary across income levels affect each of these groups.

The 2020 Global Climate Risk Index shows that low-income countries are disproportionately affected by climate-related disasters, with higher mortality rates and economic losses than high-income countries (Eckstein et al., 2021). This disparity underscores the need to examine specific drivers of climate vulnerability within different income groups to tailor effective mitigation and adaptation strategies.

The drivers of climate vulnerability are multifaceted and include socioeconomic factors (Pinto et al., 2023; Yadava et al., 2023), governance quality (Song et al., 2023; Yadava et al., 2023), and environmental conditions (Moore & Wesselbaum, 2023; Yadava et al., 2023). For instance, countries with high poverty rates (Yadava & Sinha, 2024), increased energy consumption (Yadava et al., 2023), population growth (Bozzola et al., 2023), migration (Silchenko & Murray, 2023), foreign direct investment (Shear et al., 2023), and low investment (Adhikari & Safaee, 2023) are more vulnerable to climate impacts. Nguyen et al. (2019) highlighted that low-income countries in Southeast Asia exhibit higher climate vulnerability due to limited resources and poor governance structures.

According to Maja and Ayano (2021), sensitivity to climate vulnerability is influenced by population growth and economic dependence on climate-sensitive sectors (Mallick and Rahman 2020). For example, countries that are heavily reliant on agriculture are more sensitive to climate variability and extremes. Diffenbaugh et al. (2021) and Diffenbaugh and Burke (2019) indicate that agricultural-dependent economies in SSA are particularly sensitive to climate impact, exacerbating food insecurity and economic instability.

Adaptive capacity, which assesses a nation's ability to respond to and recover from the effects of climate change, is a crucial component of climate vulnerability. Studies have shown that several factors influence adaptive capacity, including financial resources (Mihai et al., 2022) and population (Maja & Ayano, 2021). According to Chepkoech et al., countries with higher income levels typically have better access to financial resources, cutting-edge technologies, and strong institutions. (2020). The differences in how high-income and low-income nations respond to the effects of climate change demonstrate this gap.

Geographical location, weather patterns, and socioeconomic variables all influence an individual's susceptibility to climate sensitivity (Grigorescu et al., 2021; Gupta et al., 2020). Tropical and subtropical nations are more vulnerable to severe weather phenomena including hurricanes, floods, and droughts. Accordingly, the Intergovernmental Panel on Climate Change (IPCC, 2022) reported that the low adaptation capacity and geographic exposure of Small Island Developing States (SIDS) make them especially vulnerable.

The relationship between climate vulnerability and energy transition is influenced by climate readiness. Like Gani (2021) indicated, countries with high climate vulnerability often face significant barriers to transitioning to renewable energy due to limited resources and urgent adaptation needs. This study builds on previous research investigating the first the transition health outcome nexus, climate vulnerability and rate of energy transition, and drivers of climate vulnerability. We highlight the role of carbon dioxide emission, air quality and climate readiness (governance readiness, economic readiness, and social readiness) in these situations.

**Statement of the problem**

The United Nations Development Programme (UNDP) 2024 report highlights critical global health crisis, revealing that cancers, diabetes, chronic respiratory ailments, and cardiovascular diseases collectively cause one death every two seconds among individuals between the ages of 30 to 70. Additionally, air pollution, particularly from fine particulate matter, contributes to 7 million premature deaths annually. A key driver of these alarming statistics is the continued dependence on fossil fuels and duty fuel consumption, which exacerbates air pollution and accelerates climate change, posing severe risks to both human health and environmental sustainability (Deng et al., 2020; Gani, 2021; Hussain & Reza, 2023; Maciejczyk et al., 2021; Woodruff, 2024).

In response, global efforts are underway to facilitate a transition towards renewable energy sources, with projections suggesting that by 2030, two-thirds of the global population will have access to clean cooking fuels (Ritchie et al., 2019, 2021). While existing research has established a strong correlation between energy access and public health outcomes, as demonstrated in South Africa (Koomson, 2024), Australia (Bentley et al., 2023), and China (Li et al., 2022; Zhu et al., 2023), there remains a critical gap in understanding the specific pathways through which renewable energy consumption influences health. For instance, although studies indicate that increased renewable energy use is linked to higher life expectancy and reduced mortality rates (Hanif, 2018; Majeed et al., 2021), they often fail to comprehensively examine the mechanisms through which air quality improvements and reductions in carbon emissions mitigate the incidence of noncommunicable diseases (NCDs). At worst, those studies assume a direct relationship between clean fuel consumption and health outcomes.

Furthermore, while the nexus between energy and climate change is well recognised (Geng et al., 2021; Karduri & Ananth, 2023; Quaschning, 2019; Siksnelyte-Butkiene et al., 2024), significant challenges persist in achieving the Sustainable Development Goals (SDGs) by 2030-particularly Goal 13 and Target 1, which focus on enhancing resilience and adaptive capacity to climate-related risks. Although numerous studies have explored how energy transition mitigates climate change (Liu et al., 2023; Olabi & Abdelkareem, 2022), there remains a major research gap concerning the reverse impact, that is, how climate vulnerability shapes the rate of renewable energy transition. The role of climate vulnerability, encompassing exposure, adaptive capacity, and sensitivity to climate change, in shaping energy systems remains insufficiently studied, and its impact on energy transition across different income levels and geographical contexts.

Additionally, studies by Gani (2021), Li et al., (2021, 2022), Olabi and Abdelkareem (2022) and Zhao et al. (2022) overlooked the socioeconomic disparities that affect how different countries experience and respond to climate vulnerability. While climate readiness (economic, governance, and social preparedness) is believed to reduce a country's vulnerability to climate change, there is inadequate empirical evidence on how climate readiness moderates' vulnerability, and by extension, how vulnerability affects the rate of energy transition.

Finally, the global commitment to net-zero emissions reflects a concerted effort to eliminate human-induced carbon dioxide emissions by 2050, emphasising the urgent need for a transition away from fossil fuels towards sustainable energy solutions to mitigate the escalating impacts of climate change. Significant research efforts such as those by Hassan et al. (2025), Horbach and Rammer (2025), Liu and Zhou (2025) and Otim et al. (2025), have focused on identifying the drivers of climate change, they have largely overlooked the extent to which countries differ in their vulnerability to its effects. Recognizing this gap in literature, this study also investigates the drivers of climate vulnerability across different income groups. Specifically, in identifying the global drivers of climate vulnerability we also analyze the drivers of the disaggregated components: sensitivity, adaptive capacity, and exposure.

The study fills these critical research gaps by first investigating the nexus between energy transition and health outcomes, climate vulnerability and energy transition and the drivers of climate vulnerability at the global level. It aims to provide empirical evidence on how climate vulnerability and its components influence the rate of energy transition, and how these factors interact with climate readiness to shape global energy strategies. A deeper understanding of these dynamics is crucial for informing policies that enhance resilience, improve public health, and accelerate progress towards SDGs 3 (health), 7 (clean energy), and 13 (climate action).

## Purpose of the Study

The study investigates the linkages between energy transition, health outcomes and climate vulnerability in changing world by considering the potential pathways of these effects and the role of climate readiness in climate vulnerability and energy transition nexus.

## Research Objectives

Specifically, the study sought to

1. Quantify the effect of energy transition on life expectancy.
   a. To analyse the direct effect of energy transition on life expectancy.
   b. To examine the channels through which energy transition affects life expectancy.
2. Examine the effect of climate vulnerability on energy transition.
   a. To analyse the effects of exposure, adaptive capacity, and sensitivity to climate change on energy transition.
   b. To find out the extent to which climate readiness moderate the effect of climate vulnerability on energy transition.
   c. To find out the extent to which climate readiness moderate the effect of exposure on energy transition.
   d. To find out the extent to which climate readiness moderate the effect of adaptive capacity on energy transition.
   e. To find out the extent to which climate readiness moderate the effect of sensitivity on energy transition.
3. Investigate the drivers of climate vulnerability.

a. Examine the drivers of climate vulnerability across different income status.

b. Assess the factors that affect exposure to climate change across different income status.

c. Assess the factors that affect adaptive capacity to climate change across different income status.

d. Assess the factors that affect sensitivity to climate change across different income status.

## Research Hypotheses

The following null ($H_0$) hypotheses are formulated based on the objectives of the study.

1. $H_0$ Energy transition has no significant effect on life expectancy.
   a. $H_0$ Energy transition has no significant direct effect on life expectancy.
   b. $H_0$ There is no significant indirect effect of energy transition on life expectancy.
2. $H_0$ Climate vulnerability has no significant effect on energy transition.
   a. $H_0$ Exposure, adaptive capacity, and sensitivity to climate change has no significant effect on energy transition.
   b. $H_0$ climate readiness does not moderate the effect of climate vulnerability on energy transition significantly.
   c. $H_0$ climate readiness does not moderate the effect of exposure on energy transition significantly.

d. $H_0$ climate readiness does not moderate the effect of adaptive capacity on energy transition significantly.

e. $H_0$ climate readiness does not moderate the effect of sensitivity on energy transition significantly.

**Research Question**

The following researched question were formulated for objective three.

1. What are the drivers of climate vulnerability?
2. What are the drivers of climate vulnerability across different income status?
3. What factors affect exposure to climate change across different income status?
4. What factors affect adaptive capacity to climate change across different income status?
5. What factors affect sensitivity to climate change across different income status?

**Significance of the study**

It is important to conduct assessments of energy transition benefits as they will assist in formulating strategies aimed at promoting policy patterns that are more sustainable and preventing health impacts resulting from pollution and climate change. This research helps in making such assessments by modelling the connection between the pace of energy transition, air pollution, and greenhouse gas outputs.

Fewer rates of respiratory diseases, cardiovascular disorders, and premature deaths will be achieved by higher levels of healthy clean air created by lower emissions, which will extend human life and improve health in general. This research will inform policymakers, public health officials, and energy stakeholders about the health implications of energy transitions, highlighting the importance of prioritising clean energy policies to promote population health and well-being.

It is critical to examine both climate vulnerability's impact on energy transition rates, and the part climate readiness plays in it when examining governance, socio-economic and environmental determinants of renewable energy technology adoption. This study reviews opportunities to build climate resilience and transition towards sustainable energy systems by analysing the factors motivating energy transition across the globe as well as vulnerability disaggregation.

Understanding how climate vulnerability and its disaggregated dimensions affect energy transition rates can inform targeted interventions and policy strategies to address climate-related challenges and promote inclusive development. The knowledge generated from this study comes in handy if society is to create sustainable societies in the face of environmental challenges. And it helps to augment existing information on strategies for climate change adaptation and reduction initiatives.

Management responses to climate change are anchored on understanding the drivers of climate vulnerability. As such, this research concerns decision-making and policy development processes as it shows what social economic, and environmental factors define vulnerability at different levels. Moreover, understanding the drivers of climate vulnerability informs the development of targeted strategies to enhance climate readiness and accelerate energy transition. For example, improving governance frameworks and investing in adaptive capacity can reduce climate vulnerability and facilitate energy transition technologies.

That would make it easier to understand why individuals or communities are vulnerable and where resources should be targeted to assist vulnerable populations and reduce climate-related risks. This research work contributed to the understanding of the assessment of climate change sensitivity and provided valuable details of development of specific interventions to reduce risks and foster sustainable development. There is an aspiration to design solutions for more just societies and investigators have focused on the social dimensions of climate vulnerability to enable policy makers and practitioners to act in a way that can respond to the existing and future climate change conditions.

**Delimitation**

In this study, I take a broad yet focused approach to examining the relationships between energy transition, health outcomes, and climate vulnerability across 150 countries from 2000 to 2021. Geographically, this study spans diverse income levels, regions, and socio-economic contexts, offering a global perspective while acknowledging that findings may not be entirely applicable to nations not included in the dataset. The two-decade period provides a solid foundation for assessing long-term trends, but as with any historical analysis, it does not capture developments beyond 2021.

The study homes in on how energy transition influences life expectancy, both through direct effects and via key transmission channels. It further investigates how climate vulnerability-broken down into sensitivity, adaptive capacity, and exposure shapes the pace of energy transition, while also assessing the role of climate readiness (governance, economic, and social preparedness) in moderating this relationship. Recognizing that climate vulnerability is not uniform across nations, the study also identifies its key drivers across different income groups.

Given the nature of the problem, we employed quantitative, macro-level approach, relying on national and global datasets rather than delving into qualitative narratives or micro-level case studies. This decision ensures robust empirical analysis, though it means that individual health data and community-specific climate risks are beyond the study's scope. Additionally, while the findings offer valuable policy insights, they are framed in broad global and regional terms, rather than as country-specific policy blueprints. These delimitations are intentional, allowing the study to provide clear, data-driven conclusions while leaving room for future research to build on these findings with more localized or qualitative approaches.

**Limitation**

One limitation is the reliance on existing datasets for variables such as energy transition rates, health outcomes, air quality, carbon emissions, climate vulnerability, and climate readiness. The availability, accuracy, and completeness of these data may vary across regions and periods, thereby affecting the potential generalizability of the study's findings. The study's findings are limited to the periods and methodological approaches. Factors like regional variations in socio-economic conditions, environmental characteristics, and policy contexts though have provided nuanced understanding, the results may not be entirely true for individual countries. While, this limitation is expected, consistent available data for the period is used. Also, the study assumes linear relationships between energy transition rates and health outcomes, neglecting non-linear or threshold effects that could be present.

**Organization of the Study**

This study is organized in seven (7) chapters. The introductory chapter presents the background information, the problem being investigated as well as the respective objectives and their corresponding hypotheses and questions. The chapter two interrogates the specific theories that explains each objective as well as recent empirical studies relevant to the study. The method used model specification as well as justification for the choice of model and variables are presented in chapter three. The results from objectives 1, 2 and 3 are presented in chapters 4, 5 and 6 respectively and chapter 7 sheds light on the summary of the entire study by highlighting the key findings, recommendations and contributions made.

**Chapter Summary**

The section summaries the entire information in this Chapter. The chapter starts by presenting the background to the rate of energy transition, health outcomes and climate vulnerability. It also presents the problems being studied. The main objectives which translate into specific objectives were also stated and the corresponding hypotheses and research question. The significance of this study, delimitation, limitations as well as how the various chapters are organized are presented in this chapter.

# CHAPTER TWO

# LITERATURE REVIEW

## Introduction

This chapter presents a review of related literature. It started by first reviewing the various theories that guided the study, it proceeds with various concepts related to the study as well as empirical literature. The chapter ended with a chapter summary.

## Theoretical Review

The study examined the health production function, the health impact assessment model, the downward spiral hypothesis, environmental Kuznets curve, and the pollution haven hypothesis as a theoretical foundation for the investigation to comprehend the relationship among the energy transition, health outcomes, and climate vulnerability.

### *Health Production Function*

Health Production Function (HPF) has been a subject of significant interest in the field of social sciences, particularly in the areas of public health and environmental economics. This model, which was first introduced by Grossman (1972), offers a framework for understanding factors that contribute to an individual's health status. The HPF posits that health is a form of human capital that can be produced through various inputs, including medical care, lifestyle choices, and environmental factors.

A key factor influencing the HPF is the availability and utilization of medical care. Availability of good healthcare facilities and quality health services determines an individual's health status (Amoah et al., 2022).

Additionally, the efficiency and effectiveness of the healthcare system, as well as the distribution of healthcare resources, can also affect the overall health outcomes of a population. Lifestyle factors, such as diet, physical activity, and smoking behaviour, also play a crucial role in the HPF (Bhandari et al., 2021). Individuals who engage in healthier behaviours tend to experience better health outcomes, while those who engage in risky behaviours, such as smoking or poor dietary habits, are more likely to experience adverse health consequences.

Grossman (1972) has predicted that pollution and factors such as contaminated air, water and zoonotic substances also contribute a great deal to the health consequences of persons. Such environmental aspects can cause or determine the health outcomes of different diseases regarding people in any given society. Recent research has extended the HPF to incorporate the role of environmental quality as a key input in the production of health. Majeed & Ozturk, (2020) have investigated the relationship between environmental quality & health consequences and discovered that the deterioration of environmental standards is a threat to population health which is why this problem should be solved. In their study, they have joined other similar scholars to show that things like shoddy quality air, water and toxic substances may influence on the health and well-being of the people.

The HPF can be expressed as:

$$H = f(M, L, E)$$

where H represents health outcomes, M represents medical care inputs, L represents lifestyle factors, and E represents environmental quality. In this framework, environmental quality serves as a crucial input in the production of health, as it can directly affect an individual's physical and mental well-being. For example, environmental air pollution has been associated with the risks of developing respiratory and cardiovascular illnesses together with higher mortality (Schraufnagel et al., 2019). In the same context, contamination of water sources with such contaminants is a cause of water borne diseases and other related diseases (WHO, 2019).

In addition, the estimated HPF can also be used in public policy and primarily to carry out interventions among the population. Once the composite measure of the inputs that delivered health results has been established, improvement plans can be formulated based on the requirements of inputs that delivered specific outcomes, including environmental aspects. This can involve investments in infrastructure, environmental regulations, and public education campaigns to promote healthier behaviours and reduce exposure to environmental hazards.

The HPF offers a sound approach towards explaining the complex concept of health with special reference to environmental quality. In expanding this mode to include environment and health, the researchers and the policymakers can come up with better and enriched strategies for enhancing what ails man and the world in general.

The HPF explains how several factors, like medical care, lifestyle, and environmental quality, affect health outcomes, including life expectancy. In terms of energy transition, improving environmental quality, especially by reducing air pollution and carbon emissions, can directly impact health. Hypothesis one suggests that energy transition does not significantly affect life expectancy, meaning the environmental changes are not enough to be effective. However, if air quality (Hypothesis 2) or carbon emissions (Hypothesis 3) play a role in the relationship between energy transition and life expectancy, rejecting these hypotheses would mean that energy transition helps increase life expectancy by making the environment cleaner and healthier. These improvements would show how energy transition can boost health outcomes, as suggested by the HPF.

***Health Impact Assessment (HIA) Model***

The Health Impact Assessment (HIA) model is widely recognized as a practical tool at the intersection of social sciences, environmental studies, and public health. Its origins can be traced back to early 1990s Europe, where it was initially developed to evaluate the health impacts of environmental pollution (Winkler et al., 2020). Over time, the model has evolved and is now extensively applied in sectors such as transport, energy, and natural resource management.

One of the key strengths of the HIA model is its comprehensive framework, which identifies multiple determinants of population health. Rather than attributing health outcomes solely to individual behaviour or medical facilities, the model acknowledges the influence of broader structural factors, including economic systems, political dynamics, societal conditions, psychological well-being, and even climatic factors (Anser, 2021). By integrating these elements, the HIA model encourages an integrated approach to policy design, ensuring that health-related interventions target root causes rather than merely addressing symptoms of public health challenges (Jarvis, 2023). This systems-based perspective makes the HIA model particularly valuable for informed decision-making, as it promotes initiative-taking strategies that mitigate health risks at their source. Consequently, embracing the HIA framework allows policymakers and researchers to develop more effective, evidence-based policies that contribute to sustainable health and environmental outcomes.

Modelling health impact consists of an evaluation of the impact on the health of the proposed policy or project. This involves the collection and evaluation of data relating to the impact of the intervention on different dimensions of health including the physical, mental, and social health of the human being (Anser, 2021). The assessment also looks at how these impacts are distributed between the different population groups for the purpose of avoiding compounding inequities in health while implementing the interventions (Winkler et al., 2020).

The other feature of the HIA model is the participation of stakeholders in the process on a regular basis. These involve also consulting with the community and policy that is to be affected, and other stakeholders to understand their perception and views on the health and effects of an intervention that is under consideration (Dobrow et al., 2017). Through this approach, one meets the other to make sure that HIAs are sensitive to the public interests of those who will be affected.

The HIA model can be usually a sequence of steps like screening, scoping, assessment, recommendation, and monitoring (Winkler et al., 2020). The screening process helps determine the need for an HIA, while the scoping phase identifies the key issues and stakeholders to be considered. The assessment stage involves gathering and analysing data to evaluate the potential health impacts, both positive and negative. Based on these findings, the HIA model provides recommendations for decision-makers to optimize health outcomes.

The HIA model provides a framework for evaluating how energy transitions, air quality, and carbon emissions affect health outcomes like life expectancy. For Hypothesis 1, the HIA would assess whether energy transitions such as shifting from fossil fuels to renewable energy impact life expectancy by examining potential health benefits (e.g., reduced pollution) or risks. In Hypothesis 2, the HIA would specifically evaluate whether improved air quality from energy transitions leads to better health outcomes, showing if air quality mediates the effect on life expectancy. Similarly, for Hypothesis 3, the HIA would assess whether reduced carbon emissions due to energy transition positively impact health by lowering diseases related to air pollution. If the HIA model shows significant health benefits from these environmental improvements, it would challenge the null hypotheses, indicating that energy transition, air quality, and carbon emissions are critical factors in determining life expectancy.

The HIA model has been widely adopted in various contexts, from urban planning and transportation to environmental policy and public health interventions (Giles-Corti et al., 2022). By providing a comprehensive and evidence-based framework for assessing and addressing the health impacts of policies and projects, the HIA model has the potential to significantly advance population health outcomes.

***Downward Spiral Hypothesis***

The Downward Spiral Hypothesis (DSH) suggests that once population growth triggers environmental degradation, it will reinforce the problem, making it even worse (Feng & Lei, 2023). This hypothesis posits a positive feedback loop, where population growth leads to resource depletion and environmental damage, which in turn aggravates the population growth, creating a self-perpetuating cycle of decline.

One of the primary drivers of the DSH is the concept of the “tragedy of the commons” (Centanni et al., 2019). This theory postulates that each person, motivated solely by selfishness and making his/her individual choice, will overuse or exhaust a common resource(s), irrespective of the consequences to all the people in the same community. This phenomenon can be observed in various contexts, such as overfishing, deforestation, and air pollution.

The DSH suggests that as population growth increases, the demand for resources also rises, leading to the overexploitation of shared resources. This, in turn, leads to environmental degradation, which can reduce the availability of resources, further exacerbating population growth and creating a vicious cycle (Findeis & Pervez, 2021).

The implications of the DSH are significant, as they suggest that uncontrolled population growth can have devastating consequences for the environment and human well-being. This hypothesis has been used to support various policy interventions, such as family planning programs, sustainable resource management, and investments in renewable energy (Centanni et al., 2019). But, the DSH has also problems such as the overgeneralization of theories of population growth and environmental degradation. In that sense, it has been pointed out that the hypothesis ignores the possibilities of technology, consumption patterns' transitions, and the potential influence of social factors on environmental results (Levine, Milyavskaya, & Zuroff, 2020).

Regarding the concept of the DSH, the author offers everyone a tool for analysing the future of human overpopulation and its effect on the climate. This hypothesis may not completely capture all the features of this dynamic, however still emphasizes the need for consistent population management and a responsible attitude to the environment. Further research and policy interventions aimed at addressing these issues will be crucial in ensuring a more sustainable future for humanity. The hypothesis 5 which states that the effect of climate vulnerability and its disaggregation on transition does not vary among different transition quantiles, this implies that the effect of climate vulnerability on energy transition could vary across different transition stages, with more vulnerable regions being trapped in a cycle of poor environmental quality and slow progress in energy transition, particularly in lower transition quantiles. For Hypothesis b, c, d, and e of hypothesis 2, the DSH highlights the importance of climate readiness in breaking this cycle. Regions with stronger climate readiness, such as better infrastructure, governance, and technology are better equipped to mitigate climate vulnerability and successfully transition to cleaner energy sources. Rejecting the null hypotheses would align with the DSH, suggesting that both climate vulnerability and readiness play critical roles in the energy transition process, especially in preventing downward spirals in vulnerable regions.

***The Environmental Kuznets Curve***

The Environmental Kuznets Curve (EKC) hypothesis is a behavioural pattern between income level and environmental pollution, according to which, as incomes rise, pollution also increases to a peak, after which incomes reduce pollution levels (Ahmad, Muslija, & Satrovic, 2021). This concept has received significant attention in the literature in the areas of environmental economy and has significant implications for sustainable developmental policies.

The theory on which the EKC is based is the fact that as a country evolves from an agricultural economy to an industrial-based economy the pollution intensity rises. However, as the country continues to develop and reaches a certain level of affluence, the demand for a cleaner environment and the availability of more advanced technologies and environmental regulations lead to a decline in environmental degradation (Mitić, Kresoja, & Minović, 2019).

Several factors have been identified as potential drivers of the EKC, including technological progress, structural changes in the economy, environmental regulations, and the ability to invest in environmental protection (Stern, 2004). The hypothesis has been assessed empirically across various environmental indicators, such as air pollution, deforestation, water pollution, and carbon dioxide emissions, with mixed results (Stern, 2017).

Though EKC has been found to be effective to comprehend the situation between economic development and a poisonous environment, it also has some drawbacks. It has been suggested that a critical view should be taken of the EKC hypothesis thus defeating the model depending on the test environmental variable and stage of development (Stern, 2017). Third, the extension of EKC fails to consider rebound effects especially when the environment is depleted beyond reach such that changing some natural resources may lead to irreversible impacts such as climate change and elimination of species from the face of the earth (Frodyma, Papież, & Śmiech, 2022).

For this, it must be said that the EKC is a useful approach to the analysis of the connection between development and degradation as well as the preservation of the environment. However, it should be noted that the application and analysis of the EKC should be supplemented with factors that would better illustrate the prospects for sustainable environmental development in countries at various stages of development. Economic and environmental values should be made a priority by policymakers to help alleviate the future for current and future generations as sustainable development policies are made.

The EKC provides valuable implications for Hypotheses 5 and 6 by highlighting the relationship between economic development, climate vulnerability, and energy transition. For Hypothesis 5, the EKC suggests that as countries develop economically, their ability to manage climate vulnerability and transition to cleaner energy sources varies significantly across different development stages. Regions at lower income levels may struggle with climate vulnerability, leading to poor environmental outcomes, while higher income levels can signal a turning point where vulnerability decreases, and energy transitions become more feasible. In the context of Hypothesis 6, the EKC implies that climate readiness which encompasses the capacity to implement environmental policies and invest in clean technologies improves as income rises. Without adequate climate readiness, regions may find it challenging to reduce vulnerability and achieve successful energy transitions, particularly in the early development stages. Thus, if these null hypotheses are rejected, it would indicate that both climate vulnerability and climate readiness are crucial factors influencing energy transition, reinforcing the EKC's assertion that economic development fosters better environmental management and sustainable practices.

***Pollution Haven Hypothesis***

Pollution haven hypothesis (PHH) is an argument in the theory of environmental economics which holds that MNCs may transfer their manufacturing operations to countries with lax environment laws because they are cheaper to deal with (Bashir, 2022). This hypothesis has been the topic of discussion in the literature on subjects related to the social sciences because of the importance of the environmental policy and economic development connection.

One of the key arguments supporting the PHH is that stricter environmental regulations can increase the cost of production for firms, making it more attractive to relocate to countries with less stringent regulations (Fan et al., 2019). This can lead to a race to the bottom scenario, where countries compete to attract Foreign Direct Investment (FDI) by relaxing their environmental standards (Kamin, & Kysar, 2023).

The findings by earlier studies on PHH have been characterised by mixed outcomes. Kamin and Kysar (2023) have found support for the hypothesis, showing that multinational corporations do tend to invest in countries with weaker environmental regulations. Other studies, however, have found little or no evidence for the hypothesis, suggesting that other factors, such as market size, labour costs, and infrastructure, more important determinants of FDI (Fan et al., 2019; Kamin, & Kysar, 2023).

One potential explanation for the mixed findings is that the relationship between environmental regulations and FDI may be more complex than the simple PHH suggests. For instance, studies have found that stricter environmental regulations may attract FDI in certain industries, as firms seek to take advantage of the technological and competitive advantages associated with more stringent regulations (Bashir, 2022).

Additionally, the PHH may be more applicable to certain types of industries or sectors than others. For instance, pollution-intensive industries, such as manufacturing, may be more likely to relocate to countries with weaker environmental regulations, while less pollution-intensive industries, such as services, may be less affected by environmental regulations (Kamin & Kysar, 2023).

In the social sciences, there is still discussion and investigation surrounding the pollution refuge theory. The idea is supported by some evidence, although there is a complex relationship between environmental restrictions and foreign direct investment (FDI) that could be influenced by other factors. To fully comprehend the mechanisms underlying this link and its consequences for environmental policy and economic development, more research is required.

According to the PHH, nations with lenient environmental restrictions draw polluting companies, which increases pollution and degrades the ecosystem in these pollution havens. This has significant implications for Hypothesis 1, which posits that climate vulnerability, and its disaggregated dimensions do not affect energy transition. If a region becomes a pollution haven, it may experience heightened climate vulnerability due to environmental degradation, making it more susceptible to the impacts of climate change, such as extreme weather events and resource depletion. This increased vulnerability can hinder the energy transition process, as regions facing severe environmental challenges may lack the resources or political will to invest in cleaner energy technologies. As such, failure to support the null hypothesis would be supportive of the PHH and confirm that climate vulnerability does indeed play a role in energy transition. It would also afford primary importance to the increased enforcement of environmental laws to enhance positive behaviour and minimize susceptibility.

## Empirical Review

### *Renewable energy consumption and health outcomes*

Concern with the problems of climate change, environmental pollution, and deficiency of fossil resources brought the transition to renewables as a significant global priority in recent years. This change may also have an impact not only on such environmental indexes but on public health as well.

Rahman and Alam (2022) examined the role of renewable energy, environmental pollution, economic growth, and good governance on life expectancy in the Australia, New Zealand, United States (ANZUS) and

Belgium, Netherlands, Luxembourg (BENELUX) countries. Using panel data analysis, the study found that increased renewable energy consumption and improved environmental quality (reduced carbon dioxide emission) had a positive impact on life expectancy. The findings highlight that transitioning to renewable energy sources not only fosters environmental sustainability but also substantially improves public health outcomes by mitigating the adverse health impacts associated with environmental pollution. The authors emphasize that these improvements in life expectancy are a direct result of decreased environmental contaminants and the resulting reduction in health risks. This implies that advocating for prioritize renewable energy development policies are pivotal component of public health and environmental sustainability strategies.

In the case of the Republic of Kazakhstan et al. (2024) undertook a huge empirical investigation aimed at identifying the relationship between life expectancy, energy consumption, economic growth, and air quality. Employing panel data analysis, their study revealed that improved air quality, primarily achieved through increased consumption of renewable energy, significantly improved life expectancy. The researchers demonstrated that as Kazakhstan transitions towards renewable energy sources such as wind, solar, and hydroelectric power, the resultant reduction in air pollution leads to better health outcomes for the population. They highlighted that improved air quality reduces the incidence of respiratory and cardiovascular diseases, thereby extending life expectancy. They concluded that a strategic shift towards renewable energy is crucial not only for environmental sustainability but also for public health. They also advocated for policies that promote renewable energy adoption, emphasizing that such measures would yield substantial health benefits by mitigating the adverse effects of air pollution.

By conducting the Global Panel Data Analysis, Majeed, Luni and Zaka (2021) looked at the relationship between renewable energy consumption and health indicators, life expectancy as well as the infant mortality rate. Their research revealed that there is a high and positive relationship between renewed energy use low newborn mortality rates and higher expectancy of life. The authors postulated that one of the reasons for improving health, downloading, and utilization of various forms of Renewable energy is inclusive of hydroelectric, solar, and wind power. This improvement is mostly due to the great reduction in air pollution when people switch from fossil fuels, reducing the likelihood of health problems resulting from pollution. Their findings provide compelling evidence supporting the notion that a shift to cleaner energy use not only addresses environmental concerns but also yields substantial public health benefits, stressing the importance of integrating renewable energy policies into broader health and environmental strategies on a global scale.

Being its researchers, Hill et al. (2019) examined how income differences influenced the relationship between life expectancy and air quality in the United States. Using data from the U.S. Census Bureau, the study adopted a multilevel modelling analysis. The results revealed the association between life expectancy and air pollution as being inversely related but modest when the variation was assessed for the degree of inequality. The authors concluded that addressing income inequality could potentially amplify the positive health benefits of improved air quality. Similarly, Zheng, Xue, Zhao and Lei (2022) investigated the potential impact of China's 2025 air quality target on life expectancy. The researchers employed a statistical modelling approach to estimate the changes in life expectancy based on projected improvements in air quality. Their findings suggest that if China successfully achieves its 2025 air quality target, it could lead to a significant increase in life expectancy, particularly in areas with higher levels of air pollution. The study highlights the potential health benefits of targeted policies aimed at reducing air pollution.

Analysing human mortality, ambient air pollution, renewable energy consumption and FDI inflow, Shah et al. (2022) adopted an unconventional non-linear ARDL model which applied an unrestricted Distributed Lag model. The human mortality risks associated with greater use of renewable energy and less air pollution have diminished. Explaining how the adverse impact of air pollution can be minimized by expanding the use of alternative energy sources, the study corroborated the impact of the explored intervention on human health. This study was equally focused on the twofold benefits of the renewable energy shift of energy, pointing out how this shift would reduce the well-being threat of pollution and improve the quality of the environment. Shah and others concluded that policies encouraging the influx of foreign direct investment into renewable energy projects could be instrumental in achieving sustainable public health outcomes, advocating for a strategic focus on renewable energy development to lower mortality rates and enhance overall well-being. This study offers vital insights for policymakers aiming to balance economic growth with environmental and health considerations.

In addition, Liu and Zhong (2022) employed the Vector Error Correction Model (VECM) in examining the relationship between health spending, life expectancy and renewable energy in China. The authors' long-term analysis of life expectancy and RE consumption in China concluded that human health improved over time in parallel with the developing reliance on renewable energy within the country. This means that the transition to renewable energy is crucial for increasing population lifespan and health besides optimizing and navigating environmental concerns. Liu and Zhong's findings positively support policies that support the use of renewable energy for enhancing the population's health by supporting the fact that the use of renewable energy helps increase the life span of human beings.

Osei-Kusi, Wu, Tetteh and Castillo (2024) conducted a regional comparative study to investigate how carbon emissions, energy consumption, income levels, and life expectancy interact. Their research revealed that in developed regions, higher consumption of renewable energy is linked to increased life expectancy. This suggests that shifting towards renewable energy sources can significantly enhance health outcomes by mitigating environmental degradation and the health risks it poses. The study highlights that adopting renewable energy not only helps to lower carbon emissions but also promotes better public health, particularly in wealthier regions where such transitions are more feasible. The authors' arguments call for more financing to be directed towards 'renewables' as a way of improving the quality of the physical environment and thus, everyone's well-being.

Also, the regional comparative study was conducted by Osei-Kusi et al. (2024) to analyse the changes in energy, Income, life expectancy and carbon emission. Thus, the study introduced a hypothesis that assumed that life expectancy would be positively correlated with the usage of renewable energy, particularly in industrialized countries. Yielding from this they surfaced at the conclusion that through reducing environmental deterioration and the health risks that come with it the adoption of renewable energy improves health. They further revealed that in developed regions, higher consumption of renewable energy is linked to increased life expectancy. This suggests that shifting towards renewable energy sources can significantly enhance health outcomes by mitigating environmental degradation and the health risks it poses. The study highlights that adopting renewable energy not only helps to lower carbon emissions but also promotes better health outcomes, particularly in wealthier regions where such transitions are more feasible. Their conclusions advocate for greater investment in renewable energy to improve environmental quality and, consequently, public health outcomes.

Guo et al. (2024) have fitted detailed regression equations to compare the impacts of carbon dioxide emission, urbanization, and the deployment of renewable energy on life expectancy for all the South Asian Association for Regional Cooperation (SAARC) nations. They found out that, an increased level of using renewable energy sources leads to an increased level of health improvement which includes increased life expectancy of citizens, and decreased rate of newborn mortality, among others. The researchers argued that enhancing public health is therefore associated with the shift towards the use of green energy of electricity particularly the solar, wind and hydroelectric energy. This improvement is mostly due to the reduction in pollution which results from the use of clean energy and hence reduces incidences of diseases associated with pollution. The paper discusses the possibility and likelihood of decreasing the levels of environmental pollution hence enhancing the overall socio-medical gains that can be realised by embracing renewables. The findings of Guo and others are relevant in broad areas of public health and sustainable development and there is a need to adopt policies that would encourage a transition to renewable energy sources for the enhancement of health of populations in the SAARC region.

Karimi Alavijeh et al. (2023) used the moments quantile regression approach to examine how increases in the use of renewable energy affect life expectancy in different target population segments. They found that increasing the consumption of renewable energy leads to a significant and favourably increase in life expectancy, with this impact most pronounced in the upper tail of life expectancy distribution. That is, individuals with already higher life expectancies will benefit the most from renewable energy. The authors posited that this improvement in health outcomes is likely due to the reduction in air pollution and other environmental benefits associated with renewable energy. The study provides robust evidence for policymakers in G-7 countries to promote renewable energy to achieve better health outcomes and highlights the environmental and health advantages of reducing dependence on fossil fuels.

According to Polcyn et al. (2023), the correlation between energy use and the pollution, energy use and health care expenditure and health care expenditure and life expectancy within Asian countries was determined. The study, which described the benefits of such investments in promoting longer, healthier living, further revealed that health expenditure and renewable energy have positive impacts on life expectancy utilising panel data regression. Conversely, the study found that environmental pollution, measured through carbon dioxide emission, negatively affected life expectancy, highlighting the harmful effects of pollution on health outcomes. The authors stressed the critical importance of investing in renewable energy and healthcare systems to improve health outcomes across the region. Their findings advocate for an integrated approach to public health that integrates environmental sustainability and adequate healthcare provision.

Churchill and Smyth (2021) discussed the connection between health and energy poverty in Australia. Energy poverty means the absence of priced, reliable sources of energy; empirical research based on panel data has shown that energy poverty can have negative effects on health, particularly on mental health and chronic diseases. They suggested that policies aimed at improving energy affordability and accessibility could have positive implications for public health. Dorbonova and Sugözü (2024) and Churchill and Smyth (2021) in Australia analysed this same connexion. The study showed that higher health spending and the use of renewable energy had a positive and statistically significant on life expectancy. The authors highlighted the importance of integrating renewable energy and healthcare policies to enhance population health and well-being.

Nica et al. (2023) studied how financial development, health spending, energy mix, carbon dioxide emission, and institutional quality have affected Eastern European life expectancy. Using CS-ARDL and quantile regression methods, it is found that the more carbon dioxide emission, the less life expectancy, and vice versa, while renewable energy use and health budgets have positive effects and vice versa. They emphasized the need for comprehensive policies that promote renewable energy, healthcare investment, and environmental protection to improve population health outcomes.

The existing studies on renewable energy consumption and health outcomes have several weaknesses that my study seeks to address. Many focus on specific regions like ANZUS, BENELUX, and G-7 countries, which limits the understanding of these dynamics in a global context. This study broadens the geographical scope by focusing on 150 countries, offering a more global perspective. Furthermore, Majeed et al. (2021), emphasize long-term health outcomes like life expectancy, often overlooking the direct and indirect effects of transition on health outcomes. In providing a more comprehensive analysis, we examined and discussed the direct impact of the energy transition as well as the potential pathways where air quality and carbon emission were considered.

An addition, this study extended the literature by considering the socioeconomic factors influencing health, such as access to healthcare, health expenditure, population density, and access to energy, which are underexplored in previous research, but my study incorporates these variables for a more holistic understanding. While many studies rely on methodologies dominated by time series or cross-sectional data, which may not fully capture dynamic relationships, my use of the panel version of the structural equation framework allows for a deeper exploration of both direct, indirect, mediation and moderation analysis.

***Climate Vulnerability and Renewable Energy Transition***

The study conducted by Kim and Park (2023) investigated the “Impacts of renewable energy on climate vulnerability: A global perspective for energy transition in a climate adaptation framework. In this study, the association between country adoption of renewable energy and climate sensitivity was assessed in 169 countries from 2000 to 2019 using a global panel data analysis. Results suggest that there is a positive correlation between reduced climate sensitivity and a higher share of renewable energy in an energy consumption basket. Based on this assumption, the writers are reasonable in assuming that adopting renewable energy contributes towards increased durability and thus reduced vulnerability of the affected nation to the adverse impact of climate change. The study indicated that reducing climate change through transitioning to renewable energy sources could promote resilience and diminish vulnerability. The study also underscores that climate change adaptation plans must increasingly prioritize switching to renewable energy. Beyond highlighting the revolutionary potential of renewable energy in addressing climate-related hazards, Kim and Park’s research also provides policymakers with practical insights to strengthen national resilience to climate change.

Caijuan et al. (2024) conducted a comparative analysis of how the association between the shift to clean energy and climate vulnerabilities changed between 2010 and 2020 in developed nations in Europe and beyond. It found that European countries are more sensitive to the clean energy transition, defined as increased use of renewables than developed non-European countries in reducing climate vulnerability. If the institutional and policy frameworks in European nations had facilitated a more successful transition to clean energy, so the study suggests, it may have been a different story. What we found when trying to solve the climate threats with renewable energy policies and plans is that it is essential that one pays attention to variations of the socioeconomic and policy backdrop in different areas. By highlighting the differential impacts of clean energy transition across diverse contexts, the findings offer valuable insights for policymakers and stakeholders navigating the complexities of global climate action.

Similarly, Juhola et al. (2024) and Yang et al. (2021) examined the climate risks to the renewable energy sector and the strategies employed by energy companies to adapt to these risks. Polluted with various climate-related risks including weather events like extreme weather events and resource availability change, renewable energy system suffers from significant challenges in terms of reliability and sustainability. These challenges could, in turn, affect the accessibility and affordability of renewable energy, which could have implications for the equitable distribution of energy resources and, consequently, the health and well-being of communities. The study serves as a reminder of the imperative to fortify the resilience of renewable energy infrastructure against climate hazards while safeguarding the accessibility and affordability of clean energy resources for all.

Shang et al. (2024) conducted a comprehensive study to investigate the impacts of renewable energy on climate risk from a global perspective. The researchers considered physical, transitional, and responsible aspects of climate risk factors. In addition, they considered the possibility that using renewable energy could benefit climate adaptation. The panel data study included 125 nations between 2000 and 2020. When looking at the entire energy mix percentage of renewable energy sources and the risk of climate change, the researchers looked at a wide range of economic, political, and environmental factors. As the study found, the share of renewable energy in the total mix is strongly correlated with physical climate risk - the frequency and severity of extreme weather events.

Additionally, the transition to renewable energy was found to mitigate transition risks, including policy and technological changes, as well as liability risks, which are related to the legal and financial consequences of climate change. Their study concluded that switching to renewable energy can aid in improving global resilience and climate adaptation. Researchers emphasized the importance of investing and putting in place policies to encourage the use of renewable energy sources as a solution to the different challenges climate change poses.

Their study concluded that switching to renewable energy can aid in improving global resilience and climate adaptation. Researchers emphasized the importance of investing and putting in place policies to encourage the use of renewable energy sources as a solution to the different challenges climate change poses. They utilized climate vulnerability indices and renewable energy transition indicators to assess the relationship between these two factors in various geographical regions, including developed and developing countries. According to the report, areas that are more vulnerable to climate change, like poor nations in the Global South, frequently encounter more difficulties when making the switch to renewable energy. These regions' major obstacles to the adoption of renewable energy include infrastructure limitations, political instability, and a lack of financial resources. However, industrialized nations with less sensitivity to climate change were shown to have made the switch to renewable energy with comparatively less difficulty. This was due to several variables, including technological breakthroughs, financial stability, and supporting regulatory frameworks. The researchers stressed the need for a more sophisticated and situation-specific strategy to deal with the problems associated with the shift to renewable energy sources and climate vulnerability. They highlighted the importance of targeted financial and technological support, as well as the development of local capacity and resilience, to enable a just and equitable transition to renewable energy across different regions.

The study by Chen et al. (2022) investigates the impact of climate vulnerability on renewable energy technological innovation, with a focus on the role of the institutional environment. To analyse the association, the researchers used a fixed-effects model with panel data from 30 nations between 2000 and 2018. The study used a multidimensional measure of climate vulnerability, encompassing factors such as sensitivity, exposure, and adaptive capacity. The institutional environment was assessed based on variables like regulatory quality, political stability, and control of corruption. The findings suggest that climate vulnerability has a significant negative impact on renewable energy technological innovation. However, the researchers found that a favourable institutional environment can mitigate this adverse effect. Specifically, countries with stronger political stability, control of corruption, and regulatory quality were able to better leverage their climate vulnerability to drive innovation in renewable energy technologies. It stresses the urgency of improving and increasing the usage of renewable energy technology with the support of institutional frameworks to help and lay the groundwork for resolving climate-related vulnerabilities. A top priority for policymakers and stakeholders is to prioritize actions that make renewable energy systems more resilient to climate-related risks. As well as focusing on strengthening the institutional framework to foster the innovation of this crucial industry, they should also pay attention to why and how to encourage private investors to develop such an important industry dedicated to the manufacture of artificial parts.

Trinh and Tran (2023) investigate the impact of policy stringencies, exposure to carbon risk, and financial development on renewable energy and environmental performance. Using a sample of 26 emerging and developing economies from 2005 to 2018, the authors employ a panel quantile regression approach to analyse the relationships. Their findings suggest that renewable energy and the environment perform better by having carbon risk exposure and stricter regulations in countries with better financial systems. When considering the concerns regarding climate change, then financial growth is necessary to speed up the change to renewable energy sources and to improve environmental conscience. Since financial development allows countries to access such finance, technology and experience, the authors argue that countries can afford to invest in renewable energy projects and put in place efficient climate policies.

Additionally, the study highlights the importance of carbon risk exposure, as it incentivizes firms and governments to shift towards more sustainable energy sources and adopt environmentally friendly practices. The results suggest that a combination of stringent climate policies, increased carbon risk awareness, and well-developed financial markets can contribute to a successful renewable energy transition and improved environmental performance.

Min and Lee (2023) also then looked at how energy transition altered narratives describing the advantages and disadvantages surrounding how vulnerable populations are described in Pacific Northwest cities. Quantitative and qualitative data were used in a mixed-method approach to illustrate vulnerable groups and the advantages and disadvantages of the energy transition. The study shows the costs of cramming energy transition disproportionately fall on those served the least well by it, those that most need help. These communities tend to have higher energy costs relative to their incomes, limiting their ability to access and benefit from renewable energy technologies. Additionally, the researchers found that the implementation of renewable energy projects, such as wind and solar farms, can sometimes lead to the displacement of vulnerable residents, further exacerbating their challenges.

On the other hand, the study also identified potential opportunities for vulnerable communities to benefit from the energy transition. The researchers highlighted the importance of community-based renewable energy projects, where residents have a direct stake in the ownership and management of renewable energy infrastructure. Such initiatives can provide economic benefits, job opportunities, and increased energy security for vulnerable populations. The conclusions drawn from this study emphasize the need for policymakers and stakeholders to adopt a more inclusive and equitable approach to the renewable energy transition. This includes targeted efforts to address unique challenges confronted by vulnerable communities, such as providing financial assistance, improving access to renewable energy technologies, and ensuring the fair distribution of benefits and burdens accompanying the rate of energy transition.

While the studies reviewed so far provide meaningful results regarding climate change energy transition nexus, they exhibit certain weaknesses. Kim and Park (2023) conducted a global analysis, but their approach lacks a detailed examination of regional variations which limits its applicability in specific sub-regional contexts. Caijuan et al. (2024) focused on developed countries, excluding developing regions where climate vulnerability is often higher, resulting in an incomplete global picture. Juhola et al. (2024) highlight the importance of infrastructure resilience but do not address the socio-economic factors that may impede access to renewable energy in vulnerable communities. Shang et al. (2024) present a broad analysis of renewable energy's impact on climate risks but do not adequately consider the local institutional and financial barriers to renewable energy adoption in developing countries as well as the reverse effect. Ghaffar and Sardar (2023) focus on the challenges in developing regions but offer limited solutions to address these barriers beyond financial and infrastructure limitations. Chen et al. (2022) emphasize the role of institutional environments but do not explore how political or policy instability can hinder renewable energy innovation, particularly in less developed nations.

In contrast to these studies, this study specifically addressed these gaps by focusing on 150 countries, and continental variation. By employing a novel sequential dynamic panel data model and a complementary two-step system generalized method of moment, the study investigated not only the energy transition climate vulnerability nexus but also examines how climate readiness, governance, economic and social readiness, reduce the impact of climate vulnerability on energy transition. This provides a more complete, situation-specific knowledge of the benefits, and problems of the switch to renewable energy, particularly in developing nations like Ghana.

***Drivers of Climate Vulnerability***

Zapata (2023) examines the drivers of climate vulnerability more especially in the neighbouring countries of Haiti and the Dominican Republic. The study employed mixed-methods, combining qualitative and quantitative approaches to understand the drivers of climate vulnerability and to investigate the adaptive capacities of these two countries in the face of tropical storms, a prevalent climate-related threat in the region. The results of the study reveal several key findings. Firstly, the study identifies socioeconomic factors, such as inequality, poverty, and limited access to resources, as significant contributors to climate vulnerability in both Haiti and the Dominican Republic. These factors constrain individuals' and communities' ability to prepare for, respond to, and recover from the impacts of tropical storms. Additionally, the study highlights the role of governance and institutional capacity in shaping adaptive capacities. They also found that countries with stronger governance structures, effective disaster management plans, and well-coordinated emergency response systems were better equipped to mitigate the effects of tropical storms. In contrast, countries with weaker institutions and limited coordination among various stakeholders were more vulnerable to the impacts of climate-related disasters. The study recommends the need for a multifaceted approach to addressing climate vulnerability, which should encompass socioeconomic development, strengthening of governance and institutional capacities, and the empowerment of local communities. They suggest that policymakers and development practitioners should prioritize these factors in their efforts to enhance the adaptive capacities of vulnerable populations.

Hasan, Pervaiz and Raza (2017) assessed determinants of climate change vulnerability at several scales in Karachi. Using a mixed methods approach, the researchers investigated which factors contribute to climate vulnerability at diverse levels within the city. The results of the study revealed that climate vulnerability in Karachi is driven by a complex interaction of factors operating at different scales. At the household level, factors such as poverty, lack of access to resources, and limited adaptive capacity were found to be key drivers of vulnerability. At the community level, the study highlighted the role of informal settlements, poor infrastructure, and limited public services in exacerbating climate risks. At the city level, the researchers identified governance challenges, such as fragmented decision-making and limited coordination among various stakeholders, as significant contributors to climate vulnerability. The study concluded by emphasizing the need for a comprehensive, multi-scale approach to addressing climate vulnerability in Karachi. The authors recommend the implementation of targeted interventions that address the specific needs of vulnerable communities, as well as the strengthening of institutional and governance frameworks to ensure more effective climate adaptation and disaster risk reduction efforts.

Rahman and Rahman (2023) conducted a community climate vulnerability assessment (CCVA) of a hilly region of Bangladesh’s Rangamati District. The case study was conducted using a mixed-method approach to evaluate the local community’s vulnerability to climate change. Information on whether a household was exposed, sensitive, and had adaptive capacity-the three forms of vulnerability-was collected by the researchers through a household survey, focus group interviews, and key informant interviews. Findings in the study indicate that the mountainous region of Rangamati District is sensitive to climate change. The community’s livelihoods, food security and overall well-being are worsening under the influence of several types of climate-related disasters such as landslides, floods, and droughts. The main factors according to them leading to climate vulnerability include poverty, shortage of resources, poor infrastructure and lack of disaster preparation, the research concluded. The study’s conclusions suggest that those in the local community with lower socioeconomic status as well as low access to resources are more vulnerable to climate change. The researchers found that climate change had a greater effect on households that are far away and have lower incomes. In addition, community-based adaptation strategies, including increasing disaster management, expanding social networks, and changing livelihoods were highlighted as important for resisting climate change.

Çeler and Serengil (2023) considered a multi-scale climate vulnerability and risk assessment (C-VRA) methodology for corporate-scale investments in the West Bank, Palestine. The study employed a multi-scale C-VRA methodology to assess the climate vulnerability and risk associated with corporate-scale investments. They also performed spatial analysis using Geographic Information Systems (GIS) to map the distribution of climate-related hazards and the vulnerability of different communities. The results revealed several key drivers of climate vulnerability in the West Bank. The region’s high exposure to climate-related hazards, such as droughts, heatwaves, and water scarcity, was identified as a significant contributor to its vulnerability. Yet climate change is expected to further exacerbate these dangers, mucking things up even more for the communities in which this occurs. It was also found that the local population’s sensitivity, particularly of disadvantaged people and the environment dependent on agriculture, plays a key role in the region’s susceptibility. What they saw was that these communities are much less able to absorb the negative effects of climate change because they are often cut off from resources and their support networks. Among other things, they emphasized the region’s poor prospects for adapting to climate change, due in part to a lack of infrastructure, unstable political systems, and financial constraints. These restrictions of community involvement make communities more vulnerable to shocks and pressures of the climate, and less able to recover, adapt and adjust.

Ruane et al. (2022) assessed the climatic impact driver framework for its assessment of climate risk information. The study employed a comprehensive approach, analysing a wide range of climatic impact drivers, including temperature, precipitation, and sea-level rise, among others. The researchers applied a multi-model ensemble to simulate the future climate and assess the potential impacts on various sectors, such as agriculture, water resources, and human health. The results of the study indicate that the climatic impact-driver framework is a valuable tool for identifying and quantifying the risks associated with climate change. A framework that incorporates a methodology for determining the probability and severity of climate-related risks enables stakeholders and policymakers to create more successful adaptation plans by offering a systematic approach to evaluating the probability and seriousness of various climate risks. The study also makes clear how important it is to comprehend the local and regional context of climate risk analysis. However, geographical differences in the impacts of climate change can be large, and result from variations in adaptive capacity, infrastructure, and socioeconomic level. Of value is that the study provides important insights into the factors that influence climate vulnerability and highlights the importance of making decisions using climatic data relevant to risk.

The research by Fadairo et al. (2023) studied factors that make families involved in forest edge farming climate vulnerability and the adaptation strategy that they adopted. The researchers combined focus group talks with quantitative household surveys using a mixed-methods approach. The study sample included 600 households across three agro-ecological zones in Nigeria. The results indicate that household characteristics, such as age, gender, and educational level, as well as access to resources and social networks, significantly influence climate vulnerability.

Additionally, they found that farmers' adaptive strategies, including diversifying income sources, adopting climate-smart agricultural practices, and seeking support from government and non-governmental organizations, play a vital role in resolving the negative effects of climate change. The study's findings highlight the importance of understanding the unique diversities in socioeconomic and environmental factors that shape the adaptive capacity of vulnerable communities. The researchers emphasized the need for targeted policies and interventions that address the specific needs and challenges faced by forest-edge farming households in Nigeria, thereby enhancing their resilience to the effects of climate change.

Finally, Zhou et al. (2022) assessed the vulnerability of South Africa's rural and urban regions to climate change and how geography and socioeconomics affected climate susceptibility. They employed systematic review, analysing peer-reviewed articles, government reports, and other relevant sources to understand the factors that contribute to climate change vulnerability in both rural and urban settings. Infrastructure, adaptability, socioeconomic level, and resource availability were all studied. The research found that rural South African areas may be more vulnerable to the impact of climate change than urban areas. So, most rural areas lack infrastructure as well as social services and resources, making it harder for them to react to and adapt to climate change. Conversely, urban areas often have better access to resources and infrastructure, but they face challenges related to rapid urbanization, informal settlements, and the concentration of vulnerable populations. The importance of accounting for the specific requirements and contexts of rural as well as urban populations for adapting to climate change is stressed in the study. Policymakers and stakeholders should prioritize targeted interventions that address the specific drivers of vulnerability in each setting, such as strengthening infrastructure, improving access to resources, and enhancing the adaptive capacity of local communities.

***Climate readiness and climate vulnerability***

Amegavi et al. (2021) explore how preparedness for adaptation impacts vulnerability to climate change. Through analysis of panel quantile regression, the study establishes the nexus between climate vulnerability and adaptation readiness in 51 African countries from 1995 to 2018. But when adaptation plans are in place, the findings indicate the region's susceptibility to climate change is indeed much decreased. High exposure and sensitivity to climate change coupled with an exceptionally low adaptive capacity make Central Africa unique as its most vulnerable sub-region. However, the subregions of Africa least prone to climate change are the southern and the northern subregions. The wide range of susceptibility and adaptation readiness means that resources and support for climate adaptation are not likely to be evenly disbursed. This means that resource allocation for climate adaptation also needs to change.

Sarkodie, Ahmed and Owusu (2022) examined global readiness for adapting to climate change and reducing vulnerabilities in various sectors. To assess hypotheses and quantify the severity of climate vulnerability, the authors drew on the Romano-Wolf technique to look at vulnerability in food, ecosystem services, human habitat, health, infrastructure, and water. The impact of income expansion as well as preparation for sectoral vulnerabilities was also assessed by the study. The results indicate that high-income economies with strong social, governance, and economic readiness are less vulnerable to climate change while developing economies with low income are more exposed and sensitive. The researchers suggested focusing limited resources on managing extreme climate vulnerabilities.

Sarkodie and Strezov (2019) assessed preparedness in governance, and social and economic adaptation to mitigate the risk of climate change based on a review of the preparedness of 192 UN countries. The study used panel data models and mapping on the data. It was found that Africa had low adaptive capacity and high sensitivity and exposure to climate change, making it the most vulnerable continent to it. On the other hand, less developed nations with weak economies, ill governance and socially fragile societies may be vulnerable. Such nations include, for example, Norway, Switzerland, Canada, Sweden, United Kingdom, Finland France, Spain, and Germany. The study emphasizes that rich countries need to help developing countries in building their capacity to increase their resilience and adaptation to climate-related issues.

In Maina and Parádi-Dolgos (2024) the authors studied the impact of climate adaption readiness and financing on African economies' susceptibility. Using 52 African nations across adapted funds, this study analysed how adaptation funds have on climate vulnerability between 2012 and 2021 while taking into consideration how prepared the countries are for adapting to climate.

Using the Panel-Corrected Standard Error (PCSE) approach, it did this. To assess the impact, the Human Development Index (HDI) classifications were also used in the study to depict diverse levels of development. Our findings demonstrated that adaptation money significantly reduced climate vulnerability in Africa, especially in medium HDI countries. However, most nations still require increased funding for adaptation, resulting in only a minor reduction in vulnerability.

Additionally, the impact of climate readiness varied depending on the HDI category. In high HDI countries, however, economic, and social climate readiness had a bigger impact on vulnerability, while in low HDI countries governance readiness was more significant. The data inspire two policy recommendations. Furthermore, a priority is to reexamine how resources needed for adaptation should be reallocated to tackle inequalities and lessen vulnerability to climate risk. This also means African economies can look to creative local financing methods to raise more funds to adapt. Secondly, the African government’s efforts to reduce climate vulnerability would be more effective if they tailor climate-ready initiatives to their HDI levels.

Moving from crisis to resilience, Ma, Abid, Yang and Ahmad (2023) looked at how it is that OECD nations can step up their efforts to deal with climate change through energy transition and environmental legislation. The research analyses data from 1990 to 2020, using robust econometric techniques to evaluate data characteristics. A full CS-ARDL model includes all research and development (R&D), foreign direct investment (FDI), GDP from non-renewable energy sources and other control variables. Our results demonstrate that energy transitions and environmental policies can reduce carbon dioxide emission and mitigate climate change impacts. It is posited that climate change processes are positively correlated with GDP and FDI and that environmental conservation is aided by research and development (R&D), as research and development (R&D) tend to lower carbon dioxide emission. According to the report, OECD economies should implement tough regulatory measures to bolster environmental laws, compel compliance and stimulate sustainable courses of action. The study also suggests that the OECD gradually disconnect itself from the use of non-renewable energy sources and that it should start spending huge sums on sources renewable.

Alam et al. (2024) analyse the relationship between geopolitical risk and climate change susceptibility in 42 nations from 1995 to 2021. Using the Climate Vulnerability Index (CVI) and the Country Specific Geopolitical Risk (CGPR) indexes, they found that countries that tend to be particularly politically vulnerable to climate change are also more likely to be subject to geopolitical conflict. Their analysis highlighted an ESG readiness at the national level significantly improves this negative effect with an emphasis on ESG preparation metrics. Additionally, nations with strong institutional governance scored higher for ESG influence, the study found. Some of these findings were corroborated using propensity score matching (PSM) estimation based on matched samples of nations.

Lastly et al. (2023) used data from 107 nations between 1995 and 2019 to investigate the impact of climate vulnerability on green investment. The study found that green investment in climate change adaptation and mitigation technology is negatively impacted by climatic vulnerability. This result held for a variety of tests and took into consideration endogenous problems, cross-sectional dependence, and time lag. The study also showed that whereas physical vulnerability had the opposite effect, socioeconomic climate vulnerability hampered green investment. Additionally, Wen et al. found that just like higher levels of energy supply restrictions, countries with lower levels of economic readiness, as well as technical innovation experienced a more significant negative effect of climate vulnerability on green investment.

The studies reviewed revealed a significant knowledge gap. Amegavi et al. (2021) focus on adaptation readiness in Africa but do not provide detailed strategies for enhancing adaptive capacity in the most vulnerable sub-regions, such as Central Africa. Sarkodie et al. (2022) explore sectoral vulnerabilities and readiness across different economies but fall short of offering practical solutions for low-income countries to overcome their economic challenges and improve climate resilience. Maina and Parádi-Dolgos (2024) highlight the impact of adaptation financing in African countries but provide limited recommendations on how to sustain and scale up such funding to effectively reduce climate vulnerability. Lastly, Wen et al. (2023) demonstrated that there exists a negative effect of climate vulnerability on green investment, yet they lack actionable guidance on how countries with low adaptation readiness can attract green investments despite these challenges.

This study, however, addressed these gaps by focusing on 150 countries, where I investigated the current drivers of climate vulnerability and more importantly sensitivity to climate change, exposure, and adaptive capacity of countries in a global context. By employing the two-step system generalized method of moment, this study provided specific policy recommendations tailored to the global community and countries based on their regional and income groups.

## Conceptual Review

### *Health outcomes*

The concept of health outcomes has gained significant attention in the field of social sciences, as it encompasses the various measures and indicators used to assess the overall well-being and effectiveness of healthcare interventions. According to Paterick et al. (2017), health outcomes are modifications in a person's, a population's, or a group's health status that may be linked to healthcare interventions or policies. These outcomes can be measured in terms of mental, physical, and social well-being and the quality of life experienced by individuals and communities.

Studying health outcomes is crucial for understanding social factors, healthcare systems, and individual health. Social determinants of health, such as education, socioeconomic status, and environmental factors, significantly impact the health outcomes of individuals and communities (Schillinger, 2020). One of the primary ways health outcomes are measured is through various indicators, such as life expectancy, tuberculosis detection, and rate mortality rate.

A common measure of population health is life expectancy, which expresses the typical number of years that a person is predicted to live. Life expectancy is significantly influenced by socioeconomic factors, including access to healthcare, education, and income, as demonstrated by a few studies (Uddin et al., 2023). Higher socioeconomic background people often live longer than lower socioeconomic background people do because of things like easier access to healthcare, healthier lifestyles, and less exposure to risk factors (Stringhini et al., 2017). The disparities in life expectancy can be substantial, with research indicating that individuals in the highest socioeconomic group can have a life expectancy of up to 10 years longer than those in the lowest socioeconomic group (Chetty et al., 2016). These variances can be accredited to the accumulation of social and economic advantages over the life course, leading to better overall health and longevity.

Mortality rate is another important health outcome, reflecting the number of deaths within a population over a specific period. Mortality rates and socioeconomic position are correlated, with those from worse socioeconomic backgrounds dying at higher rates (Uddin et al., 2023). Many reasons account for these variations in healthcare access. Exposure to risk factors and financial capacity for preventative care, are part of the reasons for this discrepancy. Research indicates that those with lower incomes or educational attainment are more likely to die young than those with greater incomes or education (Stringhini et al., 2017). These socioeconomic inequalities in mortality can have far-reaching consequences, leading to a widening of the health gap within a population and perpetuating the cycle of disadvantage.

A major public health concern is tuberculosis (TB), especially in underdeveloped nations. For the disease to be effectively managed and controlled, cases of tuberculosis must be found. Key predictors of tuberculosis detection rates have been identified as socioeconomic factors, including poverty, substandard living circumstances, and restricted access to healthcare (Bhargava et al., 2021). Individuals from lower socioeconomic backgrounds are more likely to be affected by TB and face challenges in accessing diagnostic services, leading to lower detection rates (Chakaya et al., 2021). Factors such as lack of education, inadequate nutrition, and overcrowded living conditions can contribute to the higher prevalence of TB in these communities, further exacerbating the challenges in detecting and treating the disease (Lee et al., 2022).

The nexus between socioeconomic factors and health outcomes is multifaceted. Poverty, education, and access to healthcare are all interconnected and can have a significant effect on individual health (Bhargava, Bhargava, and Juneja, 2021). For instance, individuals with lower levels of education may have limited knowledge about preventive healthcare and healthy behaviours, leading to poorer health outcomes (Zajacova & Lawrence, 2018). Similarly, those with limited financial resources may face barriers to accessing healthcare services, resulting in delayed diagnosis and treatment, which can further exacerbate health disparities (Lee et al., 2022). Additionally, these socioeconomic variables may intersect, producing an unbreakable cycle of disadvantage. Developing comprehensive measures to eliminate health inequalities and promote population health requires addressing these intricate relationships.

***Renewable Energy Transition***

Considering the urgent need to cut carbon emissions and address climate change, the idea of a transition to renewable energy has received attention recently. As feasible substitutes for conventional fossil fuel-based energy generation, renewable energy sources including solar, wind, hydropower, and geothermal have the potential to lessen the environmental effect of energy production and consumption (Sovacool et al., 2020). The process of switching to renewable energy entails moving away from non-renewable, frequently carbon-intensive energy sources and towards sustainable, eco-friendly alternatives. Few factors, such as the desire to lessen the consequences of climate change, the depletion of fossil fuel sources, and the rising cost-competitiveness of renewable energy technologies, are driving this transformation (Jacobson et al., 2017).

Reducing carbon emissions, a primary cause of climate change is significantly impacted by the switch to renewable energy. Burning coal, oil, and natural gas is one of the main ways that fossil fuel-based energy generation contributes to greenhouse gas emissions; globally, carbon emissions from this source account for a substantial number of emissions (IPCC, 2021). Instead of releasing greenhouse gases during the energy-generating process, renewable energy sources like solar and wind power have a significantly smaller carbon footprint (Jahanger et al., 2023). Transitioning to renewable energy can help cities and nations drastically cut their carbon emissions and make a positive impact on international efforts to combat climate change. Global energy-related carbon emissions could drop by as much as 70% by 2050 if renewable energy is widely adopted, according to estimates from the International Energy Agency (IEA, 2021). This reduction in emissions could have far-reaching implications, including improved air quality, reduced environmental degradation, and the potential to slow the rate of global temperature increase.

The growing cost-competitiveness of renewable energy technology further accelerates the shift to renewable energy. The cost of renewable energy sources, such as solar and wind power, has dropped dramatically in recent years as economies of scale are reached and technology advances (Sovacool et al., 2020). This has accelerated the shift away from fossil fuels by making renewable energy more affordable and appealing to both small and large energy users.

Transition to renewable energy has potential advantages as well as difficulties that need to be resolved. The initial cost of renewable energy technology, which might be greater than that of conventional energy sources based on fossil fuels, is one of the main obstacles (Sovacool et al., 2020). For people, groups, and governments wishing to invest in renewable energy infrastructure, this may provide a financial challenge. The intermittent nature of renewable energy sources, such as wind and solar power, presents another difficulty because it can cause problems with energy storage and grid integration (Jacobson et al., 2017). Addressing these technical challenges requires substantial investment in research and development as well as the deployment of advanced energy storage technologies. Additionally, energy transition may face political and social resistance, as it can disrupt existing energy systems and industries built around fossil fuels (Stefes & Hager, 2020). The geographical distribution of renewable energy resources can also pose a challenge as some regions may have more abundant and accessible renewable energy sources than others. This can lead to uneven distribution of the costs and benefits associated with the transition, which may require carefully designed policies and incentives to ensure a just and equitable transition (Rahman et al., 2022).

To overcome these challenges, the transition to renewable energy requires multilayered approaches that address both technological and social factors. On the technological front, continued research and development into renewable energy technologies, as well as improvements in storage, distribution, and grid integration, are essential (Geels, 2019). At the same time, the transition also requires a fundamental shift in social attitudes and behaviours, as well as the development of new institutional structures and governance frameworks to support the transition (Geels, 2019).

One critical part of the social dimension of the transition energy is ensuring that the benefits of the transition are spread equally throughout society. This includes addressing energy poverty, ensuring that transition costs are not borne disproportionately by vulnerable people, and creating new economic opportunities and jobs in the renewable energy sector (Sovacool et al., 2020). This is especially significant in developing countries, where access to dependable and affordable electricity is a crucial development issue. Communities will become more resilient and sustainable and social justice issues will be addressed if the transition to renewable energy is made inclusive and equitable. The significance that grassroots movements and community-based initiatives play in the transition to renewable energy is another significant social dimension. Local communities have been at the forefront of the global shift to renewable energy, spearheading projects like community-owned wind and solar farms, energy efficiency campaigns, and community-based energy planning (Chun, 2023). These programs not only help with the overall switch to renewable energy, but they also empower and encourage local ownership, which can lead to the development of more resilient and sustainable communities.

Furthermore, transitioning to renewable energy offers chances for resilience in communities and social change. We can enable local communities to take more ownership of their energy futures and provide new economic opportunities by moving away from a centralized, fossil fuel-based energy system and towards a more decentralized, renewable energy system (Geels, 2019). This may result in the creation of new business models, the creation of jobs, and the bolstering of regional economies, all of which may help bring about a more just and long-lasting social revolution.

In conclusion, the transition to renewable energy is a complicated, comprehensive process that calls for an integrated, multidisciplinary strategy. As significant as the technological parts of the shift are, the social and political aspects also need to be properly analysed and addressed. To combat climate change and lower carbon emissions, the shift is also essential. Countries and communities can support international efforts to lessen the effects of climate change by switching from fossil fuel-based energy generation to more ecologically friendly and sustainable energy sources. In addition to addressing the urgent environmental issues of our day, adopting a more inclusive and equitable approach to the transition to renewable energy would open new avenues for social change and community resilience.

### *Climate Vulnerability*

The concept of climate vulnerability has garnered noteworthy interest within the social science community due to its comprehensive coverage of the diverse effects of climate change on human cultures. Climate vulnerability refers to the extent to which a system or community is vulnerable to the negative consequences of climate change, considering their capacity to adjust and adjust. This concept has been explored and defined by various scholars and organizations, each providing a unique perspective on the topic. The Intergovernmental Panel on Climate Change (IPCC) states that a system's susceptibility, adaptive capabilities, and the type, amount, and rate of climatic change and fluctuation to which it is exposed, determine its level of climate vulnerability (IPCC, 2022). This concept emphasises how a system's or community's internal qualities interact with external stresses connected to climate change to determine how well equipped it is to adapt to and cope with these changes.

Climate vulnerability, as defined by the United Nations Development Program (UNDP, 2019), is the extent to which a system is vulnerable and unable to adapt to the negative effects of climate change, including climate variability and extremes. This definition highlights the notion of coping capacity, a crucial aspect of climate vulnerability.

According to Naylor et al. (2020), climate vulnerability is the state in which a country is susceptible to negative outcomes because of exposure to stressors related to environmental and social change as well as the inability to adapt. The significance of environmental and societal elements in influencing climate vulnerability is highlighted by this term.

Chakraborty et al. (2020) propose a place-based model of vulnerability that considers the interaction of hazards of place, the social fabric (resilience and susceptibility), and the geographic context. This approach recognizes that climate vulnerability is not only a function of physical exposure but also shaped by social, economic, and political factors that vary across different geographic locations.

The concept of climate vulnerability has also been linked to the notion of resilience, which refers to the ability of a system or community to anticipate, absorb, recover, and accommodate the effects of a hazardous event in a timely and efficient manner (IPCC, 2022). Since resilience denotes the ability to change and adapt in the face of climate-related difficulties, it is sometimes understood to be the opposite of vulnerability (Nüchter et al., 2021). Academics have also underscored the significance of considering the varying degrees of susceptibility exhibited by diverse social groups within a community or culture (Naylor et al., 2020). The susceptibility of an individual or group to climate change can be influenced by a range of factors, including socioeconomic position, gender, age, ethnicity, and resource accessibility. This can result in disparate effects and the requirement for focused solutions.

Furthermore, the concept of climate vulnerability has been expanded to consider the interconnectedness of social, ecological, and economic systems. Researchers have explored how the vulnerability of one system can cascade and amplify the vulnerability of other systems, creating complex and interdependent challenges (Chakraborty et al., 2020). This viewpoint emphasizes the necessity of coordinated, comprehensive strategies to mitigate climate risk. These definitions emphasize how climate vulnerability is, and how it is impacted by several variables such as exposure to climatic risks, sensitivity to those hazards, and ability to adjust to changing circumstances.

Exposure refers to the degree to which a system or community is subjected to climate-related stressors, such as extreme temperatures, droughts, floods, or sea-level rise (IPCC, 2022). Conversely, sensitivity refers to how these climate-related stimuli influence a system or community, either favourably or unfavourably (Naylor et al., 2020). A system or community's adaptive capacity refers to its power to adapt to climate change, mitigate harm, seize opportunities, or deal with the fallout (IPCC, 2021).

Climate vulnerability is not evenly distributed across the globe or within societies. Certain regions, communities, and individuals are more vulnerable to the impacts of climate change due to a range of socioeconomic, demographic, and environmental factors (Chakraborty et al., 2020). Socioeconomic factors, such as poverty, inequality, and access to resources, can significantly influence climate vulnerability. Poorer communities and individuals often have fewer resources to cope with and adapt to climate-related hazards, making them more vulnerable (Nüchter et al., 2021).

Vulnerability can also be influenced by demographic characteristics including age, gender, and health status; older people, children, and those with preexisting medical disorders are more vulnerable to the effects of climate change (Chakraborty et al., 2020). Environmental factors, such as the physical characteristics of a region, can also contribute to climate vulnerability. Coastal communities, for instance, are more vulnerable to the impacts of sea-level rise and storm surges, while communities in arid or semi-arid regions may be more vulnerable to droughts and water scarcity (Nüchter et al., 2021).

Assessing climate vulnerability is a critical step in developing effective adaptation strategies. This process typically involves identifying the key climate hazards, assessing the exposure and sensitivity of the system or community, and evaluating the adaptive capacity (IPCC, 2022). Various frameworks and tools, such as vulnerability assessments and risk analyses, have been developed to support this process. Once climate vulnerability has been assessed, policymakers and communities can work to address the identified vulnerabilities through a range of adaptation strategies. These may include infrastructure improvements, such as building flood defences or improving water infrastructure; social and institutional measures, such as improving early warning systems or strengthening social safety nets; and ecosystem-based approaches, such as restoring wetlands or promoting sustainable land management practices (IPCC, 2021).

The influence of climate vulnerability on green investment was also considered in a study by Wen et al. (2023) of 107 countries between 1995 and 2019. The research shows that climate vulnerability is negatively correlated to green investment in climate change mitigation and adaptation technology. Tests were performed and factors such as time lag, cross-sectional dependence, and endogenous issues were controlled for, and this result remained consistent. This study also showed that socio-economic climate vulnerability inhibited green investment whereas physical climate vulnerability worked the opposite. The second part of the analysis and moderating factors showed that countries exhibiting lower levels of adaptation readiness, economic development, and technological advancement, and higher levels of energy supply restrictions, were more severely impacted by climate vulnerability across all measures of green investment.

***Climate Readiness***

According to the literature, climate readiness can be defined in numerous ways. Climate readiness is "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC, 2021). Similarly, the U.S. National Climate Assessment defines climate readiness as "the ability of a system or community to prepare for, respond to, and recover from climate-related hazards" (U.S. Global Change Research Program, 2018).

Researchers in the social sciences have also contributed to the understanding of climate readiness. For instance, Sarkodie, Ahmed and Owusu (2022) define climate readiness as the ability of a system, society, and community exposed to climate hazards to anticipate, resist, accommodate, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Furthermore, Galappaththi, Ford and Bennett (2019), suggest that climate readiness involves the capacity of a system to adapt and restructure itself while changing and yet fundamentally maintaining its original identity, function, structure, and feedback. This perspective highlights the dynamic nature of climate readiness, which involves not only responding to immediate threats but also adapting to long-term changes in the climate system.

The level of climate readiness within a community or society can be influenced by various factors, such as socioeconomic status, access to resources, and the availability of relevant information and education (Radunsky & Cadman, 2021). Marginalized communities and individuals, including low-income populations and certain minority groups, often face disproportionate challenges in achieving climate readiness due to limited resources and access to support. Additionally, the level of community engagement and the presence of collaborative networks can significantly impact climate readiness. When communities work together to share knowledge, pool resources, and develop coordinated response plans, they are better equipped to address the challenges posed by climate change.

Governments, non-governmental organizations, and community members must be involved in a multidimensional strategy to improve climate readiness. Some key strategies include improving risk assessment and early warning systems, investing in infrastructure adaptation, fostering community engagement and education, promoting cross-sectoral collaboration, and integrating climate readiness into policy and planning (Sarkodie, Ahmed, & Owusu, 2022).

Communities can better anticipate and respond to disasters by enhancing risk assessment and early warning systems. Resilience to the effects of climate change can be increased in communities through investments in infrastructure adaptation, such as modernizing and fortifying vital infrastructure. Encouragement of cross-sectoral collaboration can result in more complete and successful climate readiness initiatives, while community participation and education can empower individuals to take action to improve their climate readiness. A more comprehensive and integrated strategy for resolving climate change concerns can be ensured by incorporating climate readiness considerations into several policy domains.

Regardless of the importance of climate readiness, few challenges and limitations must be addressed. Funding constraints, political barriers, and the complex and multifaceted nature of climate change can all hinder the implementation of effective climate readiness strategies (Alsabbagh, & Alnaser, 2023). Additionally, the uneven distribution of resources and the disproportionate impact of climate change on certain communities can exacerbate existing inequalities and make it more difficult to achieve equitable climate readiness.

Climate readiness is a critical concept in the social sciences, as it directly affects the ability of individuals, communities, and societies to adapt to and mitigate the impacts of climate change. Understanding the factors that influence climate readiness, developing effective strategies, and addressing the challenges and limitations can help work towards building more resilient and sustainable communities. To ensure our societies' long-term prosperity and well-being in the face of a changing climate, improving climate readiness is imperative.

## Chapter Summary

The chapter presented a review of the literature by first looking at the theoretical foundation of the study. It presents, discuss and criticise the theories necessary to understand the energy transition, climate vulnerability and health outcomes in a changing world. Also, the chapter addressed empirical research on a variety of topics, including causes of climate vulnerability, the relationship between the transition to renewable energy and health outcomes, and climate vulnerability and renewable energy transition. A review of key concepts ranging from renewable energy transition, health outcomes, life expectancy, mortality rate, tuberculosis case detection rate, carbon dioxide, air quality, climate vulnerability, and climate readiness was presented.

# CHAPTER THREE

# RESEARCH METHODS

## Introduction

This chapter presents the methods that were employed in examining the energy consumption, climate vulnerability, and health outcomes nexus. The chapter starts by first explaining the philosophical foundation of the study and the research designs. The chapter also explained different models and the appropriate justification for using them based on each objective. The chapter ended with a chapter summary.

## Research Philosophy

Positivism, a key philosophy in the natural and social sciences, underpins research that seeks to understand observable phenomena through empirical evidence and objective measurements (Karupiah, 2022; Park et al., 2020). When investigating the nexus between energy transition, health outcomes, and climate vulnerability across 150 countries, a positivist approach is particularly apt. This philosophy emphasizes the use of statistical and quantitative methods to analyse data, making it ideal for panel data analysis. By relying on observable, measurable variables, positivism enables researchers to establish clear, replicable findings on how energy policies and practices influence health and climate resilience in diverse contexts (Junjie & Yingxin, 2022; Tamminen & Poucher, 2020).

In the context of panel data on energy transition and its impacts, positivism allows for the application of econometric techniques such as fixed and random effects models, which can control for country-specific factors and temporal trends. These methods are crucial in handling the longitudinal aspect of the data, where changes over time and differences between countries must be rigorously accounted for. By adopting a positivist stance, researchers can effectively test hypotheses about causal relationships, identify significant patterns, and produce generalizable insights into how shifts in energy strategies affect public health and climate vulnerability globally (Headley et al., 2024).

Moreover, positivism's focus on empirical evidence aligns with the need for robust data-driven policy recommendations. In studying energy transition, health outcomes, and climate vulnerability, positivism facilitates the translation of complex data into actionable insights for policymakers and stakeholders. This philosophy supports the generation of objective, reliable findings that can guide international efforts to mitigate climate risks and improve health outcomes through effective energy policies. By grounding the research in measurable evidence, positivism ensures that conclusions drawn are not only scientifically sound but also relevant for addressing the pressing challenges of our changing world.

**Research Design**

The explanatory research design is a fitting choice for the study investigating the objectives related to energy transition, health outcomes, and climate vulnerability across 150 countries. This design is particularly appropriate because it focuses on understanding the causal relationships between variables and uncovering underlying mechanisms to explain the underlying relationship between variables. It provides a comprehensive framework to systematically explore and elucidate how several factors over time and across different national contexts, making it for nexus.

In terms of objective one, quantifying the effect of energy transition on life expectancy, the explanatory research design supports hypothesis testing and causal inference, enabling researchers to disentangle the direct effects of energy transition on life expectancy from the indirect effects mediated by air quality and carbon emissions. This approach helps in understanding whether the adoption of cleaner energy sources leads to tangible improvements in life expectancy or if the benefits are offset by other factors, thus providing a nuanced explanation of the relationship.

The second objective, examining climate vulnerability on energy transition as well as the moderating role of climate readiness utilize the explanatory research design. This design can go beyond mere correlations to establish causal links between climate vulnerability dimensions and energy transition rates. This approach helps in understanding not just whether vulnerable countries are more likely to adopt energy transition policies, but also why certain vulnerabilities prompt more significant responses. Thereby contributing to a more targeted and effective policy framework that accounts for climate readiness in terms of economic, governance and social readiness.

In the context of investigating the drivers of climate vulnerability and its disaggregation, the explanatory research design is instrumental in identifying and understanding the effect of different macroeconomic factors that contribute to climate vulnerability across different countries. In that the design's focus on the effect and underlying mechanisms that enable the researcher to identify specific factors that exacerbate or mitigate climate vulnerability. By providing insights into the causes of vulnerability, this design informs the development of targeted interventions and policies aimed at reducing vulnerability and enhancing resilience, thus offering practical solutions for addressing climate risks.

## Model Specification

To investigate the renewable energy transition, health outcomes and climate vulnerability nexus, the study presents the theoretical and empirical model specification, and estimation strategy under each objective.

### *Theoretical model for quantifying the effect of renewable energy transition on health outcome*

The model for objective one which seeks to quantify the effect of the renewable energy transition on life expectancy is presented. Grossman (1972, 2022) explain that the health demand model is premised on the fact that health is a capital good is employed. The model expresses that an individual's health outcome depreciates over time. However, the depreciation in health can be enhanced through investment in medical services or consuming medical care (Majeed et al., 2021). And as well, Rehman et al. (2022) and Suhrcke, Stuckler, Suk, Desai, Senek, McKee, ... and Semenza, (2011) explain that improvement in environmental quality provides an input factor in the health outcome model. This means that investment in health as an input through expenditure on health, ensuring environmental quality suggests that there will be an improvement in mortality rate which leads to improved life expectancy. As expressed in

Grossman (1972, 2022), Majeed et al. (2021) and Suhrcke et al. (2011), the functional form of the health production model is:

$$\boldsymbol{H} = \boldsymbol{f}(\boldsymbol{X}) \quad (1)$$

where H stands for the health outcome variables proxy for by life expectancy, mortality rate and tuberculosis detection rate. The X on the other hand is health input. The health inputs encompass factors influencing health outcome indicators, such as cost of health, income, individuals' education level and the environment (Majeed et al., 2021). Since the original Grossman's model is a micro-level model, the macro-level indicators considered in the functional form. This includes current GDP used to capture income, population density, access to clean energy, health expenditure to capture the investment in health, and environmental quality variables like the transition to renewable energy, carbon emission and air quality proxied for by Particulate Matter ≤ 2.5 micrometres in diameter (PM2.5). Majeed and others have however classified these factors into economic, social, and environmental factors. In equation 2, J is a vector representing economic variables (current gross domestic product, health expenditure), S represents social variables (population density and access to clean energy), and V comprises environmental factors (like renewable energy transition. To address the invariant effect and account for the continent-specific heterogeneity, time and continental dummies were introduced as fixed effect in each model. This is specified as:

$$H = f(J, S, V, X) \quad (2)$$

***Empirical model for quantifying the effect of renewable energy transition on health outcome***

The fact that exposure to poor air quality is caused by energy consumption and partly accounts for the 7 million premature deaths annually suggests that factors that affect health outcomes need to be investigated (WHO, 2018). Following the equation (2), and the studies by Majeed et al. (2021), and Suhrcke et al. (2011), the empirical model for a panel of 150 countries is specified as:

$$LE_{it} = Y_0 + Y_1 Transition_{it} + Y_2 AQ_{it} + Y_3 lnCO2_{it} + Y_4 lnHExp_{it} + Y_5 \; lndensity_{it} + Y_6 lnGDP_{it} + Y_7 lnaccess_{it} + Y_8 Fixed\ effect_i + u_{it} \qquad (3)$$

In equation 3, $LE_{it}$ is the life expectancy for country $i$ in time $t$, Transition is rate of renewable energy transition, AQ is air quality, $lnCO_2$ is log of carbon dioxide emission, lnHExp, is log of current health expenditure, lndensity is log of population density, lnGDP is current GDP in dollars, lnaccess is log of population access to clean fuels and technologies for cooking. The $Fixed\ effect$ variable includes time dummy and continental dummy. Following Koomson (2024) in South Africa, Bentley et al. (2023) in Australia, Polcyn et al. (2023) in Asia, and Karimi Alavijeh et al. (2023), increases in the rate of transition could have an indirect impact on health outcome.

The use of air quality proxied for by pm2.5 and the use of carbon dioxide emission although might seem related the correlation coefficient is however moderate. Again, PM2.5 does not capture all forms of carbon emissions, particularly carbon dioxide, which is the dominant greenhouse gas but not a direct contributor to particulate matter. While carbon emissions and PM2.5

pollution are often correlated due to shared sources (such as burning fossil fuels), they do not always behave in the same way. For instance, measures that reduce carbon emissions (like the switch to cleaner fuels) may not always reduce PM2.5 to the same extent. This can complicate the interpretation of results. For example, carbon emissions primarily contribute to long-term climate change, while PM2.5 affects immediate air quality and health.

In explaining the relationship between renewable energy transition and health outcomes which has not been explored in the literature, Koomson (2024), Bentley et al. (2023), Polcyn et al. (2023), and Karimi Alavijeh et al. (2023) provide evident that renewable energy consumption improves health outcome. However, to show the transmission channels, it is evident that increased renewable energy consumption leads to a reduction in carbon dioxide emission as well as air quality. Reduction in carbon dioxide emission as well as improvement in air quality present health benefits which can lead to longevity populaces. Presenting both transition and carbon dioxide emission as well as air quality suggests that transition is endogenous, thereby presenting issues of endogeneity.

To resolve the issue of endogeneity, this study employs the Panel Structural Equation Model (PSEM), a statistical technique that combines multiple regression equations to analyse the relationships between observed (measured) and latent (unobserved) variables. The PSEM model is illustrated in Fig. 1. The PSEM figure 1 is estimated using the PSEM because the effect of the renewable energy transition rate on a health outcome (life expectancy) can also be assessed indirectly through carbon dioxide emission reduction and improved air quality.

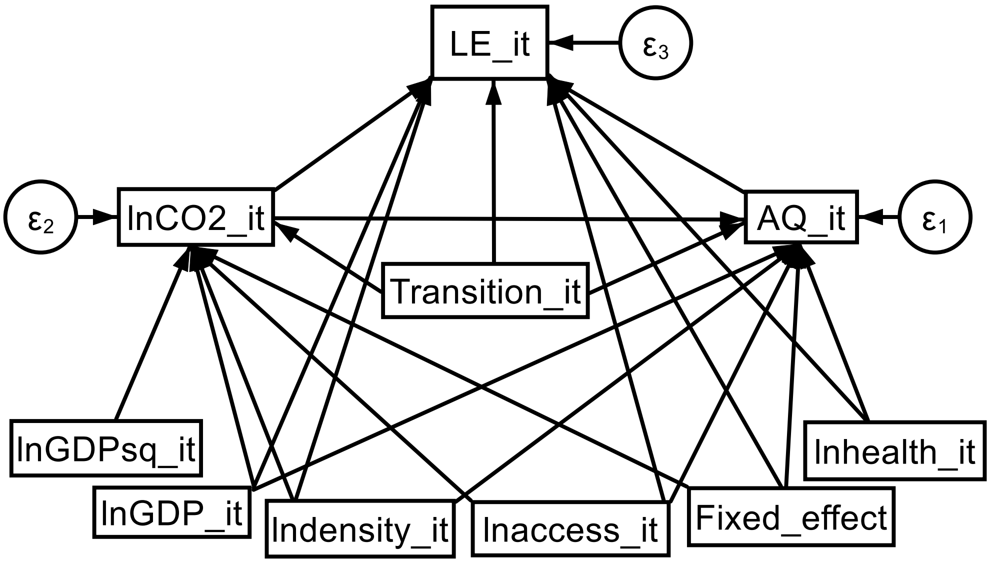



Figure 1: PSEM Model

Source: Author's computation (2024)

***Estimation strategy for quantifying the effect of renewable energy transition on health outcome***

In estimating the PSEM model in equation (4), the estimation techniques available for exploration are maximum likelihood, maximum likelihood with missing values, and asymptotic distribution-free estimation. The maximum likelihood (ML) estimation technique, though widely used (Williams et al., 2018), may not be appropriate in this context when dealing with large countries because there is the possibility of outliers. Due to this limitation of ML, when using ML estimation with missing data, one needs to handle missing values appropriately. This can involve techniques such as Full Information Maximum Likelihood (FIML) or Multiple Imputation (MI) (Du & Bentler, 2022; Ojewumi & Akinlo, 2017; Schreiber, 2017; Ziedzor, 2022). FIML was used in this study because it estimates the model parameters using all available data, effectively utilising information from cases with complete data to estimate missing data.

Maximum Likelihood (ML) estimation in P-SEM is highly efficient and precise, providing parameter estimates with the least variance and offering a variety of standard fit indices that assess model fit effectively. It supports complex models with both latent and observed variables, is simple and fast to compute, and works well with small samples under the assumption of normality. By contrast, ML with Missing Values (MLMV) is robust in handling missing data directly, although it is more computationally intensive and not universally available in SEM software. Asymptotic Distribution-Free (ADF) estimation is suitable for large samples and non-normal data, but is less efficient, requires large samples for reliable results, and offers limited fit indices. While ML is broadly implemented in SEM tools and is widely used owing to its flexibility and computational simplicity, MLMV provides advantages in dealing with incomplete datasets, and ADF caters to specific data distributions but with a more demanding sample size and computational requirements (Du & Bentler, 2022).

***Econometric model for examining the effect of climate vulnerability on energy transition***

This study employed a sequential dynamic linear panel data model. It estimates a standard linear panel model even if independent variables are not specified according to Kripfganz and Schwarz (2019). This model supports OLS and 2SLS estimation, as well as GMM estimation in the spirit of Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (2000), with a flexible choice of either internal or external instruments or both. In a case where a model is not specified for an endogenous variable, OLS, two-stage least squares estimation, or generalised method of moments is used. The estimation can be performed sequentially, meaning that it can handle models in which the parameters belong to either time-varying or invariant regressors. This allows the model to capture temporal dependencies and account for the dynamics of the system over time. The model according to Kripfganz and Schwarz (2019) is expressed in equation (5) as:

$$Y_{it} = \Upsilon_0 + \Upsilon_1 Y_{it-1} + \Upsilon_2 \boldsymbol{X}_{\boldsymbol{kit}} + \Omega_i + u_{it} \tag{5}$$

The $Y_{it}$ is the rate of energy transition for country $i$ at time $t$, $\boldsymbol{X}_{\boldsymbol{kit}}$ is a vector of independent variables for country $i$ at time t, $\Omega_i$ is the country-specific fixed effect (time-invariant), $u_{it}$ is the error term. The k takes on different potential endogenous variables in equation (6). In the spirit of the sequential dynamic linear panel data model expressed by Kripfganz and Schwarz (2019), these potential endogenous variables can be modelled as:

$$X_{kit} = \phi_1 X_{kit-1} + \beta_1 f_i + \hbar_{kit} \tag{6}$$

The k takes on different potential endogenous variables in equation one, $X_{kit-1}$ are the lags of the potential endogenous variable ($X_{kit}$) and $f_i$ the individual-specific time-invariant effect, whereas $\hbar_{kit}$ is the error term. Substituting equation (6) into (5) gives equation (7).

$$Y_{it} = \alpha_0 + \alpha_1 Y_{it-1} + \widehat{\boldsymbol{X}_{\boldsymbol{kit}}} \alpha_2 + \xi_i + \forall_{it} \tag{7}$$

The equation (7) represents the estimated sequential dynamic linear panel data model used in examining the effect of climate vulnerability on the rate of renewable energy transition. This model allows for flexible estimation using techniques such as OLS, 2SLS, or GMM, making it suitable for analyzing temporal dependencies and dynamics in panel data, as it considers both the immediate and lagged effects of the variables involved.

***Empirical model for examining the effect of climate vulnerability on energy transition***

In examining the extent to which climate vulnerability drives the rate of energy transition among countries, the sequential dynamic linear panel data model expressed in equation (7) is most appropriate. This is because of the possibility of encountering endogeneity resulting from dynamic relations. Thus, lagged values of the rate of renewable energy transition can influence the current rate of transition. From equation (7), $Y_{it}$ is $Transition_{it}$ rate of renewable energy transition), $Y_{it-1}$ is lagged value of rate of renewable energy transition, $\widehat{X_{k\iota t}}$ is a vector of potential endogenous variables like climate vulnerability (Vulnerability), foreign direct investment (lnFDI), income (lnGDP), population density (lnPop_density), access to clean fuel and technology ($lnenergy$_access), trade flow (lnTrade), and $\xi_i$ represents the fixed effect. This includes time invariant dummies like the continent, income status and time-fixed effect.

$$Transition_{it} = \alpha_0 + \alpha_1 Transition_{it-1} + \alpha_2 Vulnerability_{it} + \alpha_3 lnGDP_{it} + \alpha_4 lnPop\_density_{it} + \alpha_5 lnFDI_{it} + \alpha_6 lnenergy\_access_{it} + \alpha_7 lnTrade_{it} + \alpha_8 Fixed\ effect_i + u_{it} \quad (8)$$

The specific objective under this is to examine the effect of the disaggregated climate vulnerability on energy transition. In this case, equation (9), (10), and

(11) respectively examined the sensitivity, adaptive capacity, and exposure on the rate of energy transition.

***Effect of climate sensitivity on the rate of energy transition***

$$Transition_{it} = \Upsilon_0 + \Upsilon_1 Transition_{it-1} + \Upsilon_2 Sensitivity_{it} + \Upsilon_3 lnGDP_{it} + \Upsilon_4 lnPop\_density_{it} + \Upsilon_5 lnFDI_{it} + \Upsilon_6 lnenergy\_access_{it} + \Upsilon_7 lnTrade_{it} + \Upsilon_8 Fixed\ effect_i + u_{it} \quad (9)$$

***Effect of adaptive capacity on the rate of energy transition***

$$Transition_{it} = \delta_0 + \delta_1 Transition_{it-1} + \delta_2 Capacity_{it} + \delta_3 lnGDP_{it} + \delta_4 lnPop\_density_{it} + \delta_5 lnFDI_{it} + \delta_6 lnenergy\_access_{it} + \delta_7 lnTrade_{it} + \delta_8 Fixed\ effect + u_{it} \quad (10)$$

***Effect of climate exposure on the rate of energy transition***

$$Transition_{it} = \mu_0 + \mu_1 Transition_{it-1} + \mu_2 Exposure_{it} + \mu_3 lnGDP_{it} + \mu_4 lnPop\_density_{it} + \mu_5 lnFDI_{it} + \mu_6 lnenergy\_access_{it} + \mu_7 lnTrade_{it} + \mu_8 Fixed\ effect + u_{it} \quad (11)$$

The study also investigated the moderating role of climate readiness in the effect of climate vulnerability and its disaggregation on energy transition. Meanwhile, climate readiness as presented under the justification of variables has three dimensions; economic, governance and social readiness.

***Moderating role of climate readiness in the effect of climate vulnerability on energy transition***

Equation (12) examined the moderating role of climate readiness in the effect of climate vulnerability on the rate of transition.

$$Transition_{it} = \alpha_0 + \alpha_1 Transition_{it-1} + \alpha_2 Vunerability_{it} + \alpha_3 Readiness_{it} + \alpha_4 Vunerability * readiness_{it} + \alpha_5 lnGDP_{it} + \alpha_6 lnPop\_density_{it} + \alpha_7 lnFDI_{it} + \alpha_8 lnenergy\_access_{it} + \alpha_9 lnTrade_{it} + \alpha_{10} Fixed\ effect + u_{it} \quad (12)$$

***Moderating role of climate readiness in the effect of sensitivity to climate change on energy transition***

The equation (13) examined the moderating role of climate readiness in the effect of sensitivity to climate change on the rate of transition:

$$Transition_{it} = \Upsilon_0 + \Upsilon_1 Transition_{it-1} + \Upsilon_2 Sensitivity_{it} + \Upsilon_3 Readiness_{it} + \Upsilon_4 Sensitivity * Readiness_{it} + \Upsilon_5 lnGDP_{it} + \Upsilon_6 lnPop\_density_{it} + \Upsilon_7 lnFDI_{it} + \Upsilon_8 lnenergy\_access_{it} + \Upsilon_9 lnTrade_{it} + \Upsilon_{10} Fixed\ effect + u_{it} \quad (13)$$

***Moderating role of climate readiness in the effect of adaptive capacity on energy transition***

The equation (14) examined the moderating role of climate readiness in the effect of adaptive capacity on the rate of transition:

$$Transition_{it} = \delta_0 + \delta_1 Transition_{it-1} + \delta_2 Capacity_{it} + \delta_3 Readiness_{it} + \delta_4 Capacity * Readiness_{it} + \delta_5 lnGDP_{it} + \delta_6 lnPop\_density_{it} + \delta_7 lnFDI_{it} + \delta_8 lnenergy\_access_{it} + \delta_9 lnTrade_{it} + \delta_{10} + Fixed\ effect + u_{it} \quad (14)$$

***Moderating role of climate readiness in the effect of exposure to climate change on energy transition***

The equation (15) examined the moderating role of climate readiness in the effect of exposure to climate change on the rate of transition as

$$Transition_{it} = \mu_0 + \mu_1 Transition_{it-1} + \mu_2 Exposure_{it} + \mu_3 Readiness_{it} + \mu_4 Exposure * Readiness_{it} + \mu_5 lnGDP_{it} + \mu_6 lnPop\_density_{it} + \mu_7 lnFDI_{it} + \mu_8 lnenergy\_access_{it} + \mu_9 lnTrade_{it} + \mu_{10} Fixed\ effect + u_{it} \quad (15)$$

The study also moderates sensitivity, adaptive capacity, and exposure with the three dimensions of climate readiness (economic, governance and social readiness.

***Estimation strategy for examining effect of climate vulnerability on energy transition***

As suggested and reported by Kripfganz and Schwarz (2019), the estimation techniques appropriate to estimating a dynamic relationship with a time-fixed effect are linear dynamic panel data models with time-invariant regressors. The Sequential linear panel data model provides sequential estimation techniques for linear dynamic panel data models, incorporating the second-stage standard error correction developed by Kripfganz and Schwarz was employed. This model allows users to conduct both stages of a sequential regression or perform each stage independently. It supports one-step and two-step GMM estimation at each stage, including system-GMM based on linear moment conditions for the differenced and level equations. After estimation, users can access statistics such as the Arellano-Bond test for residual autocorrelation and Hansen's J-test to check the validity of the overidentifying restrictions.

***Theoretical model for investigating the drivers of climate vulnerability***

This study also investigated the drivers of climate vulnerability by relying on the IPAT identity. The IPAT identity developed and used by Chertow (2000), Muzayanah et al. (2022), Ozcan and Ulucak (2021), Suhrcke et al. (2011) and York et al. (2003) served as the foundational conceptual framework. Within the realms of environmental studies and ecological economics, the model offers a means to assess the influence of human activities on the environment. More specifically, the IPAT identity was employed to gain insights into the ways in which factors like population growth, rising affluence (often gauged by per capita income or consumption), and technological progress collectively influence environmental outcomes, including phenomena such as resource depletion and pollution. The IPAT identity is typically written as:

$$I = P * A * T \quad (16)$$

The I in equation 16 represent Impact, P is Population, A is Affluence, and T is technology. It is a way to express the idea that environmental impact is a function of these three factors: population dynamics, the level of affluence or consumption per capita, and the technology used to produce and consume goods and services. This framework helps researchers and policymakers analyse and address environmental issues by considering the relationship between these factors. Since the objective is to examine the drivers of climate vulnerability and its disaggregated dimensions, the modified extended version of the model from a recent study by Chertow (2000), Muzayanah et al. (2022), Ozcan and

Ulucak (2021) and York et al. (2003) is adapted. As well, the data is a panel of 150 countries from 2000 to 2021. The modified version of equation 1, according to Muzayanah et al. and Ozcan and others is the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model. In a generic form, the model is:

$$I_{it} = \emptyset P_{it}^{b} A_{it}^{c} T_{it}^{d} Z_{it} \quad (17)$$

where $\emptyset$ is the constant term, I, P, A and T are the same as those in equation 1. The $Z$ captures the other factors that affect the environmental outcome. The $b$, $c$, and $d$ are the elasticities to the impact, $i$=*countries* and $t$=2000, 2001, ..., 2021.

***Empirical model for investigating the drivers of climate vulnerability***

Investigating the drivers of climate vulnerability demands that we transform the theoretical model into an empirical form. An econometric model formulated by taking the log transformation of equation (1.1) as follows:

$$\ln(I_{it}) = ln\emptyset + b\ln(P_{it}) + c\ln(A_{it}) + d\ln(T_{it}) + Z_{it} + e_{it} \quad (18)$$

According to Muzayanah et al. (2022) and York et al. (2003), equation (18) which is the STIRPAT model is extended to include additional factors that can affect the impact (I). To proxy for the environmental impact (I), climate vulnerability and its disaggregated components (sensitivity, exposure, and adaptive capacity) were used. Population density for P and current GDP per capita was used to capture A. The use of current GDP instead of real GDP is justified on the grounds that current GDP captures the actual economic situation at a given time, including inflation effects, which may influence a country's ability to respond to climate vulnerabilities. T is proxied by transition to renewable energy (such as solar, wind, hydro, and geothermal) which reflects improvements in technological efficiency and innovation, crucial for reducing the environmental impact of energy production. By shifting from fossil fuels to renewable sources, the technology factor T captures the effectiveness of newer, cleaner technologies in reducing greenhouse gas emissions, pollution, and resource depletion. Lastly, the $Z$ captures all relevant variables that could potentially affect climate vulnerability. These include carbon dioxide emission, distance between countries, FDI, migration, trade flow and investment. The $e_{it}$ is the error term. Including these variables in equation (18) gives equation (19) as:

$$Vunerability_{it} = \delta_0 + \delta_1 Vunerability_{it-1} + \delta_2 \mathrm{lnCO2}_{it} + \delta_3 \mathrm{Renewable}_{it} + \delta_4 \mathrm{lnDistance}_{it} + \delta_5 \mathrm{lnGDP}_{it} + \delta_6 \mathrm{lnGDP}sq_{it} + \delta_7 \mathrm{lnPop\_growth}_{it} + \delta_8 \mathrm{lnFDI}_{it} + \delta_9 \mathrm{lnInvestment}_{it} + \delta_{10} \mathrm{lnTradeflow}_{it} + \delta_{11} \mathrm{lnMigration}_{it} + \delta_{12} \mathit{Fixed\ effect} + \varepsilon_{it} \quad (19)$$

We introduced the lagged value of climate vulnerability ($Vunerability_{it-1}$) in equation 19 to capture potential endogeneity resulting from a dynamic relationship. To be able to assess the factors that drive the different dimensions of climate vulnerability, the study estimated equations 20, 21 and 22 for sensitivity, adaptive capacity, and exposure to climate change, respectively.

$$Sensitivity_{i,t} = \gamma_0 + \gamma_1 Sensitivity_{i,t-1} + +\gamma_2 \mathrm{lnCO2}_{it} + \gamma_3 \mathrm{Renewable}_{it} + \gamma_4 \mathrm{lnDistance}_{it} + \gamma_5 \mathrm{lnGDP}_{it} + \gamma_6 \mathrm{lnGDP}sq_{it} + \gamma_7 \mathrm{lnPop\_growth}_{it} + \gamma_8 \mathrm{lnFDI}_{it} + \gamma_9 \mathrm{lnInvestment}_{it} + \gamma_{10} \mathrm{lnTradeflow}_{it} + \gamma_{11} \mathrm{lnMigration}_{it} + \gamma_{12} \mathit{Fixed\ effect} + \varepsilon_{i,t} \quad (20)$$

$$Capacity_{i,t} = \partial_0 + \partial_1 Capacity_{i,t-1} + \partial_2 \text{lnCO2}_{it} + \partial_3 \text{Renewable}_{it} + \partial_4 \text{lnDistance}_{it} + \partial_5 \text{lnGDP}_{it} + \partial_6 \text{lnGDP}sq_{it} + \partial_7 \text{lnPop\_growth}_{it} + \partial_8 \text{lnFDI}_{it} + \partial_9 \text{lnInvestment}_{it} + \partial_{10} \text{lnTradeflow}_{it} + \partial_{11} \text{lnMigration}_{it} + \partial_{12} \textit{Fixed effect} + \varepsilon_{i,t} \quad (21)$$

$$Exposure_{i,t} = \emptyset_0 + \emptyset_1 Exposure_{i,t-1} + \emptyset_2 \text{lnCO2}_{it} + \emptyset_3 \text{Renewable}_{it} + \emptyset_4 \text{lnDistance}_{it} + \emptyset_5 \text{lnGDP}_{it} + \emptyset_6 \text{lnGDP}sq_{it} + \emptyset_7 \text{lnPop\_growth}_{it} + \delta\emptyset_8 \text{lnFDI}_{it} + \emptyset_9 \text{lnInvestment}_{it} + \emptyset_{10} \text{lnTradeflow}_{it} + \emptyset_{11} \text{lnMigration}_{it} + \emptyset_{12} \textit{Fixed effect} + \varepsilon_{i,t} \quad (22)$$

In all, equations 19, 20, 21, and 22 are estimated as well as for low, lower middle, middle and high-income countries, respectively.

***Estimation strategy and robustness checks for investigating the drivers of climate vulnerability***

Owing to the fact the level of climate vulnerability in the previous period has the potential to affect a country's current level of climate vulnerability, a dynamic panel model is most preferred. Adapting the strategy by Li et al. (2016) and Baek (2016) which was built on the GMM model by Hansen (1982) and Arellano and Bond (1991). The core concept behind the difference Generalized Method of Moments (GMM) is to use lagged values of explanatory variables as instruments for the same variables in a different equation. However, Arellano and Bover (1995) and Blundell and Bond (2000) pointed out that this approach may inherently suffer from the problem of weak instruments. To address this, Arellano, Bover, Blundell, and Bond introduced the system GMM estimator, which constructs a system that includes both the original level equation, and the equation derived from differences. The model is the System GMM.

The system GMM presents more advantages over other dynamic and static models by helping to resolve endogeneity resulting from unobserved heterogeneity using lagged dependent variables and or lagged independent variables as regressors. The lag control for autocorrelation improves model fitness and addresses endogeneity without extra variables in the model. It also addresses serial correlation in panel data settings (Baek, 2016; Li et al., 2016).

## Data Source and Description

The study outsourced data on 150 countries from 2001 to 2021. The choice of year and country are both motivated by the availability of data. Data on foreign direct investment, trade openness, urban population, gross fixed capital formation, carbon dioxide GDP per capita, and population density were obtained from World Development Indicators, while that of air quality was obtained from the NASA Socioeconomic Data and Applications Centre (SEDAC). The climate vulnerability dataset was sourced from the Notre Dame University database under the Global Adaptation Initiative (ND-GAIN) project. Finally, data on renewable and non-renewable energy consumption was sourced from British Petroleum Statistics and the U.S. Energy Information Administration.

## Justification of Variables

### *Energy Transition*

The rate of renewable energy transition can positively impact health outcomes by reducing carbon emissions and improving air quality. Increased renewable energy deployment mitigates air pollution-related health risks, contributing to higher life expectancy and lower mortality rates (Suhrcke et al., 2011; van Daalen et al., 2024). Cleaner energy sources also support respiratory health and immune function, potentially lowering TB incidence and improving case detection rates through reduced exposure to air pollutants (Yadava et al., 2023). This empirical evidence highlighted the health co-benefits of renewable energy transitions, underscoring their role in promoting sustainable development and public health. In measuring the rate of transition, the rate change in the proportion of renewable energy consumption to total energy consumption was used. The rate of transition was proxied by renewable energy consumption to total energy consumption, similar to Cagnano and De Tuglie (2015) and Shahbaz et al. (2015).

***Climate vulnerability***

Climate vulnerability, including sensitivity, adaptive capacity, and exposure to climate vulnerability, significantly influences the rate of renewable energy transition. Countries with higher sensitivity to climate vulnerabilities, such as extreme weather events are more incentivized to invest in renewable energy sources to reduce dependency on fossil fuels and mitigate environmental risks. Enhanced adaptive capacities, through robust infrastructure and disaster preparedness, enable smoother integration and adoption of renewable energy technologies. It is also demonstrated by Adelekan et al. (2024) and Xu et al. (2024) that countries facing higher climate risks have accelerated their transition to renewable energy, driven by the imperative to enhance resilience and reduce greenhouse gas emissions.

***Carbon emission***

Carbon emissions significantly impact health outcomes such as life expectancy, mortality rates, and tuberculosis (TB) case detection rates. High levels of carbon emissions, primarily from fossil fuel combustion, contribute to air pollution and climate change, exacerbating respiratory and cardiovascular diseases. Studies indicate that exposure to particulate matter (PM2.5) and other pollutants from carbon emissions correlates with increased mortality rates and reduced life expectancy (Suhrcke et al., 2011; Yin et al., 2020). Moreover, air pollution can compromise immune responses, potentially affecting TB case detection rates by increasing susceptibility to respiratory infections and complicating diagnosis and treatment effectiveness (WHO, 2018).

***Air quality***

Air quality, particularly levels of fine particulate matter (PM2.5), significantly influences health outcomes. Elevated PM2.5 concentrations are associated with decreased life expectancy and increased mortality rates due to respiratory and cardiovascular diseases (Suhrcke et al., 2011). Poor air quality can also impact TB case detection rates by affecting respiratory health and immune responses, potentially leading to higher incidence and severity of TB infections (Davies et al., 2011; Suhrcke et al., 2011; WHO, 2018). Evidence from these underscores the detrimental health impacts of PM2.5 exposure, highlighting the importance of air quality management and pollution control measures in improving public health outcomes.

***Gross Domestic Product***

Gross domestic product can influence health outcomes through various pathways. Countries with higher GDP typically allocate more resources to healthcare infrastructure, services, and social determinants of health, contributing to improved life expectancy and reduced mortality rates (Deng et al., 2020; Schenkman, & Bousquat, 2021; Zhou et al., 2020). Increased GDP often correlates with better healthcare access, disease prevention programs, and medical advancements, which can enhance TB case detection rates and treatment outcomes (Chakaya et al., 2021). However, disparities in healthcare access and socioeconomic inequalities within countries may affect these relationships, emphasizing the need for equitable health policies alongside economic growth.

Gross Domestic Product (GDP) influences the rate of renewable energy transition by shaping financial investments, technological advancements, and infrastructure development. Countries with higher GDP often have greater financial resources to invest in renewable energy research, development, and deployment. They can afford to implement supportive policies, such as subsidies and tax incentives, which encourage renewable energy adoption. Moreover, higher GDP correlates with technological innovation and infrastructure readiness, facilitating the integration of renewable energy sources into existing energy systems. Hao and Shao (2021) and Seriño (2022) show that countries with higher GDP per capita tend to invest more in renewable energy technologies and achieve higher renewable energy shares in their energy portfolios.

Gross Domestic Product (GDP) significantly influences climate vulnerability, sensitivity, adaptive capacity, and exposure. Higher GDP typically correlates with greater resources for infrastructure development and technological advancements, reducing vulnerability and enhancing adaptive capacity. Wealthier nations can invest in climate-resilient infrastructure and effective disaster response systems, mitigating sensitivity to climate risks. Conversely, lower GDP often means limited financial resources for climate adaptation and risk management, increasing vulnerability and sensitivity. Countries with lower GDP are also more exposed due to inadequate infrastructure and reliance on climate-sensitive sectors. Empirical evidence shows that higher GDP per capita reduces climate vulnerability in African countries (Carleton et al., 2020) and that wealthier countries tend to have better adaptive capacities (Andrijevic et al., 2020; Maja, & Ayano, 2021).

***Population density***

Population density can influence health outcomes due to its impact on healthcare access, disease transmission dynamics, and environmental conditions. High population density areas may experience higher mortality rates and reduced life expectancy due to increased exposure to infectious diseases and environmental hazards (Kan et al., 2024; Ruktanonchai et al., 2021). TB case detection rates can be affected by population density through crowded living conditions and healthcare resource strain, influencing timely diagnosis and treatment outcomes. Assenting to this, Connolly et al. (2021) highlighted the interactions between population density, health infrastructure capacity, and disease burden, underscoring the importance of urban planning and public health strategies in densely populated regions.

***Access to clean fuel and technology***

Access to clean fuel and technology directly impacts health outcomes by reducing exposure to indoor and outdoor air pollution. Clean cooking fuels and technologies can lower respiratory illnesses and cardiovascular diseases linked to household air pollution, thereby potentially increasing life expectancy and reducing mortality rates (Onyeneke et al., 2023). Improved air quality resulting from cleaner technologies also supports better respiratory health and immune function, influencing TB case detection rates by reducing respiratory infections and complications (Kumar et al., 2023; Robertson et al., 2024; Tan et al., 2023).

Access to clean fuel and technology is critical for accelerating the rate of renewable energy transition. Countries with widespread access to affordable and efficient clean energy technologies can more readily replace fossil fuels with renewable alternatives. Clean energy technologies, such as solar photovoltaics and wind turbines, contribute to reducing greenhouse gas emissions and enhancing energy security. Moreover, access to clean fuel and technology supports sustainable development goals and environmental objectives, fostering public and private investments in renewable energy infrastructure. Adelekan et al. (2024), Naeem et al. (2023) and Ullah and Akhtar (2023) highlighted that regions with greater access to clean energy technologies exhibit higher shares of renewable energy in their energy mix, underscoring the role of technology access in driving the transition.

Access to clean fuel and technology reduces climate vulnerability by lowering greenhouse gas emissions and mitigating environmental degradation. This access enhances adaptive capacity by providing more efficient energy use and reducing dependence on fossil fuels, which are subject to market and supply fluctuations. Improved technology and clean fuels can decrease sensitivity by promoting sustainable practices and reducing health risks from pollution. Studies supported the fact that access to clean energy improves resilience to climate impacts (Chen et al., 2021; Osman et al., 2023) and that clean technology adoption is crucial for reducing vulnerability in developing regions (Griffiths et al., 2023). A limitation of using access to clean fuel and technology as a proxy for energy prices is that it does not directly reflect actual price levels or fluctuations but rather the availability and adoption of clean energy sources, which can be influenced by government policies, infrastructure, and socioeconomic factors. As a result, this measure may not fully capture the actual cost burden of energy access across different regions.

***Health expenditure***

Health expenditure plays a crucial role in determining health outcomes by facilitating access to quality healthcare services, disease prevention measures, and treatment interventions. Higher health expenditure per capita is associated with improved life expectancy and lower mortality rates, reflecting enhanced healthcare access and service delivery (Behera, & Dash, 2020; Behera, & Mishra, 2020; Kiross et al., 2020). Adequate health expenditure also supports TB case detection and treatment efforts through enhanced diagnostic capabilities, medication availability, and patient care infrastructure (Wesseling et al., 2017).

***Climate readiness***

Climate readiness, encompassing economic readiness, governance, and social factors, plays a pivotal role in influencing the rate of renewable energy transition. Economically prepared countries, with stable financial frameworks and investment incentives for renewables, tend to adopt these technologies more rapidly. Effective governance structures, including supportive policies, regulatory frameworks, and institutional capacities, facilitate the deployment and scaling of renewable energy projects. Social readiness, reflected in public awareness, acceptance, and participation in sustainable energy initiatives, also accelerates the transition. Empirical studies highlight that countries with strong governance frameworks and proactive climate policies have achieved higher shares of renewable energy in their energy mix, underscoring the importance of readiness factors in driving the transition (Bakhsh et al., 2024; Bersalli et al., 2020; Huihui et al., 2024).

***Population growth***

Population growth influences the rate of renewable energy transition by impacting energy demand patterns and infrastructure requirements. Rapidly growing populations increase energy consumption, driving the need for sustainable energy solutions to meet demand while reducing environmental impacts. Moreover, demographic shifts can influence policy priorities towards energy security and environmental sustainability, accelerating the adoption of renewable energy sources. However, rapid population growth can also strain resources and infrastructure, challenging the implementation of large-scale renewable energy projects. Empirical studies suggest that countries experiencing demographic changes, such as urbanization and population growth, are increasingly investing in renewable energy as part of their energy diversification strategies (Gu et al., 2021; Udemba et al., 2024).

Population growth intensifies climate vulnerability by increasing demands on resources and infrastructure, escalating exposure to climate-related risks like food insecurity and water scarcity. Rapid population growth strains adaptive capacities by diverting resources away from climate resilience efforts towards immediate societal needs. Regions experiencing high population growth rates often face heightened sensitivity to climate impacts due to inadequate infrastructure and resource management. Empirical evidence demonstrates that rapid population growth exacerbates climate vulnerabilities, particularly in developing countries where per capita investment in climate adaptation may be insufficient (Adom, & Amoani, 2021; Jain, & Bardhan, 2023; Kala et al., 2023).

***Foreign direct investment***

Foreign Direct Investment (FDI) plays a crucial role in the rate of renewable energy transition by providing capital, technology transfer, and market access for renewable energy projects. FDI inflows into renewable energy sectors can enhance technological capabilities, increase production efficiency, and drive down costs, making renewables more competitive. Moreover, FDI promotes policy convergence and regulatory harmonization conducive to renewable energy deployment. However, the impact of FDI on renewable energy transition varies depending on sectoral preferences and regulatory frameworks in recipient countries. Countries attracting substantial FDI in renewable energy industries experience accelerated adoption rates and expansion of renewable energy capacities (Dossou et al., 2023; Mahbub et al., 2022; Vakulchuk et al., 2023).

Foreign Direct Investment (FDI) can influence climate vulnerability by enhancing economic resources and technological knowledge, thereby bolstering adaptive capacity. FDI often brings modern technology and practices that can improve resilience to climate impacts, such as advanced agricultural techniques or infrastructure development. However, FDI in extractive or polluting industries can increase sensitivity and exposure to climate risks by degrading the environment or amplifying carbon emissions. Foreign direct investment according to Fagbemi et al. (2024), Fagbemi and Oke (2024), Shear et al. 2023; and Vakulchuk et al. (2023) contributes to better climate adaptation in host countries through technology transfer and it can both positively and negatively impact climate vulnerability depending on the sector.

***Trade flow***

Trade flow influences the rate of renewable energy transition through technology transfer, market integration, and policy diffusion. Open trade policies facilitate the exchange of renewable energy technologies, enabling countries to access innovations and expertise from global markets. Trade agreements that prioritize environmental sustainability and renewable energy cooperation can accelerate the deployment of renewable energy projects. However, trade flows in fossil fuels and carbon-intensive products can create dependencies and hinder the transition to renewables. Aisbett et al. (2023), and Hassan et al. (2024) explained that countries engaged in diversified and sustainable trade practices tend to adopt renewable energy technologies more rapidly, benefiting from global supply chains and collaborative research initiatives.

Trade flow influences climate vulnerability by shaping economic activities and resource management practices globally (Barnett, 2020; Friel et al., 2020; Kasperson et al., 2022). Open trade can facilitate the exchange of climate-resilient technologies and adaptation strategies, thereby enhancing adaptive capacities across regions. However, trade patterns that prioritize resource extraction or carbon-intensive industries can exacerbate sensitivity to climate vulnerabilities like deforestation and biodiversity loss. Countries integrated into global trade networks often exhibit varying levels of exposure to climate risks depending on their economic specialization and environmental policies. Empirical evidence suggests that diversified trade portfolios can contribute positively to climate resilience by supporting sustainable development goals and reducing environmental impacts (Friel et al., 2020).

***Investment***

Investment decisions significantly influence climate vulnerability and adaptive capacities. Investments in green technologies, sustainable infrastructure, and climate-resilient industries can enhance adaptive capacities by promoting low-carbon development and resilience-building measures. Conversely, investments in carbon-intensive sectors or environmentally harmful practices may increase sensitivity to climate vulnerabilities, such as deforestation and pollution. The type and direction of investment flows can shape a country's exposure to climate risks and its ability to implement effective adaptation strategies. Evidence by Rodriguez (2021) shows that targeted investments in renewable energy and sustainable development contribute positively to climate resilience, whereas investments in fossil fuels and extractive industries can undermine adaptive capacities.

***Distance***

The distance between countries plays a crucial role in influencing climate vulnerability and adaptive capacities. Proximity or distance affects the spread and intensity of climate-related events like hurricanes, droughts, and sea-level rise. Countries closer to each other may share similar climate risks and vulnerabilities, leading to coordinated adaptation efforts and resource sharing. Conversely, countries separated by large distances may face different climate challenges, impacting their adaptive capacities differently. Empirical evidence suggests that geographic proximity enhances regional cooperation in climate adaptation and disaster response, improving resilience across neighbouring countries. Huber et al. (2023) indicate that countries geographically isolated or distant from international trade routes may experience reduced access to climate adaptation technologies and resources. This isolation can exacerbate sensitivity to climate vulnerabilities such as extreme weather events and sea-level rise, limiting adaptive capacity and increasing exposure to climate risks over time. A study by Coulibaly (2021), West et al. (2021) and Yang et al. (2024) highlights that neighbouring countries often exhibit shared climate vulnerabilities and risks due to geographic proximity. This proximity facilitates regional cooperation in climate adaptation strategies, disaster preparedness, and resource sharing, thereby enhancing adaptive capacities collectively.

***Migration***

Migration significantly impacts climate vulnerability dynamics by altering population distribution, resource use, and infrastructure demands. Climate-induced migration, whether internal or international, can increase sensitivity to climate vulnerabilities in both origin and destination areas. Displaced populations often face challenges accessing adequate resources and infrastructure, exacerbating their exposure to climate risks such as extreme weather events and water scarcity. Moreover, migration can strain adaptive capacities by placing additional demands on host communities and local governments, potentially leading to social tensions and resource conflicts. Studies on climate-related migration patterns concluded that climate can reshape demographic landscapes and influence regional resilience strategies, highlighting the complex interplay between migration dynamics and climate vulnerability (Marandi, & Main, 2021; Pan, 2020).

**Table 1: Variables, Measurement, and their Source**

| Variables | Definition/Measurement | Source | Signs |
|---|---|---|---|
| Life Expectancy | Life expectancy at birth, total (years). | WDI | NA |
| Mortality | Mortality rate | WDI | NA |
| Tuberculosis | Tuberculosis case detection rate | WDI | NA |
| $CO_2$ | Carbon dioxide emission (MMtonnes CO2) | WDI | - |
| Air quality | PM2.5 exposure using the number of age-standardized disability-adjusted life-years lost per 100,000 persons (DALY rate) due to exposure to fine air particulate matter smaller than 2.5 micrometres | NASA SEDAC | + |
| Transition | Renewable energy consumption (% of total final energy consumption). | WDI, EIA | + |

| | | | |
|---|---|---|---|
| GDP | GDP (current US$) | WDI | + |
| Population density | Population density (people per sq. km of land area) | WDI | +/- |
| Access to energy | Access to clean fuels and technologies for cooking, urban (% of urban population) | WDI | + |
| Health expenditure | Current health expenditure (% of GDP) | WDI | + |
| Transition | Renewable energy consumption (% of total final energy consumption). | WDI, IEA | |
| Vulnerability | Degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Exposure, Sensitivity and Adaptive capacity 0-100. | ND-GAIN | - |
| Sensitivity | Degree to which people and the sectors they depend upon are affected by climate related perturbations. | ND-GAIN | - |
| Capacity | Ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events. | ND-GAIN | + |
| Exposure | Extent to which human society and its supporting sectors are stressed by the future changing climate conditions. | ND-GAIN | - |
| Readiness | Country's ability to leverage investments to adaptation actions. | ND-GAIN | + |
| Economic | Investment climate that facilitates mobilizing capitals from private sector. | ND-GAIN | + |
| Governance | Stability of the society and institutional arrangements that contribute to investment risks. | ND-GAIN | + |
| Social | Social conditions that help society to make efficient and equitable use of investment and yield more benefit from the investment | ND-GAIN | + |
| GDP | GDP (current US$) | WDI | + |
| Population growth | Population growth rate | WDI | +/- |
| FDI | Foreign direct investment, net (BoP, current US$) | WDI | + |
| Access to energy | Access to clean fuels and technologies for cooking, urban (% of urban population) | WDI | |
| Trade | Trade flow (in thousands current US$) | WDI | |
| Vulnerability | The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Exposure, Sensitivity and Adaptive capacity 0-100. | ND-GAIN | NA |

| | | | |
|---|---|---|---|
| Sensitivity | Degree to which people and the sectors they depend upon are affected by climate related perturbations. | ND-GAIN | NA |
| Capacity | Ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events. | ND-GAIN | NA |
| Exposure | Extent to which human society and its supporting sectors are stressed by the future changing climate conditions. | ND-GAIN | NA |
| CO2_emi | carbon dioxide emission (MMtonnes CO2) | EIA | + |
| Renewable | Renewable energy consumption (% of total final energy consumption). | WDI, IEA | - |
| Distance | Average distance between the most populated city of each country, in km, bilateral. | CEPII's GeoDist | + |
| GDP | GDP (current US$) | WDI | - |
| Population density | Population density (people per sq. km of land area) | WDI | +/- |
| FDI | Foreign direct investment, net (BoP, current US$) | WDI | - |
| Investment | Gross fixed capital formation (current US$) | WDI | - |
| Trade flow | Trade flow (in thousands current US$) | CEPII's BACI | +/- |
| Migration | Net migration is the net total of migrants during the period, that is, the number of immigrants minus the number of emigrants, including both citizens and non-citizens. | WDI | - |

Source: Author's computation (2024)

**Post Estimation Test**

The study conducted a series of post estimation tests to ensure that the results are robust. Regarding the empirical objective which quantifies the effect of the rate of renewable energy transition on life expectancy, we conducted several model fit indices and tests to evaluate the model's adequacy and robustness. The likelihood Ratio (LR) test was conducted to compare the goodness of fit between a restricted model (null) and a less restricted model (alternative), stability index assesses the stability of parameter estimates over time in panel data (Gulati, & Singh, 2021), Modification Indices (MIs) to check, if possible, improvements to the model can be made to improve the model fit as well as the Wald tests to assess the significance of individual parameters or sets of parameters within the equations. The equation-level goodness of fit was also provided in Tables 5 and 6 to assess the goodness of fit for individual equations within a panel-SEM framework.

The second empirical chapter examines the extent to which climate vulnerability drives the rate of energy transition and the third empirical chapter focuses on the drivers of climate vulnerability. These two chapters conducted similar and several diagnostic tests. First, the two chapters check whether there is a dynamic relationship by assessing the significance of the lagged value of the rate of renewable energy transition on current values. In the context of a system Generalized Method of Moments (GMM) and Sequential Dynamic Linear Panel Data (SDLPD) estimation, the AR (1), AR (2), and Hansen's J-test are important diagnostic tests that help assess the validity and reliability of the model. The AR (1) test checks for first-order autocorrelation in the residuals. In the context of system GMM, we often expect the residuals to exhibit first-order autocorrelation because of the dynamic nature of the model (Borges et al., 2022; Ghannouchi et al., 2023). The AR (2) test checks for second-order autocorrelation in the residuals. The presence of second-order autocorrelation would suggest that the instruments used in the GMM estimation are not valid, as it indicates that the residuals are still correlated beyond the first lag. Meanwhile, Hansen's J-test is used to evaluate the overall validity of the instruments used in the GMM and SDLPD estimation.

Last, to address the moderating role of climate readiness in the effect of climate vulnerability on the rate of renewable energy transition, we conducted a Testparm to check the significance or otherwise of the interaction term. Again, the Testparm is the Wald test for the joint significance of a set of parameters of which the interacted term is tested (Ray et al., 2022; Sweidan, 2023). These diagnostic tests collectively provide the appropriateness of using the P-SEM, Sequential dynamic linear panel data estimation, and system GMM estimations in the respective empirical chapters.

## Chapter Summary

The Chapter presented the methodology of the study. It started by highlighting the research philosophy and the design appropriate for the work. This is shortly followed by the theoretical and empirical models that were estimated as well as their corresponding estimation techniques. A detailed justification of each variable in each model is also presented as well as a summary of definitions and measurement of the variables and their corresponding sources from which data was collected.

# CHAPTER FOUR

# EFFECTS OF ENERGY TRANSITION ON HEALTH OUTCOMES

## Introduction

Energy transition, the shift from fossil fuel-based energy systems to sustainable and low-carbon alternatives, plays a crucial role in shaping health outcomes. It has implications for variables such as life expectancy, mortality rate, and tuberculosis detection rate. The pathways through which energy transition affects health outcomes primarily include the reduction of carbon dioxide emission and improvement in air quality, but this has remained unexplored. By transitioning to cleaner energy sources, such as renewable energy, the emission of carbon dioxide and other greenhouse gases decreases, mitigating climate change and its associated health risks. Additionally, the shift away from fossil fuels reduces air pollution, leading to improved air quality and subsequently reducing the burden of respiratory diseases, cardiovascular problems, and premature mortality. In this regard, this chapter first provided a baseline model for the effect of rate of energy transition on life expectancy using pooled OLS and subsequently used a Panel Structural Equation Model (PSEM) as the main model. The PSEM mediation analysis was estimated to determine the pathways. Last, the chapter presents a sensitivity analysis using mortality rate and tuberculosis detection rate as alternative health outcome indicators.

## Summary statistics

This section presents the summary statistics of the variables used in analysing the effect of energy transition on health outcomes. From Table 2, the average total life expectancy across the 150 countries is 69.27 years, with a standard deviation of 9.02. This suggests that, on average, people can expect to live around 69 years. The range of life expectancy spans from 41.96 years to 84.56 years, indicating significant variations in health and socio-economic conditions across countries.

The average life expectancy for males is slightly lower at 66.77 years, with a standard deviation of 8.70. This implies that, on average, males have a slightly shorter life expectancy compared to the overall average. The range of male life expectancy is from 40.69 years to 83.1 years. The difference between male and female life expectancy can be attributed to a range of factors, including biological and societal factors.

The average life expectancy for females is higher at 71.87 years, with a standard deviation of 9.52. This suggests that, on average, females have a longer life expectancy compared to the overall average. The range of female life expectancy is from 42.49 years to 87.71 years. This difference in life expectancy between males and females could be influenced by factors such as biological advantages, healthcare access, and societal norms.

The average mortality rate across the countries is 387.93, with a standard deviation of 232.44. This indicates the average number of deaths per unit of population and time. A higher mortality rate implies poorer health conditions and healthcare systems, while a lower rate suggests better healthcare and overall well-being. The range of mortality rate is from 64.69 to 1527.72, highlighting significant disparities in mortality risks among the studied countries.

**Table 2: Summary statistics**

| Variable | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|
| Total life expectancy | 69.266 | 9.021 | 41.957 | 84.56 |
| Male's life expectancy | 66.766 | 8.700 | 40.689 | 83.1 |
| Female's life expectancy | 71.87 | 9.52 | 42.49 | 87.71 |
| Mortality rate | 387.93 | 232.44 | 64.69 | 1527.72 |
| Tuberculosis case detection rate | 70.73 | 19.1034 | 0 | 160 |
| Energy Transition | 34.52 | 30.914 | 0 | 98.34 |
| Air quality | 33.17 | 22.374 | 0 | 100 |
| carbon dioxide emission | 173.93 | 850.88 | 0 | 11420.23 |
| Health expenditure | 6.03 | 2.86 | 0.44 | 34.41 |
| Population density | 189.61 | 615.886 | 1.584 | 7965.88 |
| GDP | 3.54E+11 | 1.59E+12 | 3.33E+08 | 2.33E+13 |
| Access to energy | 77.42 | 30.90 | 1.28 | 100 |

Number of countries=150 and Years=22, Observation=3300

Source: Author's computation (2024)

The average tuberculosis case detection rate is 70.73, with a standard deviation of 19.10. This indicates the effectiveness of detecting and diagnosing tuberculosis cases in the studied countries. A higher detection rate suggests a better ability to identify and treat tuberculosis cases, which is crucial for controlling the spread of the disease. The range of case detection rate is from 0 to 160, indicating variations in healthcare infrastructure and practices.

The average energy transition score is 34.52, with a standard deviation of 30.91. This reflects the progress and extent of transitioning to sustainable and low-carbon energy systems in the studied countries. A higher score indicates greater progress in adopting renewable energy sources and reducing reliance on fossil fuels. The range of energy transition scores is from 0 to 98.34, highlighting variations in countries' efforts towards sustainable energy practices.

The average air quality score is 33.17, with a standard deviation of 22.37. This indicates the quality of air in the studied countries. A higher score suggests better air quality, while a lower score indicates higher levels of air pollution. The range of air quality scores is from 0 to 100, reflecting variations in environmental conditions and pollution levels across the countries.

The average carbon dioxide emission is 173.93, with a standard deviation of 850.88. This measures the amount of carbon dioxide emissions in metric tons per capita, reflecting the countries' contribution to greenhouse gas emissions. A higher average emission implies a greater carbon footprint, while a lower average emission suggests a lower environmental impact. The range of carbon dioxide emission is from 0 to 11420.23, indicating variations in countries' carbon emissions and their environmental sustainability practices.

The average health expenditure is 6.03, with a standard deviation of 2.86. This represents the average health expenditure per capita in the studied countries. A higher average expenditure implies greater financial resources allocated to healthcare, which can contribute to better healthcare access and outcomes. The range of health expenditure is from 0.44 to 34.41, reflecting variations in countries' healthcare spending capacities and priorities.

The average population density is 189.61, with a standard deviation of 615.89. This indicates the number of individuals per unit of land area in the studied countries. A higher average density suggests higher population concentration and potential challenges in resource allocation and urban planning. The range of population density is from 1.58 to 7965.88, highlighting significant variations in population distribution and urbanization levels.

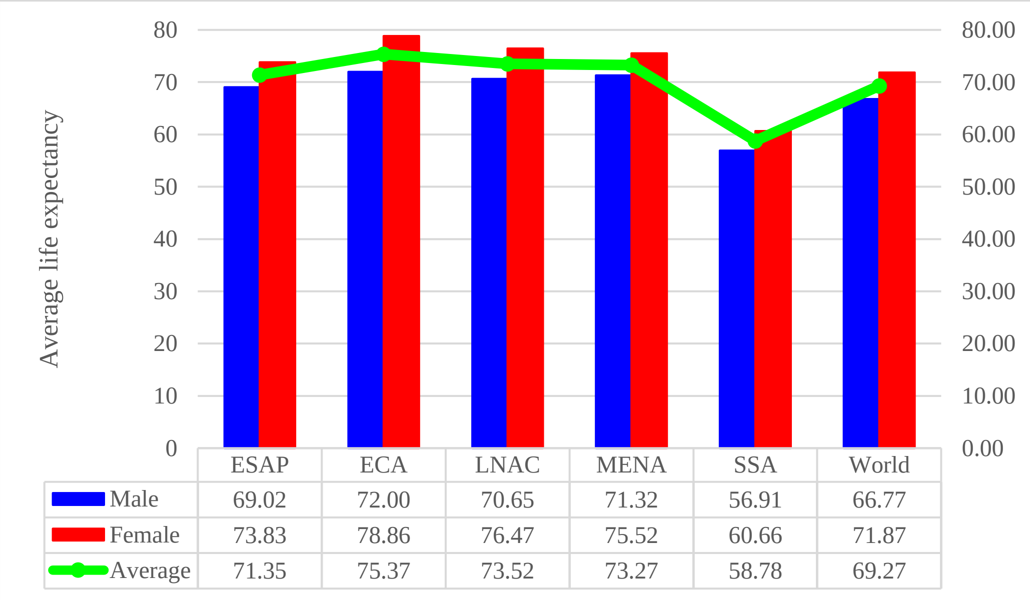
The average Gross Domestic Product (GDP) is US$354 billion, with a standard deviation of US$1.6 trillion. This represents the economic output of the studied countries. A higher average GDP implies greater economic productivity and potential for economic development. The range of GDP is from US$333 million to US$23.3 trillion, indicating significant variations in countries' economic performance and levels of development.

The average, access to energy is 77.42% of the 150 countries' population, with a standard deviation of 30.90. This measures the level of access to modern and reliable energy sources in the studied countries. A higher score indicates better access to energy, which is crucial for various aspects of socio-economic development, including healthcare, education, and industry. The range of access to energy scores is from 1.28 to 100, suggesting variations in energy infrastructure and availability across the countries.

These summary statistics provide insights into various aspects of health, energy, environment, and economy in the studied countries. Understanding these variables and their implications can help identify areas of improvement, assess disparities, and inform policy decisions to promote better health outcomes, sustainable energy practices, environmental quality, and economic development.

**Average life expectancy by continents**

Figure 2 present a descriptive of life expectancy by continent. This is done to highlight significant variations in life expectancy between different continents. It can be observed that females have an average life expectancy higher than males. The average life expectancy for all continents is 69.27 years where males are said to record an average of 66.76 years and that of females is 71.87 years. As depicted, Sub-Saharan Africa has the lowest (58.78 years) life expectancy with males being 56.91 years and females 60.66 years among the continent tend.




| | ESAP | ECA | LNAC | MENA | SSA | World |
|---|---|---|---|---|---|---|
| Male | 69.02 | 72.00 | 70.65 | 71.32 | 56.91 | 66.77 |
| Female | 73.83 | 78.86 | 76.47 | 75.52 | 60.66 | 71.87 |
| Average | 71.35 | 75.37 | 73.52 | 73.27 | 58.78 | 69.27 |

Figure 2: Average life expectancy by continents
Source: Author's computation (2024)

On the other side, Europe and Central Asia have the highest average life expectancy of 75.37 years where males have 72.00 years and females 78.86 years. Contrasting life expectancies across continents underscores the need to bridge global health inequities and promote discussions on international collaboration, aid, and policies aimed at reducing disparities and improving health outcomes worldwide. As variations exist among country's life expectancy, the implication from the result suggests that these variations can be as results of environmental factors, lifestyle choices, cultural practices, and socio-economic conditions on life expectancy, guiding efforts to address these determinants through targeted interventions and policies.

**Effect of energy transition on health outcome (baseline results)**

The preliminary estimates for the association between renewable energy transition and health outcomes are shown in Table 3. Results for the full model as well as male life expectancy, and female life expectancy models are reported in Model1 to Model3, respectively. In terms of the continental variants of the analysis, Model4 takes care of the effect of energy transition and other covariates on life expectancy in East and South Asia and Pacific (ESAP), Model5 for Europe and Central Asia (ECA) Model6 for Latin and Noth America and the Caribbean (LNAC) Model7 for MENA and Model-8 for SSA.

In Model1, the coefficient for transition is positive and statistically significant (0.212, $p < 0.01$), indicating that countries undergoing significant transitions experience higher life expectancy. Thus, for every one percentage increase in the proportion of renewable energy consumption (transition), there is a 0.212-year increase in the average life expectancy. However, in Model 2, which focuses on male life expectancy, the coefficient becomes smaller and statistically insignificant (0.0642). In contrast, in Model 3, which focuses on female life expectancy, the coefficient becomes larger and remains statistically significant (0.340, $p < 0.01$). This suggests that the effect of transition on life expectancy differs between genders, with females having a longevity than males. In many societies, men are more likely to work in high-risk occupations such as construction, mining, and manufacturing, which expose them to hazardous conditions and health risks. Even with the shift towards renewable energy, certain male-dominated industries may still pose occupational hazards that negatively impact male health and life expectancy.

Consistently, this significant gender difference in the benefit associated with the renewable energy transition is understood and evident in the work of Koomson (2024) who found that an increase in energy poverty worsens mental distress. This reemphasizes the fact that as the populace has access to renewable energy, health outcome improves. An intriguing observation is however made when significant different exist among continents. Thus, the effect of transition has varied impact on life expectancy among continents (Model-4 to Model-8). While the effect of transition on life expectancy tends to be positive and significant for East, South Asia and Pacific (ESAP), Latin, Noth America and Caribbean (LNAC, Model-6) and Sub-Saharan Africa (SSA, Model-8), the effect in Europe and Central Asia (ECA, Model-5) and Middle East and North Africa (MENA, Model-7) were contrary. Thus, a positive effect of 0.361, 0.315 and 0.885 and a negative effect of 0.592 and 2.093 of life expectancy for every percentage increase in transition was observed, respectively.

In regions like Europe and Central Asia (ECA) and the Middle East and North Africa (MENA), the effect of transition on life expectancy is negative. This unexpected finding could be due to several factors such as conflicts, political instability, or environmental degradation that may counteract the potential positive impacts of societal or economic transitions on health outcomes. Additionally, in regions with already high levels of development, the marginal benefits of further transitions may be lower or could even lead to unintended consequences that negatively affect health outcomes. Europe and Central Asia countries have implemented comprehensive renewable energy policies and incentives to encourage the adoption of clean energy technologies.

This includes feed-in tariffs, subsidies, and regulatory frameworks that promote renewable energy investments. In contrast, MENA countries have been slower to adopt renewable energy policies, partly due to their reliance on fossil fuel exports. However, recent initiatives in some MENA countries, driven by concerns over energy security and climate change, have led to increased interest in renewable energy development of which its gain has not yet been realised.

The coefficient for air quality is positive and statistically significant in all three models (ranging from 0.050 to 0.071, all $p < 0.01$). This aligns with existing literature emphasizing the detrimental effects of air pollution on health. Consistently, improved air quality is associated with higher life expectancy, as well as for both males and females and across continents except SSA. The reduction in life expectancy in SSA suggests that measures to improve air quality result in a significant indirect impact on life expectancy since the cost associated with improving air quality comes at the expense of improving access to healthcare, and hence, worsening living conditions.

Lastly, as can be seen in Table 3, carbon dioxide ($CO_2$) emissions have significant negative effects whereas increased health expenditure, population density, current income level of countries and access to clean fuels and technologies for cooking tend to improve life expectancy. The effect across the continent also remains consistent and there exists marginal variation. In a global world, one expects that variations in transition among different countries, sex and continents produces unique environmental and public health benefits, hence warranting the use of the baseline (Koomson, 2024; Churchill, & Smyth, 2021).

**Table 3: Baseline results of the effect of energy transition on life expectancy**

| **Life expectancy** | **Model-1** | **Model-2** | **Model-3** | **Model-4** | **Model-5** | **Model-6** | **Model-7** | **Model-8** |
|---|---|---|---|---|---|---|---|---|
| Transition | 0.212** | 0.0642 | 0.340*** | 0.361** | -0.592*** | 0.315*** | -2.093*** | 0.885*** |
| | (0.097) | (0.099) | (0.100) | (0.160) | (0.159) | (0.120) | (0.188) | (0.261) |
| Air quality | 0.060*** | 0.071*** | 0.050*** | 0.091*** | 0.072*** | 0.031*** | 0.088*** | -0.050*** |
| | (0.004) | (0.004) | (0.004) | (0.007) | (0.005) | (0.007) | (0.007) | (0.010) |
| $\ln CO_2$ | -0.242*** | -0.165*** | -0.312*** | -0.581*** | 0.273*** | -0.148** | 0.267*** | -0.167 |
| | (0.046) | (0.047) | (0.048) | (0.082) | (0.082) | (0.070) | (0.086) | (0.105) |
| lnhealth expenditure | 2.004*** | 1.880*** | 2.024*** | 2.254*** | 6.139*** | 3.901*** | 1.685*** | -1.982*** |
| | (0.194) | (0.198) | (0.200) | (0.388) | (0.389) | (0.404) | (0.272) | (0.405) |
| lnpopulation density | 0.835*** | 0.900*** | 0.757*** | 0.631*** | 0.691*** | 0.237** | 1.284*** | 1.039*** |
| | (0.056) | (0.057) | (0.057) | (0.091) | (0.104) | (0.0980) | (0.103) | (0.138) |
| lnincome | 0.561*** | 0.569*** | 0.556*** | 0.962*** | 0.409*** | 0.012 | 0.897*** | -1.022*** |
| | (0.046) | (0.047) | (0.048) | (0.080) | (0.080) | (0.063) | (0.132) | (0.137) |
| lnaccess to energy | 5.376*** | 5.023*** | 5.766*** | 7.898*** | 17.72*** | 13.70*** | 16.14*** | 3.591*** |
| | (0.157) | (0.160) | (0.162) | (0.467) | (6.259) | (0.603) | (1.179) | (0.226) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | 24.70*** | 23.14*** | 26.40*** | 3.165 | -35.26 | -0.355 | -30.98*** | 72.37*** |
| | (1.318) | (1.342) | (1.357) | (2.400) | (28.75) | (2.980) | (3.983) | (3.541) |
| *N* | 3300 | 3300 | 3300 | 506 | 770 | 660 | 396 | 968 |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01, Model-1 is average life expectancy, 2 is female average life expectancy, 3 is males average life expectancy

Source: Author's computation (2024)

Addressing the research gap of the potential pathways of the effect of transition on life expectancy demands the use of the Structural Equation Model (SEM). Also, in OLS, the assumption that all variables are without measurement error is not realistic in many cases does not inherently provide information about causality and cannot address simultaneous relationships. SEM on the other hand allows for the simultaneous estimation of multiple dependent and independent variables, handles multicollinearity issues, allows researchers to modify and refine the model based on theoretical considerations and statistical criteria, adds or removes paths between variables, includes additional variables, or specify alternative models to improve the fit. This notwithstanding, the preliminary results can be biased by the endogeneity problem associated with renewable energy transition which can be resolved using the SEM (Abbas et al., 2021; Koomson, 2024).

**Partial and semi-partial correlates of health outcome**

This section accesses and measures the strength of a relationship between life expectancy energy transition and other variables while controlling for the effect of mediators (air quality and income). To do this, the partial and semi-partial correlates of health outcomes were estimated and the results presented in Table 4. The partial correlation (Partial corr.) measures the strength and direction of the linear relationship between life expectancy and each independent variable while controlling for the influence of all other variables in the model. The semi-partial correlation (Semi-partial corr.) however, isolates the unique contribution of each independent variable to the variance in life expectancy, while holding constant the other variables in the model.

**Table 4: Partial and semi-partial correlations of Life expectancy**

| Variable | Partial corr. | Semi-partial corr. | Partial corr.^2 | Semi-partial corr.^2 | Significance value |
|---|---|---|---|---|---|
| Transition | 0.038 | 0.018 | 0.002 | 0.000 | ** |
| Air quality | 0.274 | 0.135 | 0.075 | 0.018 | *** |
| $CO_2$ emission | -0.091 | -0.043 | 0.008 | 0.002 | *** |
| health expenditure | 0.177 | 0.085 | 0.032 | 0.007 | *** |
| Population density | 0.254 | 0.124 | 0.065 | 0.015 | *** |
| lnincome | 0.207 | 0.100 | 0.043 | 0.010 | *** |
| Access to energy | 0.513 | 0.283 | 0.264 | 0.080 | *** |

* p<.10, ** p<.05, *** p<.01

Source: Author's computation (2024)

The partial correlation squared (Partial corr.^2) and semi-partial correlation squared (Semi-partial corr.^2) represent the proportion of variance in life expectancy explained by each independent variable, either considering all other variables (partial) or holding other variables constant (semi-partial).

The partial correlation coefficient of energy transition is 0.038, indicating a weak but positive relationship with life expectancy. However, when considering its squared value (0.2%), it suggests that transition explains only a small proportion of the variance in life expectancy controlling for the influence of all other variables in the model. Despite its small effect, it is significance and hence, indicates that the energy transition has an important implication for life expectancy. Again, its magnitude points to the fact that transition may not have that high significant effect on life expectancy for which the indirect effect is accessed in Table 7.

Air quality has a partial correlation coefficient of 0.274, demonstrating a moderate to strong positive relationship with life expectancy. With respect to the magnitude of the variation, air quality produces a 7.5 percent variation in life expectancy considering the other variables in the model. Also, it implies that air quality explains a substantial proportion of the variance in life expectancy, and this is significant at 5% alpha level. The partial correlation effect of carbon dioxide ($CO_2$) emission is also assessed. Although the partial correlation coefficient is negative, they are marginally small (-0.091). Similar to carbon emission, the partial correlation of energy transition, air quality, health expenditure, population density and income is low, hence, no multicollinearity.

Similarly to transition, and air quality, the partial correlation of health expenditure, population density, income, and access to clean energy with life expectancy are 0.177, 0.254, 0.207 and 0.513. In terms of the square of the correlation coefficient, they explained 3.2%, 6.5%, 4.3% and 26.4% proportion of the variance in life expectancy, respectively. Notably, access to energy stands out with a high partial correlation coefficient and variance, indicating a significant impact on life expectancy.

In summary, while some variables like population density and access to energy have strong positive correlations with life expectancy and explain a sizeable proportion of its variance, others such as transition and carbon dioxide emission have smaller effects. However, all variables except for $CO_2$ emission, show a statistically significant negative relationship with life expectancy, implying their importance despite differences in effect sizes all other variables have a positive relationship.

**Postestimation results**

The post estimation results presented in this section provide information on the overall goodness of fit, stability, and Wald tests for equations in your structural equation model (SEM). The goodness of fit test displays various fit indices, including the comparative fit index (CFI), the root Mean Square Error of Approximation (RMSEA), and the standardized root mean square residual (SRMR), among others.

The significant of the likelihood ratio chi-square tests (chi2_ms and chi2_bs) can be inferred from Table 5. This indicates that the proposed model fits significantly better than the saturated and baseline models, respectively. The RMSEA value of 0.028, along with the 90% confidence interval, suggests a good fit of the model to the data. The high values of CFI (0.998) and TLI (0.969) further support the adequacy of the model fit. The overall goodness of fit results indicate that the SEM accurately represents the relationships between the variables in the context of energy transition, carbon dioxide emission, air quality, and life expectancy. Therefore, the accuracy of the models' predictions and interpretations regarding the effect of the energy transition on life expectancy, mediated by carbon dioxide emission and air quality, is high.

The stability index examines whether the parameter estimates in the model are consistent and reliable across different samples or over time. The stability index, with a value close to zero (1.44e-06), indicates that the models' estimates are consistent and reliable across different samples or over time. This suggests that the relationships between variables, including the mediating pathways of carbon dioxide emission and air quality, are robust and not heavily influenced by minor variations in the data or sampling procedures. Thus, the models' conclusions regarding the effects of energy transition on life expectancy are stable and reliable.

**Table 5: Overall goodness of fit, stability and Wald tests for equations**

| Fit statistic | Value | Acceptance level |
|---|---|---|
| Likelihood ratio: Model vs. saturated (chi2_ms (6)) | 22.035*** | |
| Likelihood ratio: Baseline vs. saturated (chi2_bs (87)) | 7470.747*** | |
| Root mean squared error of approximation (RMSEA) | 0.028 | Less than 0.08 (absolute fit) |
| 90% CI, lower bound | 0.002 | |
| Upper bound | 0.042 | |
| Probability RMSEA <= 0.05(Pclose) | 0.997 | |
| Comparative fit index (CFI) | 0.998 | Above 0.9 (absolute fit) |
| Tucker–Lewis's index (TLI) | 0.969 | Above 0.9 (absolute fit) |
| Standardized root mean squared residual (SRMR) | 0.001 | Less than 0.08 (absolute fit) |
| Coefficient of determination (CD) | 0.887 | Closer to 1 (absolute fit) |
| Stability index | 1.44e-06 | Close to 0 (parameters are stable) |
| Modification indices (score tests) | 3.842 | Below 5 (Model fit) |
| Wald tests for equations (Observed dependent variables) | | |
| Air quality(df=27) | 4286.45 *** | |
| $lnCO_2$(df=27) | 536.27*** | |
| Life expectancy(df=28) | 8499.88*** | |

* p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

The Wald test for equation was also conducted and it examined the overall impact of the exogenous variables on the endogenous variables with the three equations. The significant Wald test values for air quality, $CO_2$ emission, and life expectancy indicate that the exogenous variables have a statistically significant impact on these outcomes. The significant Wald tests provide evidence that energy transition, as represented by the exogenous variables, plays a significant role in influencing carbon dioxide emission, air quality, and life expectancy. Again, test results support the hypothesized pathways, suggesting that reducing carbon dioxide emission by increasing energy transition can positively impact air quality and subsequently improve life expectancy.

**Table 6: Equation-level goodness of fit**

| **Observed dependent** | | **Variance** | | |
|---|---|---|---|---|
| **variables** | **Fitted** | **Predicted** | **Residual** | **R-squared** |
| Air quality | 5.705 | 3.223 | 2.481 | 0.565 |
| $lnCO_2$ | 501.357 | 70.864 | 430.493 | 0.141 |
| Life expectancy | 81.403 | 58.649 | 22.753 | 0.720 |
| Overall | | | | 0.887 |

Source: Author's computation (2024)

The modification indices indicate potential improvements to the model's fit that can be achieved by adding or removing parameters. Identifying significant modification indices helps to identify areas where the model's fit can be improved. A modification index score of 3.842 and less than 5 shows that adding or removing variables from the model does not affect the model significantly. This further implies that adjustments based on these indices cannot further enhance the model's accuracy and provide a better representation of the underlying relationships in the data.

In all, the model exhibits a good fit to the data, indicating that it accurately captures the relationships between the variables. The stability of the estimates ensures consistency and reliability. Additionally, the significant Wald tests validate the hypothesized pathways and provide evidence for the impact of energy transition on carbon dioxide emission, air quality, and life expectancy. These findings enhance the confidence in the SEM results and contribute to a better understanding of the effects of energy transition on public health outcomes.

The overall goodness-of-fit for the equations, represented by the R-squared values in Table 6, is 0.887. This suggests that the model explains approximately 88.7% of the total variance in the dependent variables across all equations. These equation-level goodness-of-fit measures provide insights into the fit and explanatory power of the SEM for each specific equation. The residuals represent the differences between the observed and predicted values, with smaller values indicating a better fit.

**Drivers of carbon dioxide emission and air quality (SEM Model)**

Using the SEM provide the opportunity to find out the drivers of the potential pathways variable, here carbon dioxide ($CO_2$) emission and air quality measured by PM2.5. As can be seen from Table 7, renewable energy transition tends to reduce (1.349) carbon emissions. This was consistent across the different continents where ESAP continents experienced the least (1.203) impact and SSA had the highest impact (1.648). The situation was not much different as an additional percentage increase in the proportion of the population having access to clean fuel reduces carbon emissions by 13.4% on a yearly basis. Consistent with Akinwale et al. (2022) and Mensah et al. (2021), renewable energy consumption and increased access to clean fuels are effective drivers in reducing carbon dioxide ($CO_2$) emissions across different continents.

The findings regarding the presence of the EKC are consistent with Hou et al. (2023), Li et al. (2023) and Yadava et al. (2023). Specifically, our study found that across all continents, when per capita income reaches 52.5%, there is an improvement (a reduction) in environmental pollution, as measured by carbon dioxide emissions. This aligns with the previous findings that renewable energy transition and increased access to clean fuels tend to reduce carbon emissions across different continents, with varying degrees of impact (Akinwale & George, 2023; Mensah, 2023; Owusu et al., 2023). Again, the result highlights the continental variations in the relationship between per capita income and carbon dioxide emission. It is reported that the MENA region needs to spend about 46% of per capita income at the current United States Dollar to achieve a 10.3% reduction in carbon dioxide emission, while the ECA region needs to spend as high as 53.9% of per capita income to reduce carbon dioxide emission by 9.4% (Cao et al., 2020; 2021). This suggests that the level of per capita income required to achieve environmental improvements may differ across regions, reflecting the nuanced and non-linear nature of the EKC theory.

The case of air quality is not too different as the study found that increases in carbon dioxide emission reduce air quality drastically. As can be seen, when carbon dioxide emission increases by a percentage point, there is a 1.196 reduction in air quality. The study found no evidence of the effect of carbon dioxide emission on air quality in ESAP and LNAC. However, the effect is quiet high among other continents. Particularly in the ECA, there is a 1.999 reduction in air quality for a percentage increase in carbon dioxide emission. Similarly, in the MENA region and SSA region, we found air quality by 6.967 and 0.873 respectively for a percentage increase in a MMtonnes of carbon emission. Just like Cao et al. (2020), Gani (2021) and Salahuddin et al. (2020) indicated, increased carbon dioxide emission from various sources such as industrial processes, transportation, and energy production contribute to air pollution, including the formation of particulate matter (PM2.5) and other pollutants, thus deteriorating air quality.

Increasing the rate of transition shows an improvement in air quality. In Model-1 (over all model), there is a 4.024 improvement in air quality when countries increase their renewable energy consumption. Countries undergoing transitions, whether economic, political, or social, tend to experience improvements in air quality. This could be due to the adoption of cleaner technologies, better environmental regulations, and shifts towards more sustainable practices during transition periods.

Population density, access to clean fuel for cooking, and increase per capita income are among other variables that help improve air quality. Higher population density is associated with a positive effect as one expects innovation among individuals in cluster communities to profile environmental solutions of which reducing air quality is part. Apart from SSA, lower air quality is observed as population density increases. This relationship could be driven by factors such as increased vehicular traffic, industrial activities, and energy consumption in densely populated areas, leading to higher emissions of pollutants and poorer air quality.

Unlike densely populated areas in other regions where industrialization and vehicular emissions contribute significantly to air pollution, urbanization in SSA may follow different patterns. In some cases, urbanization in SSA might be associated with the expansion of less polluting economic activities, such as agriculture or service sectors, rather than heavy industries or high-density transportation networks. Land use practices in SSA might involve more green spaces, vegetation, and natural environments compared to heavily industrialized urban areas in other regions. Green spaces can function as sinks for pollutants, absorb emissions, and improve air quality, offsetting the potential negative effects of population density.

Improved access to clean energy is significantly associated with better air quality. At a 5% alpha level, having access to cleaner energy significantly increases air quality by 4.865. This relationship may be explained by the transition to cleaner energy sources such as natural gas, solar, and hydro power, which produce fewer pollutants compared to traditional sources like coal and biomass. The relationship between health expenditure and air quality varies across models. In most cases, higher health expenditure is associated with better air quality, due to investments in healthcare infrastructure, pollution control measures, and public health programs. However, in the case of SSA, higher health expenditure is associated with poorer air quality, suggesting potential inefficiencies or challenges in addressing pollution-related health issues.

Like health expenditure, the relationship between income per capita and air quality varies across models. In some instances, higher per capita income is associated with better air quality, reflecting investments in environmental protection and cleaner technologies as countries become wealthier across all continents except SSA. However, in SSA, higher per capita income is associated with poorer air quality, potentially due to increased industrialization, urbanization, and energy consumption associated with economic growth inefficiencies or challenges in addressing pollution-related health issues.

**Effect of energy transition on life expectancy (SEM Model)**

Based on the SEM results provided in Table 7, we analyse the effect of the renewable energy transition by considering the mediation effects of carbon dioxide emission and air quality. This analysis was estimated for five different continents aside the overall average. Model-1 to Model-6 present the effect of the overall model, ESAP, ECA, LNAC, MENA, and SSA, respectively. The direct effect of carbon dioxide emission on life expectancy is observed to have a significant negative impact at the 5% alpha level. Specifically, we observe a 0.196-year reduction in average life expectancy with a percentage increase in the megatonnes (MMtonnes) of carbon dioxide emission. Except for SSA, the study found the direct impact of a percentage increase in MMtonnes of carbon dioxide emission to reduce average life expectancy by 0.581, 0.273, 0.148, and 0.267 years in ESAP, ECA, LNAC, and MENA, respectively. This suggests that an increase in carbon dioxide levels is associated with a decrease in life expectancy. The magnitude of the effect varies across models. While acknowledging the impact in ESAP to be as high as 0.581, no significant impact was found in SSA. High levels of carbon dioxide are often associated with environmental pollution and can have detrimental effects on public health, leading to lower life expectancy (Li et al., 2021; Wang et al., 2023; Zhao et al., 2022).

In the SEM model provided, carbon dioxide emission is not statistically significant in Model-6, which focuses on the SSA (Sub-Saharan Africa) region. The lack of statistical significance suggests that there is no convincing evidence supporting the relationship between carbon dioxide emission and life expectancy in Sub-Saharan Africa, at least within the context of the model and variables included. While carbon dioxide emission is associated with environmental pollution and potential health impacts, the relationship between carbon dioxide emission and life expectancy can be influenced by various other factors specific to the SSA region. These factors might include socioeconomic conditions, healthcare infrastructure, disease burden, access to clean water and sanitation, and other contextual variables that were not accounted for in the model (Bera et al., 2021; Miring'u et al., 2022).

The impact of air quality is positive, indicating that improvement in air quality is associated with a 0.068-year increase in average life expectancy. The effect size varies across models. In the ESAP continents, the impact is 0.091, whereas, in ECA, LNAC, MENA, and SSA, the impacts are 0.072, 0.031, 0.088, and 0.050, respectively. The effect of per capita income, population density, access to clean energy, and health expenditure leads to an improvement in the average life expectancy of countries, with slight variations across continents. Improved air quality reduces exposure to harmful pollutants and contributes to better health outcomes, resulting in higher life expectancy (Balaj et al., 2024; Fadnes et al., 2022). Higher per capita income contributes to improved healthcare infrastructure, better access to medical services, and overall socio-economic development, which positively influence life expectancy (Rahman, & Alam, 2022).

Population density can affect access to healthcare, sanitation facilities, and disease transmission. Higher population density may lead to increased healthcare resources and better health outcomes, thereby positively impacting life expectancy (Griffiths et al., 2023; Yadava et al., 2023). Improved energy access facilitates access to modern healthcare facilities, electricity, and clean cooking fuels, which can significantly improve health outcomes and life expectancy (Pondie et al., 2024). Higher health expenditure reflects increased investment in healthcare systems, medical research, and healthcare services, leading to improved health outcomes and higher life expectancy (Karimi Alavijeh et al., 2023; Majeed et al., 2021).

Transition, being the shift from non-renewable energy (like coal) to clean energy (like solar), tends to be associated with health benefits. As observed, a percentage increase in the proportion of renewable energy consumption to total energy consumption increases average life expectancy directly by 0.213 years. A similar result is observed across continents: ESAP recorded an effect of 0.361, ECA 0.592, LNAC 0.315, MENA 2.093, and SSA 0.885. The magnitude of the effect differs across models, with the MENA continent recording the highest impact, followed by SSA, ECA, ESAP, and LNAC.

**Table 7: Effect of energy transition on life expectancy (SEM Model)**

| Variables | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 |
|---|---|---|---|---|---|---|
| $lnCO_2$ | | | | | | |
| Transition | -1.349*** | -1.203*** | -1.236*** | -1.145*** | -1.371*** | -1.648*** |
| | (0.027) | (0.073) | (0.055) | (0.037) | (0.096) | (0.062) |
| lnGDP | 4.145*** | 0.740 | 5.067*** | 6.018*** | 4.739*** | 5.813*** |
| | (0.239) | (0.734) | (0.665) | (0.293) | (1.439) | (0.844) |
| lnGDP square | -0.079*** | -0.010 | -0.094*** | -0.117*** | -0.103*** | -0.119*** |
| | (0.005) | (0.015) | (0.013) | (0.006) | (0.029) | (0.018) |
| lnpop_density | 0.032 | 0.005 | -0.169*** | -0.033 | 0.138** | 0.008 |
| | (0.020) | (0.051) | (0.042) | (0.043) | (0.069) | (0.043) |
| lnenergy access | -0.134*** | -0.441* | -3.821*** | -1.032*** | 4.725*** | -0.091 |
| | (0.043) | (0.254) | (0.524) | (0.254) | (0.753) | (0.064) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -52.058*** | -9.418 | -1.845 | -70.371*** | 33.004** | -69.182*** |
| | (2.927) | (9.232) | (14.757) | (3.904) | (16.746) | (9.852) |
| Air quality | | | | | | |
| $lnCO_2$ | -1.196*** | -0.092 | -1.999*** | -0.523 | -6.967*** | -0.873*** |
| | (0.220) | (0.524) | (0.606) | (0.374) | (0.544) | (0.329) |
| Transition | 4.024*** | 2.360** | 2.714** | 1.291** | 3.082** | 2.080** |
| | (0.458) | (1.022) | (1.182) | (0.644) | (1.003) | (0.828) |
| lnpop_density | 0.114 | -0.057 | -4.762*** | -2.208*** | -4.258*** | 4.140*** |
| | (0.263) | (0.579) | (0.757) | (0.521) | (0.741) | (0.420) |
| lnenergy access | 4.865*** | 2.071** | 7.946*** | 3.408*** | 7.203*** | 8.739*** |
| | (0.557) | (0.876) | (1.082) | (0.205) | (0.168) | (0.664) |
| Lnhealth expenditure | 4.611*** | 4.481*** | 5.210*** | 6.522*** | -7.317*** | 1.270 |
| | (0.822) | (1.034) | (1.596) | (2.166) | (2.044) | (1.287) |
| lnGDP | 1.133*** | -1.092** | 2.435*** | 1.712*** | -4.784*** | -0.908** |
| | (0.214) | (0.498) | (0.590) | (0.334) | (0.941) | (0.420) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -5.903 | -37.365** | -1.9e+03*** | 54.630*** | -124.948*** | 64.037*** |
| | (5.159) | (15.494) | (202.395) | (15.908) | (29.479) | (10.865) |
| Life expectancy | | | | | | |
| $lnCO_2$ | -0.196*** | -0.581*** | -0.273*** | -0.148** | -0.267*** | -0.167 |
| | (0.051) | (0.080) | (0.080) | (0.068) | (0.082) | (0.103) |
| Air quality | 0.068*** | 0.091*** | 0.072*** | 0.031*** | 0.088*** | 0.050*** |
| | (0.004) | (0.007) | (0.005) | (0.007) | (0.006) | (0.010) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Transition | 0.213** | 0.361** | 0.592*** | 0.315*** | 2.093*** | 0.885*** |
| | (0.106) | (0.156) | (0.156) | (0.117) | (0.181) | (0.257) |
| lnGDP | 0.699*** | 0.962*** | 0.409*** | 0.012 | 0.897*** | -1.022*** |
| | (0.050) | (0.078) | (0.079) | (0.062) | (0.127) | (0.135) |
| lnpop_density | 0.914*** | 0.631*** | 0.691*** | 0.237** | 1.284*** | 1.039*** |
| | (0.061) | (0.088) | (0.102) | (0.096) | (0.099) | (0.136) |
| lnenergy access | 8.292*** | 7.898*** | 17.717*** | 13.704*** | 16.142*** | 3.591*** |
| | (0.129) | (0.454) | (6.140) | (0.589) | (1.135) | (0.223) |
| Lnhealth expenditure | 2.932*** | 2.254*** | 6.139*** | 3.901*** | 1.685*** | -1.982*** |
| | (0.198) | (0.376) | (0.382) | (0.395) | (0.262) | (0.399) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | 5.645*** | 3.165 | -35.263 | -0.355 | -30.981*** | 72.372*** |
| | (1.185) | (2.330) | (28.199) | (2.914) | (3.835) | (3.487) |
| var (e.ln$CO_2$) | 2.481*** | 3.629*** | 1.381*** | 1.276*** | 3.023*** | 2.486*** |
| | (0.061) | (0.228) | (0.070) | (0.070) | (0.215) | (0.113) |
| var (e. Air quality) | 430.493*** | 472.764*** | 407.729*** | 188.146*** | 353.221*** | 259.789*** |
| | (10.598) | (29.722) | (20.780) | (10.357) | (25.102) | (11.809) |
| var (e. Life expectancy) | 22.753*** | 10.846*** | 7.095*** | 6.200*** | 5.729*** | 24.801*** |
| | (0.560) | (0.682) | (0.362) | (0.341) | (0.407) | (1.127) |
| *Observation* | 3300 | 506 | 770 | 660 | 396 | 968 |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01

Model-1 is average life expectancy, Model-2 is ESAP average life expectancy, Model-3 is ECA average life expectancy, Model-4 is LNAC average life expectancy, Model-5 is MENA average life expectancy and 6 is SSA average life expectancy.

Source: Author's computation (2024)

The varying effects of the renewable energy transition across different continents highlight the complexities and varying degrees of potential implications for health outcomes. While transitioning to renewable energy sources is generally expected to have higher health impacts, the specific impacts may depend on the pace of transition, accompanying policies, and regional socio-economic which (Li et al., 2021; Suhrcke et al., 2011; Zhang et al., 2020) have all admitted.

The positive associations between GDP, energy access, health expenditure, and life expectancy underscore the importance of socio-economic factors in determining health outcomes. Transitioning to renewable energy sources may have socio-economic implications, such as changes in employment patterns, investment priorities, and resource allocation, which in turn have a direct impact on individual health (Ojewumi, & Akinlo, 2017). Ensuring that the transition process is accompanied by policies that support equitable access to healthcare, education, and economic opportunities is therefore essential for mitigating potential socio-economic disparities and promoting positive health outcomes for all segments of society (Majeed, & Ozturk, 2020; Polcyn et al., 2023).

In conclusion, while the transition to renewable energy sources holds significant potential to improve public health outcomes by reducing carbon dioxide emission and improving air quality helps in mitigating climate change, its health implications are multifaceted and context dependent. Addressing these implications requires a comprehensive approach that considers the interplay between environmental, socio-economic, and policy factors to promote health equity and sustainable development.

**Channel analysis**

Table 8 presents the results of a mediation analysis examining the potential pathways through which renewable energy transition impacts life expectancy. In doing so, the study presents the direct, indirect, and total effects of transitions on life expectancy, mediated by air quality (AQ) and carbon dioxide emission. The idea is that for renewable energy transition to provide health benefits, it can lead to first a reduction in carbon emission and as well as improvement in air quality. Table 8 also presents the analysis for the different continents: East and South Asia and Pacific (ESAP), Europe and Central Asia (ECA), Latin and North America and Caribbean (LNAC), Middle East and North Africa (MENA), and Sub-Saharan Africa (SSA) respectively. Following Baron and Kenny's approach which is adjusted by Iacobucci et al., (2007) and Zhao et al., (2010) for use with structural equation modelling, the Sobel, Monte Carlo, RIT (Ratio of Indirect effect to Total effect), and RID (Ratio of Indirect effect to Direct effect) statistics were provided to assess the significance and magnitude of the indirect effects. Here, the focus is on the indirect effect and its magnitude in relation to the direct effect.

The direct effect represents the effect of the transition on life expectancy without considering air quality (AQ) and carbon dioxide ($CO_2$) emissions as mediators. As such, the direct effect results presented here in Table 8 are the same as those in Table 7, just that they are presented here for comparison. In the main model, both air quality (AQ) and carbon dioxide emission serve as significant mediators in the transitions and life expectancy nexus. We found the direct impact of transition on life expectancy to be 0.213 and the indirect effect is 0.273. This implies that the indirect impact of renewable energy transition on life expectancy is 28.1% (RID) more than the direct impact. A similar result (21.4%) was found for carbon emissions. The indirect effect here is negative (-0.258), suggesting a potentially adverse impact mediated through carbon dioxide emission which Kan et al. (2024), Wang et al. (2023), and Yadava et al. (2023) have explained.

In the main models, the indirect effect of the transition to renewable energy on life expectancy via air quality consistently outweighs the direct effect. This implies that improvements in air quality mediated by the transition to renewable energy contribute to increases in life expectancy. The analysis disaggregated by continents reveals variations in the magnitude. For all the five continents (ESAP, ECA, LNAC, MENA and SSA) used, AQ was observed to improve life expectancy indirectly and consistently whereas increases in carbon emission reduce the positive impact that transition has on life expectancy. This strong negative mediation effect depicted by the significant negative coefficient of indirect effect signifies the negative consequences that carbon emission has on public health which is consistent with Behera and Mishra (2020) and Zhu et al. (2023).

**Table 8: Channel analysis: total, direct and indirect effect of transition on life expectancy**

| Estimates | Direct effect | Indirect effect | Total effect | Sobel | Monte Carlo | RID |
|---|---|---|---|---|---|---|
| Main model | | | | | | |
| Transition>AQ>LE | 0.213** | 0.273*** | 0.485*** | 0.273*** | 0.272*** | 1.281 |
| | | | | (0.035) | (0.035) | |
| Transition>CO2>LE | 0.213** | -0.258*** | 0.045*** | 0.258*** | 0.258*** | 1.214 |
| | | | | (0.067) | (0.067) | |
| ESAP | | | | | | |
| Transition>AQ>LE | 0.361** | 0.215** | 0.577*** | 0.215 | 0.214 | 0.596 |
| | | | | (0.095) | (0.095) | |
| Transition>CO2>LE | 0.361** | -0.699*** | -0.337*** | -0.699*** | -0.698*** | 1.936 |
| | | | | (0.105) | (0.105) | |
| ECA | | | | | | |
| Transition>AQ>LE | 0.592*** | 0.195** | 0.787*** | 0.195*** | 0.196*** | 0.329 |
| | | | | (0.086) | (0.086) | |
| Transition>CO2>LE | 0.592*** | -0.338*** | 0.254*** | 0.338*** | 0.337*** | 0.571 |
| | | | | (0.101) | (0.101) | |
| LNAC | | | | | | |
| Transition>AQ>LE | 0.315*** | 0.040** | 0.355*** | 0.040*** | 0.040*** | 0.127 |
| | | | | (0.022) | (0.023) | |
| Transition>CO2>LE | 0.315*** | -0.169*** | 0.146*** | 0.169*** | 0.169*** | 0.537 |
| | | | | (0.078) | (0.078) | |
| MENA | | | | | | |
| Transition>AQ>LE | 2.093*** | 1.149** | 0.945*** | 1.149*** | 1.147*** | 0.549 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | (0.139) | (0.139) | |
| Transition>CO2>LE | 2.093*** | -0.366*** | 1.727*** | 0.366*** | 0.366*** | 0.175 |
| | | | | (0.116) | (0.116) | |
| SSA | | | | | | |
| Transition>AQ>LE | 0.885*** | 0.104** | 0.989*** | 0.104*** | 0.105*** | 0.118 |
| | | | | (0.046) | (0.047) | |
| Transition>CO2>LE | 0.885*** | -0.274*** | 0.611*** | 0.274*** | 0.275*** | 0.310 |
| | | | | (0.170) | (0.171) | |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01, RIT is Ratio of Indirect effect to Total effect, RID is Ratio of Indirect effect to Direct effect, AQ is air quality, LE is life expectancy, ESAP is East and South Asia and Pacific, ECA is Europe and Central Asia, LNAC is Latin and Noth America and Caribbean, MENA is Middle East and North Africa and SSA is Sub-Saharan Africa
Source: Author’s computation (2024)

A cursory look at the results across continents suggests that MENA recorded the highest mediated impact (1.149) of AQ in the transition life expectancy nexus whereas ESAP recorded the highest mediated impact (0.699) of carbon emission. But in terms of the magnitude of the effect size in relation to the RID, the indirect air quality is 59.6% lower and carbon emission is 93.6% higher than the direct impact.

The result suggests that despite lower levels of life expectancy and transition in Sub-Saharan Africa (SSA) compared to other continents, there are still significant mediated impacts of air quality (AQ) and carbon emissions on the transition-life expectancy relationship. The low levels of average life expectancy and slow rate of renewable energy transition in SSA may indicate a greater susceptibility to environmental influences, making the mediation effects particularly relevant in this context. It underscores the importance of addressing environmental factors in SSA to improve public health outcomes and mitigate the impact of transitions on life expectancy, aligning with global efforts to promote sustainable development and health equity (Akinwale, & George, 2023; Mensah, 2023; Owusu et al., 2023).

Interestingly, the mediation effect through carbon dioxide emission is negative in most regions, indicating that the direct effect of carbon dioxide emission counteracts the positive indirect effect mediated by air quality. This suggests that while improvements in air quality positively impact life expectancy, the adverse effects of carbon dioxide emission partially offset these benefits. Thus, implying that the mediation role of air quality is complementary whereas carbon emission is competitive.

The results underscore the importance of considering continental contexts in understanding the relationship between transitions, environmental factors, and life expectancy. Improving air quality could have significant positive implications for life expectancy across various continents, as evidenced by the strong mediation effects observed in all the continents. Conversely, the negative mediation effect of carbon dioxide emission highlights the potential health risks associated with environmental degradation, particularly in continents where the carbon dioxide emission impact on life expectancy is high. These findings align with existing literature emphasizing the critical role of environmental factors in shaping population health outcomes (Howarth et al., 2019; Landrigan et al., 2018; Smith et al., 2019).

**Sensitivity analysis**

The study also used the incidence of tuberculosis as another measure of health outcome to test the sensitivity of the model. The result is presented in Table 9. The direct effects of transition on air quality and carbon emission are the same as those in Table 7, meanwhile, the effect direct and indirect effects of the transition on mortality rate and tuberculosis case detection rate are different. The result of the full model for the sensitivity analysis is presented in Appendix 3. However, the direct impact is presented in Table 9.

In comparing the results of your primary model focusing on life expectancy with the sensitivity analyses regarding mortality rate and tuberculosis case detection rate, the following observations were made. Across all models, the coefficient for transition remains consistently significant. This indicates that the transition to renewable energy sources has a substantial impact on health outcomes regardless of the specific health metric being examined.

**Table 9: Effect of energy transition on mortality rate and tuberculosis case detection rate**

| Variables | Model-1 Mortality | Model-2 Tuberculosis |
|---|---|---|
| Heath outcomes | | |
| $\ln CO_2$ | 7.069*** | 1.182*** |
| | (1.676) | (0.173) |
| Air quality | -1.490*** | -0.109*** |
| | (0.192) | (0.013) |
| Transition | -6.683** | -0.239*** |
| | (2.940) | (0.053) |
| lnGDP | -7.458*** | -0.233 |
| | (1.701) | (0.166) |
| lnpop_density | -8.910*** | 0.251 |
| | (1.756) | (0.203) |
| lnenergy access | -9.469*** | 4.508*** |
| | (2.586) | (0.460) |
| Lnhealth expenditure | -3.620** | -9.574*** |
| | (1.447) | (0.691) |
| Fixed effect | Yes | Yes |
| Constant | 5.684*** | -3.274*** |
| | (1.585) | (0.876) |
| var (e.$\ln CO_2$) | 2.481*** | 2.481*** |
| | (0.070) | (0.070) |
| var (e. Air quality) | 430.493*** | 430.493*** |
| | (12.833) | (12.833) |
| var (e. Mortality rate) | 2.4e+04*** | |
| | (1372.447) | |
| var (e. Tuberculosis) | | 216.194*** |
| | | (7.521) |
| *Observation* | 3300 | 3300 |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01

Source: Author's computation (2024)

In the primary model focusing on life expectancy, the coefficient for transition suggests a significant positive impact on life expectancy. In the sensitivity analyses focusing on mortality rate and tuberculosis case detection rate, the coefficients for transition suggest negative and significant (Ansah et al., 2023). Thus, for a percentage increase in the rate of transition, there is a 6.68 and 0.24 reduction in mortality and tuberculosis case detection rates respectively which indicate the positive impact of transition on health outcomes.

The sensitivity analyses serve as robustness checks for the model's main result presented in Table 9. Discussing how the results align or diverge across different health metrics demonstrates the robustness of your conclusions regarding the impact of renewable energy transition on health outcomes.

**Chapter Summary**

This chapter presented the impact of renewable energy transition on life expectancy and found that renewable energy transition increases life expectancy. The study found that the results vary among continents as demonstrated by the continental analysis. The assumption that renewable energy transition could have an indirect effect on life expectancy was also tested and investigated by carrying out a mediation analysis. Consistently, the mediation analysis demonstrates the significant role of air quality and carbon emission in mediating the relationship between renewable energy transition and life expectancy. Robustness checks carried out using mortality rate and tuberculosis case detection rate validate the claim that renewable energy transition produces substantial health benefits.

# CHAPTER FIVE

# EFFECT OF CLIMATE VULNERABILITY ON ENERGY TRANSITION

## Introduction

Transition to sustainable energy is a critical global priority, yet its progress varies significantly across regions due to climate vulnerability. Climate vulnerability-encompassing sensitivity, adaptive capacity, and exposure to climate risks-plays a crucial role in shaping how countries adopt and integrate renewable energy solutions. While many studies focus on how energy transition mitigates climate change, fewer have explored the reverse connexion, particularly how climate vulnerability itself influences the speed and extent of energy transition. Countries with higher climate sensitivity and exposure often face infrastructure challenges, economic instability, and policy uncertainties, which can either accelerate or hinder their shift toward renewable energy use. Conversely, adaptive capacity, driven by governance, economic, and social readiness, can enable a smoother transition. This chapter investigates the effect of climate vulnerability on energy transition. It also analyse the role of climate readiness in the climate vulnerability energy transition nexus using a Sequential linear panel data estimation model by Kripfganz and Schwarz (2019). We ended this chapter by providing a robustness check using the System GMM technique.

## Descriptive statistics

Table 10 presents the summary statistics of the variables used in examining the effect of climate vulnerability on renewable energy transition. Transition represents the rate of the renewable energy transition; vulnerability means climate vulnerability. Sensitivity, adaptive capacity, and exposure indicate sensitivity, adaptive capacity, and exposure to climate vulnerability. Climate readiness (Readiness) and its disaggregation are economic, governance and social readiness. GDP is Gross Domestic Product at current United State Dollars, population growth (Popgrowth), foreign direct investment (FDI), access to clean energy (Energy access), and Trade as a percentage of GDP.

The average energy transition score is 34.52, with a standard deviation of 30.91. This reflects the progress and extent of transitioning to sustainable and low-carbon energy systems in the studied countries. A higher score indicates greater progress in adopting renewable energy sources and reducing reliance on fossil fuels. The range of energy transition scores is from 0 to 98.34, highlighting variations in countries' efforts towards sustainable energy practices.

Climate vulnerability shad a score of 0.437, implying that on average, these 150 countries being studied are 43.7% vulnerability to climate change. With a standard deviation of 8.9%, the country with the minimum climate vulnerability score is 24.4% whereas the maximum vulnerable country is 98.34%. In terms of disaggregation, on average, all 150 countries are 43.4% exposed to climate change, 33.6% sensitivity to climate change and 55.2% capacity to contain climate conditions. While the descriptives suggest that countries are more capable of containing the vulnerability, the impact of climate change on countries remains a critical issue that countries are battling with. This has led many countries to adopt differing climate adaptation strategies to ensure that they are ready to deal with the menace.

Data from the Notre Dame University database of the Global Adaptation Initiative (ND-GAIN) which statistics have been presented in Table 10 shows that despite that countries are 55.2% capable of containing the climate change issues, they are however 39.7% ready. Per the 2023 report, climate readiness involves the effective use of investments by countries and their ability to leverage investments to adaptation actions. Three aspects of readiness were identified (Governance, Economic and Social). In Table 10, while the overall average readiness is 39.7%, in terms of governance, countries are 47.4% ready, 41.4% economically ready and 30.5% socially ready. A clear implication for this descriptive shows that show a climate disaster happens now, countries are going to suffer its consequences for a longer time is they do not read, yet they are more vulnerable.

On the side of Gross Domestic Product (GDP), the average for the 150 countries is US$354 billion, with a standard deviation of US$1.6 trillion. A higher average GDP implies greater economic productivity and potential for economic development. The range of GDP is from US$333 million to US$23.3 trillion, indicating significant variations in countries' economic performance and levels of development. As a predeterminant of demand for economic resources, population growth cannot be discounted. Among these 150 countries, the average population growth is 1.51%. With a standard deviation of 1.598% growth, the country with the lest growth is negative 6.852% growth and a maximum growth of 19.36. Overall, these statistics highlight the diversity in population growth rates among the countries studied, some experiencing population decline, and others experiencing rapid population growth. This information can be important for understanding the demographic dynamics and potential implications for energy demand that can affect the rate of transition.

Like GDP, the average net foreign direct investment is US$1.8 billion and a standard deviation of US$16.1 billion. The minimum net FDI of US$333 million and the maximum of US$23.3 trillion, indicating a huge variation in net FDI flow to countries. The range of these statistics therefore suggests that some countries are more than negative inflow compared to their FDI outflows.

**Table 10: Descriptive Statistics**

| Variable | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|
| Transition | 34.522 | 30.914 | 0 | 98.34 |
| Vulnerability | 0.437 | 0.089 | 0.244 | 0.664 |
| Exposure | 0.434 | 0.075 | 0.267 | 0.722 |
| Sensitivity | 0.336 | 0.087 | 0.143 | 0.627 |
| Capacity | 0.552 | 0.169 | 0.187 | 0.928 |
| Readiness | 0.397 | 0.138 | 0.115 | 0.813 |
| Governance | 0.474 | 0.181 | 0.093 | 0.898 |
| Economic | 0.414 | 0.152 | 0 | 0.881 |
| Social | 0.305 | 0.149 | 0.082 | 0.806 |
| GDP | 3.54E+11 | 1.59E+12 | 3.33E+08 | 2.33E+13 |
| Popgrowth | 1.51 | 1.598 | -6.852 | 19.36 |
| FDI | 1.797e+09 | 1.609e+10 | -1.380e+09 | 2.183e+11 |
| Energy access | 77.42 | 30.90 | 1.28 | 100 |
| Trade | 85,012 | 49,249 | 4,128 | 437,327 |

Std. Dev. is standard deviation, number of countries=150 and Years=22, Observation=3300.

Source: Author's computation (2024)

The average, access to energy is 77.42% of the 150 countries' population, with a standard deviation of 30.90. This measures the level of access to modern and reliable energy sources in the studied countries. A higher score indicates better access to energy, which is crucial for various aspects of socio-economic development, including healthcare, education, and industry. The range of access to energy scores is from 1.28 to 100, suggesting variations in energy infrastructure and availability across the countries. The average trade flow is US$85,012 and the standard deviation of US$49,249. The minimum of US$4,128 and a maximum of US$437,327 indicate the huge variations in trade activity among the observed countries. Countries with higher levels of trade activity may have more resources and opportunities to invest in renewable energy infrastructure, research, and development. They may also benefit from international collaborations and partnerships aimed at advancing energy transition goals.

In summary, Table 10 provides a comprehensive overview of various variables crucial in assessing the impact of climate vulnerability on renewable energy transition. It outlines statistics such as the average energy transition score (34.52), reflecting progress in adopting sustainable energy systems, and the climate vulnerability score (0.437), indicating the susceptibility of the studied countries to climate change. Despite showing significant capacity to contain vulnerability, countries still grapple with climate change impacts, leading to varying levels of readiness (39.7%) across governance, economic, and social dimensions. Additionally, GDP and population growth statistics highlight economic productivity and demographic dynamics, while net foreign direct investment and trade flow variations underscore potential influences on renewable energy investment and development.

**Correlations analysis**

Table 11 presents the level of correlation among variables. The result in the table reveals that there is a weak negative correlation (-0.054) between climate vulnerability and the rate of the renewable energy transition. This means a weak correlation, suggests that countries with higher vulnerability to climate-related risks may have lower levels of renewable energy transition. Other variables, such as sensitivity, capacity, exposure, and readiness to climate change, may also play significant roles. Like the overall vulnerability, sensitivity, and exposure to climate change (0.129 and 0.062) correlate with renewable energy transition but weakly whereas capacity to contain climate change (0.006) does so positively. This implies that countries with higher sensitivity to climate vulnerability or lower capacity to address climate vulnerability may exhibit slightly lower levels of renewable energy transition. However, the correlations are weak, suggesting that exposure, sensitivity, and capacity alone cannot solely explain the variations in the transition.

Among the components of climate readiness, governance, economic, and social readiness exhibit weak positive correlations with renewable energy transition (0.118, 0.029, and 0.034, respectively). This indicates that countries with better governance structures, stronger economic foundations, and higher social preparedness may have slightly higher levels of renewable energy transition. These findings suggest that the readiness of a country to embrace renewable energy, beyond its vulnerability, is a crucial factor in driving the transition.

**Table 11: Pairwise correlations**

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Transition | 1.000 | | | | | | | | | | | | | |
| (2) Vulnerability | -0.054 | 1.000 | | | | | | | | | | | | |
| (3) Sensitivity | -0.129 | 0.758 | 1.000 | | | | | | | | | | | |
| (4) Capacity | 0.006 | 0.924 | 0.601 | 1.000 | | | | | | | | | | |
| (5) Exposure | -0.062 | 0.607 | 0.219 | 0.403 | 1.000 | | | | | | | | | |
| (6) Readiness | 0.065 | -0.710 | -0.490 | -0.791 | -0.257 | 1.000 | | | | | | | | |
| (7) Governance | 0.118 | -0.634 | -0.444 | -0.693 | -0.242 | 0.881 | 1.000 | | | | | | | |
| (8) Economic | 0.029 | -0.540 | -0.382 | -0.606 | -0.175 | 0.826 | 0.597 | 1.000 | | | | | | |
| (9) Social | 0.034 | -0.646 | -0.431 | -0.727 | -0.233 | 0.828 | 0.609 | 0.535 | 1.000 | | | | | |
| (10) GDP | 0.044 | -0.038 | -0.085 | -0.015 | -0.009 | 0.001 | -0.084 | 0.027 | 0.076 | 1.000 | | | | |
| (11) Popgrowth | -0.082 | 0.414 | 0.382 | 0.379 | 0.226 | -0.341 | -0.250 | -0.239 | -0.385 | -0.028 | 1.000 | | | |
| (12) FDI | 0.001 | -0.223 | -0.090 | -0.309 | -0.010 | 0.356 | 0.292 | 0.269 | 0.361 | 0.021 | -0.097 | 1.000 | | |
| (13) Energy access | 0.049 | -0.702 | -0.552 | -0.693 | -0.355 | 0.476 | 0.357 | 0.464 | 0.386 | 0.077 | -0.352 | 0.105 | 1.000 | |
| (14) Trade | 0.080 | -0.269 | -0.012 | -0.296 | -0.279 | 0.329 | 0.369 | 0.252 | 0.198 | -0.073 | -0.053 | 0.010 | 0.182 | 1.000 |

Source: Author’s computation (2024)

Additionally, GDP similarly shows a weak positive correlation (0.044) with energy transition. This suggests that countries with higher GDP, which often reflects stronger economic development, may have slightly higher levels of energy transition. Additionally, energy access and trade flows also display weak positive correlations with transition (0.049 and 0.080, respectively). This implies that countries with better access to clean energy and higher trade activity may have slightly higher levels of renewable energy transition. These findings highlight the importance of economic factors, access to energy, and international trade in facilitating the transition to renewable energy.

In summary, the correlation matrix indicates that while climate vulnerability has a weak negative correlation with the transition to renewable energy, other factors such as readiness (governance, economic, and social readiness), energy access, and trade flow play significant roles as well. The weak correlations suggest that a combination of multiple factors, rather than vulnerability alone, influence the transition and rule out the chances of multicollinearity issues that usually impact regression outputs if not dealt with. These findings underscore the importance of addressing not only vulnerability but also readiness, governance, economic factors, social factors, energy access, and trade to drive successful transitions in energy systems.

**Effect of climate vulnerability and its disaggregations on energy transition**

Table 12 presents the results of the effect of climate vulnerability and disaggregated components on the renewable energy transition. Models, 2, 3 and 4 are the effect of climate vulnerability, sensitivity, capacity, and exposure on energy transition, respectively. In terms of the diagnostics, the first and second-order autocorrelation tests are presented with Hansen's J-test of identification.

The significance of the AR (1) suggests the presence of first-order autocorrelation in all four models. However, the AR (2) coefficients are not statistically significant, indicating that there is no compelling evidence of second-order autocorrelation. The statistics of Hansen's J-test of overidentifying restrictions are presented and the results show that the instrumental variables used in the model are valid and not correlated with the error term.

Regarding the dynamic nature of the renewable energy transition (transition), the previous level of transition increases the current transition rate. From Table 12, the previous pass transition rate increases the current transition by about 20% yearly across all four models. In Model-1, the coefficient for climate vulnerability is statistically significant and negative at a 5% alpha level, indicating that a percentage increase in vulnerability to climate-related risks is associated with a 0.958 reduction in the rate of renewable energy transition. This suggests that addressing climate vulnerabilities is crucial for promoting sustainable remains insignificant energy transition. In the case of sensitivity to climate change, the effect is 1.508 and that of exposure to climate change is 0.344. Adaptive capacity to contain the vulnerability remains insignificant. This finding resonates with existing literature that discusses how increased exposure to climate risks, such as extreme weather events and sea-level rise, can strain national resources and hinder the progress towards sustainable energy infrastructure (Karduri, & Ananth, 2023).

**Table 12: Effect of climate vulnerability and disaggregated vulnerability on energy transition**

| Energy Transition | Model-1 | Model-2 | Model-3 | Model-4 |
|---|---|---|---|---|
| L.Transition | 0.201*** | 0.181*** | 0.202*** | 0.200*** |
| | (0.002) | (0.002) | (0.003) | (0.003) |
| Vulnerability | -0.958*** | | | |
| | (0.228) | | | |
| Sensitivity | | -1.508*** | | |
| | | (0.117) | | |
| Capacity | | | 0.024 | |
| | | | (0.093) | |
| Exposure | | | | -0.344* |
| | | | | (0.182) |
| lnGDP | 0.028*** | 0.027*** | 0.032*** | 0.038*** |
| | (0.002) | (0.003) | (0.003) | (0.003) |
| Population growth | -0.028*** | -0.006* | -0.039*** | -0.038*** |
| | (0.003) | (0.003) | (0.003) | (0.004) |
| lnFDI | 0.045*** | 0.058*** | 0.050*** | 0.046*** |
| | (0.002) | (0.002) | (0.002) | (0.001) |
| lnEnergy access | 0.253*** | 0.176*** | 0.166*** | 0.132*** |
| | (0.037) | (0.038) | (0.029) | (0.029) |
| lnTrade | 0.062*** | 0.070*** | 0.124*** | 0.151*** |
| | (0.016) | (0.014) | (0.013) | (0.017) |
| Fixed effect | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -1.760*** | -2.477*** | -2.962*** |
| | (0.268) | (0.266) | (0.214) | (0.206) |
| Observations | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.298*** | -4.065*** | -4.103*** |
| AR (2) | -1.043 | -1.071 | -0.929 | -0.964 |
| Hansen's J-test | 126.678 | 124.738 | 136.140 | 134.680 |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01, Model-1, 2, 3 and 4 is the effect of climate vulnerability, sensitivity, capacity and exposure on energy transition respectively

Source: Author's computation (2024)

Additionally, GDP per capita, population growth, foreign direct investment, access to clean energy, and trade flow are the control variables. Consistently, the effect of GDP per capita (lnGDP) has a significant positive and significant effect on the renewable energy transition. Thus, a percentage increase in GDP per capital is associated with a 2.8% increase in the rate of transitioning all things being equal. The effect in the other three models is similar and rang from 2.7% to 3.8%. This means that wealthier countries tend to have higher energy transition levels. Economic development because of higher per capita GDP and financial resources plays a significant role in facilitating the adoption of renewable energy sources. Countries with higher GDP may have more capacity to invest in renewable energy technologies, infrastructure, and research and development, promoting energy transition.

Population growth has a negative and statistically significant coefficient. Specifically, a percentage increase in population growth reduces the transition rate by 2.8%, 0.6%, 3.9% and 3.8% in model-1 to model-4, respectively. This implies that higher population growth rates are associated with lower levels of energy transition. Rapid population growth poses challenges in meeting increasing energy demands sustainably. Since renewable energy adoption is capita intensive, rapid population growth may lead to a greater reliance on conventional energy sources and hinder the adoption of renewable energy technologies. Balancing energy needs with population growth and implementing sustainable energy solutions are therefore important considerations for policymakers.

Foreign direct investment (lnFDI) has a positive and statistically significant coefficient. The significant positive effect of foreign direct investment on energy transition with a coefficient of 0.045. This means that countries with higher FDI tend to have higher energy transition levels. Foreign investments contribute to the development and implementation of renewable energy projects. They bring in capital, technology, and expertise that can accelerate the adoption of renewable energy sources and support energy transition efforts.

Access to clean energy (log of energy access) and trade flow (log of trade) both have positive and statistically significant coefficients across all models. This suggests that better energy access and higher levels of trade flow are associated with greater energy transition. Improved energy access enables the adoption of renewable energy technologies and reduces dependence on traditional energy sources. Increased trade facilitates the exchange of renewable energy-related goods and services, thereby promoting the growth of renewable energy markets.

In conclusion, Model-1's results highlight the importance of addressing climate vulnerability, alongside economic factors, population growth, foreign investment, energy access, and trade flow, in shaping energy transition. Higher vulnerability to climate change is associated with slower progress in energy transition, emphasizing the need to mitigate climate-related risks. Economic development, foreign investments, improved clean energy access, and increased trade flows are significant drivers of energy transition.

**Climate readiness and the effects of climate vulnerability on energy transition**

This section provides the results of interacting climate readiness with climate vulnerability to affect renewable energy transition. Models 1, 3, 5 and 7 are the same as Models, 2, 3, and 4 in Table 13, just that it is presented here for purposes of comparison. The interaction terms between vulnerability components and readiness (Vul_read, Sen_read, Exp_read, Cap_read) highlight the moderating effect of readiness on the relationship between vulnerability and energy transition. For example, the significant negative coefficient of 7.651 for interacting climate vulnerability with climate readiness in Model 2 suggests that high climate readiness can mitigate the adverse effects of vulnerability on energy transition. This implies that countries with strong climate readiness mechanisms (such as robust governance, economic stability, and social infrastructure) are better positioned to advance their energy transition despite high vulnerability.

Furthermore, the significant positive coefficients for readiness itself across different models (e.g., 3.496 in Model2, 1.345 in Model4, 2.752 in Model6 and 2.416 in Model8) underscore the importance of enhancing climate readiness to support energy transition. This result aligns with the broader literature emphasizing the role of governance, economic stability, and societal readiness in facilitating sustainable energy transitions. Countries that invest in improving these areas can better manage the risks associated with climate vulnerability and thus progress more effectively towards energy sustainability.

The lnGDP variable is also positively and significantly associated with energy transition across all models. The coefficients for lnGDP range from 0.027 to 0.038, with all models showing significance at the 1% level. This suggests that higher economic growth supports the transition to sustainable energy. Wealthier countries are better positioned to invest in the necessary infrastructure and technologies required for energy transition. The positive impact of GDP on energy transition aligns with studies that emphasize the importance of economic resources in enabling countries to pursue and sustain clean energy initiatives (Batra, 2023; Salvarli, & Salvarli, 2020).

**Table 13: Climate readiness and the effect of climate vulnerability on energy transition**

| Transition | Model-1 Vulnerability | Model-2 Vul_read | Model-3 Sensitivity | Model-4 Sen_read | Model-5 Exposure | Model-6 Exp_read | Model-7 Capacity | Model-8 Cap_read |
|---|---|---|---|---|---|---|---|---|
| L.Transition | 0.201*** | 0.172*** | 0.181*** | 0.177*** | 0.200*** | 0.183*** | 0.202*** | 0.176*** |
| | (0.002) | (0.003) | (0.002) | (0.004) | (0.003) | (0.003) | (0.003) | (0.002) |
| Vulnerability | -0.958*** | 3.554*** | | | | | | |
| | (0.228) | (0.395) | | | | | | |
| Readiness | | 3.496*** | | 1.345*** | | 2.752*** | | 2.416*** |
| | | (0.360) | | (0.237) | | (0.283) | | (0.166) |
| Vul_read | | -7.651*** | | | | | | |
| | | (0.930) | | | | | | |
| Sensitivity | | | -1.508*** | 0.349 | | | | |
| | | | (0.117) | (0.388) | | | | |
| Sen_read | | | | -3.121*** | | | | |
| | | | | (0.658) | | | | |
| Exposure | | | | | -0.344* | 2.466*** | | |
| | | | | | (0.182) | (0.288) | | |
| Exp_read | | | | | | -4.957*** | | |
| | | | | | | (0.617) | | |
| Capacity | | | | | | | 0.024 | 2.175*** |
| | | | | | | | (0.093) | (0.202) |
| Cap_read | | | | | | | | -3.361*** |
| | | | | | | | | (0.353) |
| lnGDP | 0.028*** | 0.025*** | 0.027*** | 0.022*** | 0.038*** | 0.031*** | 0.032*** | 0.029*** |
| | (0.002) | (0.004) | (0.003) | (0.003) | (0.003) | (0.002) | (0.003) | (0.004) |
| Population growth | -0.028*** | -0.092*** | -0.006* | -0.022*** | -0.038*** | -0.058*** | -0.039*** | -0.088*** |
| | (0.003) | (0.004) | (0.003) | (0.003) | (0.004) | (0.003) | (0.003) | (0.004) |
| lnFDI | 0.045*** | 0.042*** | 0.058*** | 0.062*** | 0.046*** | 0.021*** | 0.050*** | 0.026*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.001) | (0.002) | (0.002) | (0.002) |
| lnEnergy access | 0.253*** | 0.141*** | 0.176*** | 0.173*** | 0.132*** | 0.169*** | 0.166*** | 0.103*** |
| | (0.037) | (0.037) | (0.038) | (0.031) | (0.029) | (0.026) | (0.029) | (0.037) |
| lnTrade | 0.062*** | 0.088*** | 0.070*** | 0.084*** | 0.151*** | 0.072*** | 0.124*** | 0.105*** |
| | (0.016) | (0.021) | (0.014) | (0.018) | (0.017) | (0.024) | (0.013) | (0.018) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -3.849*** | -1.760*** | -2.707*** | -2.962*** | -3.041*** | -2.477*** | -3.625*** |
| | (0.268) | (0.340) | (0.266) | (0.336) | (0.206) | (0.257) | (0.214) | (0.263) |
| Observations | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.206*** | -4.298*** | -4.456*** | -4.103*** | -4.238*** | -4.065*** | -4.213*** |
| AR (2) | -1.043 | -1.550 | -1.071 | -1.136 | -0.964 | -1.325 | -0.930 | -1.563 |
| Hansen's J-test | 126.678 | 124.534 | 124.738 | 134.514 | 134.680 | 126.235 | 136.140 | 118.917 |
| Testparm | | 67.75*** | | 22.52*** | | 64.61*** | | 90.73*** |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01

Source: Author's computation (2024)

Population growth shows a consistent negative impact on energy transition across all models, with coefficients ranging from -0.028 to -0.039, all significant at the 1% level. This indicates that higher population growth rates are associated with slower progress in energy transition. The negative relationship suggests that rapid population growth increases energy demand and puts additional pressure on existing energy resources, making it more challenging to shift towards renewable energy sources. This finding is supported by the literature, which highlights the strain that high population growth can place on energy systems and the need for more aggressive policy measures to accommodate growing energy demands while promoting sustainability (Rogelj et al., 2021).

Foreign Direct Investment (FDI) consistently shows a positive and significant impact on energy transition across all models in Table 13. The coefficients for lnFDI range from 0.045 to 0.058, all significant at the 1% level. This indicates that higher levels of FDI are associated with more robust energy transition efforts. The positive relationship suggests that FDI brings not only capital but also technological advancements and expertise essential for developing renewable energy infrastructure. This finding is consistent with the literature, which highlights the role of FDI in facilitating the transfer of clean technologies and enhancing the capacity for sustainable energy development (Geng et al., 2021).

Energy access is another crucial control variable that shows a positive and significant relationship with energy transition across all models. The coefficients for access to clean energy (lnEnergy) range from 0.132 to 0.253, with significance at the 1% level. This suggests that improved access to energy is strongly linked to better outcomes in energy transition. Enhanced energy access facilitates the adoption of renewable energy technologies by providing the necessary infrastructure and supporting the development of clean energy systems. This finding resonates with Carley and Konisky (2020) who emphasize the role of energy access in enabling broader economic and social development, which in turn supports sustainable energy transitions.

Trade flow also exhibits a positive and significant effect on energy transition across all models, with coefficients ranging from 0.062 to 0.151, significant at the 1% level. This indicates that countries engaged in more international trade are better positioned to transition to sustainable energy. The positive relationship suggests that trade openness facilitates the exchange of technologies, best practices, and investments necessary for developing renewable energy infrastructure. Accordingly, Cantarero (2020) and Yang et al. (2024) indicate that global integration and trade promote the diffusion of clean energy technologies and support sustainable energy transitions.

In conclusion, the analysis of Table 13 underscores the interplay between climate vulnerability, readiness, and energy transition. While higher vulnerability poses significant challenges, ensuring climate readiness can mitigate these effects and support countries in their transition to sustainable energy. This reinforces the need for holistic and integrated policy approaches that address both vulnerability and readiness to achieve long-term energy sustainability. Higher levels of Foreign direct investment, income, access to clean energy, and trade flows are positively associated with energy transition, while higher population growth has a negative impact. These findings highlight the importance of economic and infrastructural factors in facilitating sustainable energy transitions. Also, it emphasizes the need for policies that attract foreign investment, promote economic growth, enhance energy access, and encourage international trade to support the transition to sustainable energy systems.

**Governance and climate vulnerability on energy transition**

This section presents the effect of interacting climate readiness and its disaggregated component with climate vulnerability on renewable energy transition. Table 14 provides insights into the effect of interacting governance readiness with climate vulnerability on the renewable energy transition. Model-1 examines the direct effect of climate vulnerability, indicating a significant negative impact on renewable energy transition with a coefficient of -0.451. This suggests that higher climate vulnerability hinders renewable energy adoption. However, when governance readiness interacts with climate vulnerability in Model 2, the interaction term (Vul_gov) has a significantly positive coefficient of 0.482. This highlights the crucial role governance readiness plays in mitigating the adverse effects of climate vulnerability on renewable energy transition. Empirical evidence from recent studies supports this finding, demonstrating that strong governance frameworks can effectively facilitate renewable energy adoption even in highly vulnerable regions (Dogan et al., 2022; Dogan et al., 2022; Ge et al., 2022; Hou et al., 2023; Wang et al., 2024).

**Table 14: Governance and climate vulnerability on energy transition**

| | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 | Model-7 | Model-8 |
|---|---|---|---|---|---|---|---|---|
| L.Transition | 0.201*** | 0.175*** | 0.181*** | 0.171*** | 0.200*** | 0.185*** | 0.202*** | 0.176*** |
| | (0.002) | (0.003) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Vulnerability | -0.958*** | 4.048*** | | | | | | |
| | (0.228) | (0.343) | | | | | | |
| Governance | | 3.205*** | | 1.475*** | | 2.456*** | | 2.013*** |
| | | (0.179) | | (0.226) | | (0.249) | | (0.156) |
| Vul_gov | | -6.708*** | | | | | | |
| | | (0.437) | | | | | | |
| Sensitivity | | | -1.508*** | 0.890** | | | | |
| | | | (0.117) | (0.449) | | | | |
| Sen_gov | | | | -3.797*** | | | | |
| | | | | (0.596) | | | | |
| Exposure | | | | | -0.344* | 3.202*** | | |
| | | | | | (0.182) | (0.406) | | |
| Exp_gov | | | | | | -4.531*** | | |
| | | | | | | (0.587) | | |
| Capacity | | | | | | | 0.024 | 2.177*** |
| | | | | | | | (0.093) | (0.175) |
| Cap_gov | | | | | | | | -2.861*** |
| | | | | | | | | (0.257) |
| All controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -3.480*** | -1.760*** | -2.627*** | -2.962*** | -3.515*** | -2.477*** | -3.705*** |
| | (0.268) | (0.305) | (0.266) | (0.391) | (0.206) | (0.283) | (0.214) | (0.272) |
| Observations | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.188*** | -4.298*** | -4.456*** | -4.103*** | -4.217*** | -4.065*** | -4.115*** |
| AR (2) | -1.043 | -1.705* | -1.071 | -1.200 | -0.964 | -1.407 | -0.929 | -1.648* |
| Hansen’s J-test | 126.678 | 122.955 | 124.738 | 127.401 | 134.680 | 125.562 | 136.140 | 124.866 |
| Testparm | | 235.19*** | | 40.59*** | | 59.49*** | | 124.08*** |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01

Source: Author’s computation (2024)

The analysis continues with Model 3, which shows that sensitivity to climate change has a significant negative impact on renewable energy transition, with a coefficient of 0.350. However, Model 4 reveals that governance readiness mitigates this negative effect, as indicated by the positive interaction term (Sen_gov) of 0.229. Similarly, Model 5 highlights the negative impact of exposure to climate vulnerability with a coefficient of -0.167, which is mitigated by governance readiness in Model 6, with an interaction term (Exp_gov) of 0.192. Finally, Model 7 shows that adaptive capacity to climate change positively influences renewable energy transition with a coefficient of 0.228, and Model 8 demonstrates that this positive impact is enhanced by governance readiness, with an interaction term (Cap_gov) of 0.315. These findings underscore the importance of effective governance in promoting renewable energy transitions, aligning with recent empirical studies that emphasize the need for strong governance structures to support sustainable energy policies (Guo et al., 2023; Habiba & Xinbang, 2023; Hafner et al., 2021; Hou et al., 2023). The specific net effect of interacting governance readiness climate vulnerability is presented in Figure 3.

**Economic readiness and the effect of climate vulnerability on energy transition**

Table 15 analyses the role of economic readiness in mitigating the impact of climate vulnerability on the renewable energy transition. Model-1 shows that climate vulnerability has a significantly negative effect on renewable energy transition, with a coefficient of 0.451. This means that vulnerable countries and continents struggle more with transitioning to renewable energy. However, when economic readiness is considered (Model-2), the interaction term (Vul_eco) is significantly negative (-0.179), suggesting that higher economic readiness can mitigate the negative impact of climate vulnerability on renewable energy transition. This highlights the importance of economic stability and preparedness in supporting renewable energy initiatives in the face of climate challenges. Recent empirical research by supports these findings, emphasizing that economic resilience is crucial for effective climate adaptation and sustainable energy policies.

The analysis extends to specific dimensions of climate vulnerability. Model 3 shows that sensitivity to climate change has a negative effect on renewable energy transition (-0.350). However, Model-4 illustrates that economic readiness can mitigate this effect, with the interaction term (Sen_eco) being significantly negative (-0.120). Similarly, Model-5 demonstrates that exposure to climate change negatively impacts renewable energy transition (-0.167), but Model-6 shows that economic readiness reduces this adverse effect (-0.125). Finally, Model-7 examines adaptive capacity, with results indicating a positive effect on renewable energy transition (0.228), and Model-8 shows that economic readiness further enhances this positive impact Cap_eco (0.093). These findings underline the role of economic readiness in supporting renewable energy transitions by mitigating the adverse effects of climate vulnerability (Dogan et al., 2022; Habiba, & Xinbang, 2023; Hafner et al., 2021). The specific net effect of interacting economic readiness climate vulnerability is presented in Figure 3.

**Table 15: Economic readiness and the effect of climate vulnerability on energy transition**

| | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 | Model-7 | Model-8 |
|---|---|---|---|---|---|---|---|---|
| L.Transition | 0.201*** | 0.186*** | 0.181*** | 0.173*** | 0.200*** | 0.195*** | 0.202*** | 0.184*** |
| | (0.002) | (0.003) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) | (0.004) |
| Vulnerability | -0.958*** | 5.236*** | | | | | | |
| | (0.228) | (0.529) | | | | | | |
| Economic | | 1.544*** | | 0.481** | | 0.714*** | | 1.533*** |
| | | (0.224) | | (0.208) | | (0.189) | | (0.154) |
| Vul_eco | | -3.861*** | | | | | | |
| | | (0.442) | | | | | | |
| Sensitivity | | | -1.508*** | 0.382 | | | | |
| | | | (0.117) | (0.771) | | | | |
| Sen_eco | | | | -1.150** | | | | |
| | | | | (0.469) | | | | |
| Exposure | | | | | -0.344* | 3.053*** | | |
| | | | | | (0.182) | (0.520) | | |
| Exp_eco | | | | | | -1.638*** | | |
| | | | | | | (0.392) | | |
| Capacity | | | | | | | 0.024 | 4.424*** |
| | | | | | | | (0.093) | (0.402) |
| Cap_eco | | | | | | | | -2.831*** |
| | | | | | | | | (0.274) |
| All controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -2.750*** | -1.760*** | -2.134*** | -2.962*** | -3.311*** | -2.477*** | -3.000*** |
| | (0.268) | (0.254) | (0.266) | (0.310) | (0.206) | (0.272) | (0.214) | (0.249) |
| Observations | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.153*** | -4.298*** | -4.373*** | -4.103*** | -4.038*** | -4.065*** | -4.074*** |
| AR (2) | -1.043 | -1.281 | -1.071 | -1.186 | -0.964(0.335) | -1.032 | -0.923 | -1.357 |
| Hansen's J-test | 126.678 | 132.408 | 124.738 | 129.805 | 134.680{0.997) | 129.330 | 136.140 | 128.335 |
| Testparm | | 76.37*** | | 6.01** | | 17.48*** | | 106.38*** |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

**Social readiness and the effect of climate vulnerability on energy transition**

Table 16 provides insightful findings on the effect of social readiness and climate vulnerability on renewable energy transition. Model-1 reveals that climate vulnerability has a direct significant negative effect on renewable energy transition, as indicated by the coefficient (-0.958) which suggests that higher climate vulnerability hinders the transition. Like Suhrcke et al. (2011) found, regions with higher climate vulnerability struggle more with energy transitions due to existing infrastructural and socio-economic challenges. Interacting social readiness with climate vulnerability (in Model-2) shows a direct significant improvement in transition (Vulnerability: 2.033, Social: 2.668). The net effect of this interaction in presented in Figure 3.

In examining the disaggregated components of vulnerability, Model3 and Model4 focus on sensitivity to climate change. Sensitivity alone has a significantly negative impact (-1.508), but when interacted with social readiness, the negative impact is less pronounced (-0.792). Similarly, Model5 and Model6 reveal that exposure to climate change negatively affects the transition (-0.344), yet social readiness can improve this effect (Exposure: 1.983) on transition. Finally, Model7 and Model8 illustrate that adaptive capacity has a positive effect on the transition (0.024), and this effect is amplified when combined with social readiness (Capacity: 1.516). These findings underscore the critical role of social readiness in facilitating renewable energy transitions amid climate vulnerabilities, supporting the assertion by Brown (2022) and Leal Filho et al. (2022) that social factors are pivotal in overcoming barriers to sustainable energy adoption. The specific net effect of interacting social readiness climate vulnerability is presented in Figure 3.

**Table 16: Social readiness and the effect of climate vulnerability on energy transition**

| | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 | Model-7 | Model-8 |
|---|---|---|---|---|---|---|---|---|
| L.Transition | 0.201*** | 0.190*** | 0.181*** | 0.177*** | 0.200*** | 0.191*** | 0.202*** | 0.184*** |
| | (0.002) | (0.003) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Vulnerability | -0.958*** | 2.033*** | | | | | | |
| | (0.228) | (0.371) | | | | | | |
| Social | | 2.668*** | | 0.512* | | 2.349*** | | 1.665*** |
| | | (0.302) | | (0.282) | | (0.254) | | (0.112) |
| Vul_soc | | -5.813*** | | | | | | |
| | | (0.925) | | | | | | |
| Sensitivity | | | -1.508*** | -0.792** | | | | |
| | | | (0.117) | (0.343) | | | | |
| Sen_soc | | | | -0.764 | | | | |
| | | | | (0.756) | | | | |
| Exposure | | | | | -0.344* | 1.983*** | | |
| | | | | | (0.182) | (0.302) | | |
| Exp_soc | | | | | | -4.488*** | | |
| | | | | | | (0.633) | | |
| Capacity | | | | | | | 0.024 | 1.516*** |
| | | | | | | | (0.093) | (0.152) |
| Cap_soc | | | | | | | | -2.365*** |
| | | | | | | | | (0.324) |
| All controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -2.923*** | -1.760*** | -1.779*** | -2.962*** | -2.932*** | -2.477*** | -3.512*** |
| | (0.268) | (0.316) | (0.266) | (0.237) | (0.206) | (0.236) | (0.214) | (0.264) |
| Observations | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.136*** | -4.298*** | -4.364*** | -4.103*** | -4.118*** | -4.065*** | -4.203*** |
| AR (2) | -1.043 | -1.138 | -1.071 | -1.154 | -0.964 | -1.094 | -0.929 | -1.158 |
| Hansen's J-test | 126.678 | 128.212 | 124.738 | 129.47 | 134.680 | 129.818 | 136.140 | 123.186 |
| Testparm | | 39.51*** | | 1.02 | | 50.33*** | | 53.24*** |

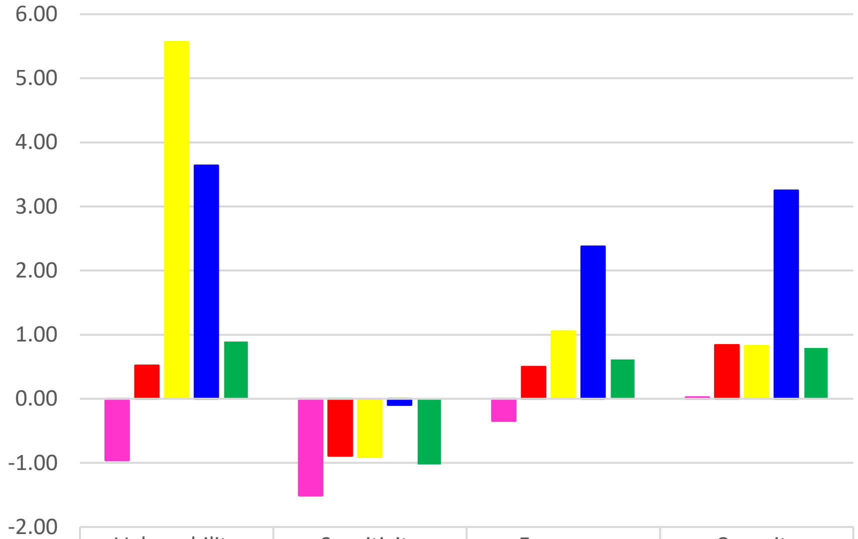
Standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

## Influence of Climate Readiness on Energy Transition

In Figure 3, the direct effect of climate vulnerability and its components sensitivity, capacity, and exposure on energy transition is depicted in blue colour, along with the net effect of these variables when interacted with climate readiness, governance readiness, economic readiness, and social readiness in red, yellow, ash and green colour respectively. The net effects are calculated at the average of climate readiness, governance readiness, economic readiness, and social readiness. The average values are presented in the descriptive statistics in Table 10. This analysis in Figure 3 provides an understanding of how different dimensions of vulnerability impact the progress towards energy transition, and how readiness and governance factors can mitigate or exacerbate these effects.

The direct effect of climate vulnerability on energy transition indicates a significant negative impact. This suggests that higher levels of vulnerability, characterized by greater susceptibility to climate impacts, hinder the progress of energy transition initiatives. This is consistent with literature suggesting that regions with higher climate vulnerability often face greater challenges in adopting and implementing sustainable energy practices due to limited resources, infrastructural deficits, and higher exposure to climate risks (Kim, & Park, 2023).

When examining the components of vulnerability, sensitivity shows a pronounced negative direct effect on energy transition. Sensitivity, defined as the degree to which a system is affected by climate stimuli appears to severely impede energy transition efforts. Similar to Maino and Emrullahu (2022), they highlighted those areas with high sensitivity to climate impacts, such as those with significant agricultural dependencies or fragile ecosystems, struggle more with the adoption of new energy technologies.




| | Vulnerability | Sensitivity | Exposure | Capacity |
|---|---|---|---|---|
| Direct Effect | -0.96 | -1.51 | -0.34 | 0.02 |
| Readiness | 0.52 | -0.89 | 0.50 | 0.84 |
| Governance | 5.57 | -0.91 | 1.05 | 0.82 |
| Economic | 3.64 | -0.09 | 2.37 | 3.25 |
| Social | 0.90 | -1.03 | 0.61 | 0.79 |

Direct Effect Readiness Governance Economic Social

Figure 3: Influence of Climate Readiness on Energy Transition

Source: Author's computation (2024)

Adaptive capacity to climate vulnerability, however, does not show a significant direct effect. This indicates that merely having the potential to cope with climate impacts, through available resources or infrastructure, does not necessarily translate into effective energy transition unless these capacities are mobilized effectively. This nuance is critical as it points to the need for not just capacity but active deployment and utilization of resources in driving energy transition (Panori et al., 2022).

Exposure's direct effect is marginally significant and negative, suggesting that areas with higher exposure to climate hazards face barriers to transitioning their energy systems. High exposure increases the risk and cost associated with energy infrastructure investments, making stakeholders more cautious and possibly delaying transition efforts (Gandhi et al., 2022).

The interaction effects reveal more complex dynamics. Climate readiness, when interacted with vulnerability and its components, shows a mitigating effect on the negative impacts. For instance, the interaction of readiness with vulnerability improves the rate of transition by 0.52 from the negative effect of 0.96. When sensitivity is interacted with readiness, there is a reduction in the effect from a negative effect of 1.51 to a positive effect of 0.89 and similarly from a negative effect of 0.34 to a positive effect of 0.5 when exposure interacts with readiness. Regarding the role of readiness in adaptive capacity, the effect on energy transition improves from an insignificant 0.02 to a significant 0.84. Indicating that higher readiness can significantly buffer the adverse effects of these vulnerabilities on energy transition. Climate readiness, which encompasses the ability to implement effective policies, governance, and infrastructure improvements, can facilitate energy transition despite underlying vulnerabilities (Alsabbagh, & Alnaser, 2023; Sarkodie et al., 2022).

Governance also plays a crucial role. Effective governance and when government institutions are climate-ready, vulnerability and sensitivity enhance the capacity to manage and adapt to climate impacts, thereby supporting the energy transition. The effect across the dimensions of vulnerability shows a 5.57, 0.91, 1.05 and 0.82 improvement in transition. This finding aligns well with the literature that emphasizes good governance as a cornerstone for successful climate adaptation and sustainable development (Hughes et al., 2018).

Economic and social readiness, when interacted with adaptive capacity show significant effects on transition. Economic readiness (e.g., financial stability and investment in renewable energy) enhances the ability to transition despite vulnerabilities, highlighting the role of economic resilience in energy policy (Hallegatte, & Rozenberg, 2017). Social factors, such as public awareness and community engagement, are critical in driving the adoption of new energy practices and technologies, mitigating the negative impacts of exposure as well as sensitivity to climate risks (Jerrett et al., 2024; Leichenko, & O'Brien, 2024).

Overall, Figure 3 illustrates the many-sided relationship between climate vulnerability, readiness, governance, and socio-economic factors in shaping energy transition pathways. The findings highlight the need for integrated approaches that enhance readiness and governance to effectively manage vulnerabilities and promote sustainable energy transitions.

**Chapter Summary**

This chapter presented an analysis of the effect of climate vulnerability on the rate of the renewable energy transition. The study among other things presents first, a description of the variable used in this chapter. Secondly, the chapter examines the effect by using a sequential dynamic linear model. The effect is also disaggregated for sensitivity, adaptive capacity, and exposure to climate vulnerability. Climate vulnerability reduces renewable energy transition. When climate readiness was interacted with climate vulnerability, there is an improvement in energy transition.

# CHAPTER SIX

# DRIVERS OF CLIMATE VULNERABILITY

## Introduction

Climate vulnerability is a multifaceted issue driven by a range of factors that interact in complex ways to determine the extent to which countries and continents are susceptible to the adverse impacts of climate change. Understanding these factors is crucial for developing targeted policies and interventions aimed at mitigating climate vulnerability and enhancing adaptive capacity across different contexts. In this regard, this chapter presents drivers of climate vulnerability, sensitivity, adaptive capacity, and exposure to climate change among different continents using the System Generalized Method of Moment technique and Sequential linear panel data estimation as a robustness check.

## Descriptive statistics

The descriptive statistics presented in Table 17 encompass various variables used in examining the drivers of climate vulnerability across 22 years by 150 countries. The vulnerability index has a mean of 0.437 with a standard deviation of 0.089, ranging from 0.244 to 0.664. Similarly, sensitivity has a mean of 0.336 and a standard deviation of 0.087, with a minimum of 0.143 and a maximum of 0.627. Adaptive capacity exhibits a higher mean value of 0.552 and greater variability (SD = 0.169), ranging from 0.187 to 0.928, indicating a disparity in the ability of countries to manage and mitigate climate impacts. Exposure has a mean of 0.434 and a standard deviation of 0.075, with values between 0.267 and 0.722, showing a consistent exposure level across countries.

The data on carbon dioxide emissions reveal extreme variability, with a mean of 173.928 and a standard deviation of 850.879, ranging from 0 to 11,420.234 MMtonnes, indicating substantial disparities in emissions among countries. Renewable energy consumption, with a mean of 7.437 and a standard deviation of 39.945, also shows high variability, suggesting varying reliance on renewable energy sources. The distance variable, which represents geographical or economic distance, shows substantial variability as well, with a mean of 8,046.465 and a standard deviation of 4,416.662, ranging from 65 to 19,629 kilometres between two countries, highlighting diverse contextual backgrounds among the studied countries.

**Table 17: Descriptive Statistics**

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Vulnerability | 0.437 | 0.089 | 0.244 | 0.664 |
| Sensitivity | 0.336 | 0.087 | 0.143 | 0.627 |
| Capacity | 0.552 | 0.169 | 0.187 | 0.928 |
| Exposure | 0.434 | 0.075 | 0.267 | 0.722 |
| CO2 | 173.928 | 850.879 | 0 | 11420.234 |
| Renewable | 7.437 | 39.945 | 0 | 990.946 |
| Distance | 8046.465 | 4416.662 | 65 | 19629 |
| GDP | 3.54E+11 | 1.59E+12 | 3.33E+08 | 2.33E+13 |
| Pop density | 189.614 | 615.886 | 1.584 | 7965.878 |
| Distance | 8046.465 | 4416.662 | 65 | 19629 |
| FDI | 1.797e+09 | 1.609e+10 | -1.380e+09 | 2.183e+11 |
| Investment | 1.004e+11 | 4.627e+11 | 6974332 | 7.476e+12 |
| Trade flow | 274944.85 | 1858156 | .001 | 59500000 |
| Migration | -4441.446 | 197863.82 | -2290411 | 1479676 |

Std. Dev. is standard deviation, number of countries=150 and Years=22, Observation=3300
Source: Author’s computation (2024)

Economic drivers of climate vulnerability such as net foreign direct investment has an average value of US$1.797 billion and US$16.1 billion standard deviation. Population density exhibits extreme variability, with a mean of 189.614 and a standard deviation of 615.886, ranging from 1.584 to 7,965.878. Foreign direct investment (FDI) and investment figures also show large variability. FDI has a mean of 1.8 billion and a standard deviation of 16.1 billion, ranging from significant disinvestment to substantial investment. Investment figures have a mean of 100.4 billion and a standard deviation of 462.7 billion, ranging from minimal to massive investments. Trade flow and migration statistics further highlight the diverse economic and social conditions, with trade flow showing a mean of US$274,944.85 thousand and a standard deviation of US$1.9 million, and migration displaying a wide range with a mean of US$4,441.446 thousand and a standard deviation of US$197,863.82 thousand. These statistics collectively underscore the extensive variability across different economic, social, and environmental metrics among the countries studied.

**Pairwise correlations**

The Pairwise Correlation Matrix measures the strength and direction of linear relationships between variables. Correlation coefficients range from -1 to 1, where values close to 1 or -1 indicate strong positive or negative relationships, respectively, and values close to 0 indicate weak or no linear relationships. The correlation matrix reveals that vulnerability is strongly correlated with sensitivity (0.758) and capacity (0.924). The strong correlation with capacity suggests that regions with high vulnerabilities are highly exposed.

**Table 18: Pairwise correlations**

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Vulnerability | 1.000 | | | | | | | | | | | | |
| 2. Sensitivity | 0.758 | 1.000 | | | | | | | | | | | |
| 3. Capacity | 0.924 | 0.601 | 1.000 | | | | | | | | | | |
| 4. Exposure | 0.607 | 0.219 | 0.403 | 1.000 | | | | | | | | | |
| 5. CO2 | 0.079 | 0.115 | -0.073 | 0.012 | 1.000 | | | | | | | | |
| 6. Renewable | -0.095 | -0.141 | 0.090 | -0.019 | 0.849 | 1.000 | | | | | | | |
| 7. Distance | -0.011 | -0.088 | -0.014 | -0.121 | 0.029 | 0.012 | 1.000 | | | | | | |
| 8. GDP | 0.038 | 0.085 | 0.015 | 0.009 | -0.018 | -0.016 | -0.014 | 1.000 | | | | | |
| 9. Pop density | 0.042 | 0.060 | -0.166 | 0.152 | -0.021 | -0.022 | 0.044 | -0.049 | 1.000 | | | | |
| 10. FDI | -0.223 | -0.090 | 0.309 | -0.010 | -0.003 | 0.007 | -0.012 | 0.130 | 0.012 | 1.000 | | | |
| 11. Investment | -0.167 | -0.191 | 0.215 | -0.092 | 0.570 | 0.663 | 0.018 | 0.220 | -0.002 | 0.351 | 1.000 | | |
| 12. Trade flow | 0.118 | -0.068 | 0.153 | -0.006 | 0.160 | 0.157 | -0.043 | 0.076 | 0.019 | 0.190 | 0.285 | 1.000 | |
| 13. Migration | -0.222 | -0.184 | 0.223 | -0.077 | -0.125 | -0.089 | 0.004 | -0.029 | -0.015 | 0.279 | 0.285 | 0.089 | 1.000 |

Source: Author’s computation (2024)

Vulnerability also shows a moderate positive correlation with exposure (0.607), underscoring those regions facing higher exposure to climate change, such as natural disasters or extreme weather events, are more vulnerable. Interestingly, the correlations with carbon dioxide emission (0.079) and renewable energy (-0.095) are weak. These findings imply that while long-term climate mitigation is crucial, reducing vulnerability in the short term might require direct interventions to manage exposure and enhance local adaptive capacities.

Other socio-economic factors such as GDP (0.038), population density (0.042), and investment (-0.167) show weak correlations with vulnerability. This suggests that while economic factors play a role, they do not significantly determine vulnerability on their own. Similarly, the weak correlations with trade flow (0.118) and migration (-0.222) indicate that these factors alone are not strong. Overall, the analysis highlights that vulnerability is multifaceted and influenced by a combination of local conditions, capacity, and exposure, rather than solely by broader economic indicators or emissions levels.

**Drivers of climate vulnerability**

Table 19 examines the drivers of climate vulnerability (Model-1), sensitivity to climate change (Model-2), adaptive capacity (Model-3), and exposure (Model-4). The study considers carbon emissions, renewable energy consumption (Renewable), the distance between countries (lnDistance), current gross domestic product (lnGDP), the square of current gross domestic product (lnGDPsq), population density (lnPop_density), foreign direct investment (lnFDI), trade flows (lnTradeflow), investment (lnInvestment), and net migration (lnMigration). It is important to note here that FDI captures only foreign capital flows (mostly private), and investment (Gross Fixed Capita Formation) includes both domestic and public investment. The analysis highlights the relationship between economic, social, and environmental factors in shaping climate-related outcomes.

The coefficient for carbon emissions is positive (0.088), indicating that higher levels of carbon emissions are significantly associated with increased climate vulnerability. Specifically, a percentage increase in MMtonnes of carbon dioxide increases climate vulnerability by 0.088. To Fleming-Muñoz et al. (2020) and Qiu et al. (2024), the detrimental impact of high emissions on local environments contributes to global warming and exacerbating vulnerability. Increased carbon emissions led to more frequent and severe climate events, thereby heightening the vulnerability of affected regions.

Furthermore, renewable energy consumption shows a negative coefficient (-0.093), suggesting that higher renewable energy consumption reduces climate vulnerability by 0.093. This finding aligns with Griffiths et al. (2023) and Sovacool et al. (2023). They emphasize the role of renewable energy in enhancing resilience by reducing reliance on fossil fuels and stabilizing energy supplies. Meanwhile, distance between countries has a negative coefficient (-0.548) significant effect, increased distances between countries is associated with increased climate vulnerability. An explanation for this relationship is that geographically isolated nations particularly small island states or landlocked developing countries may face greater challenges in accessing climate adaptation resources, technology, and international support.

**Table 19: Drivers of climate vulnerability**

| | Model-1 Vulnerability | Model-2 Sensitivity | Model-3 Capacity | Model-4 Exposure |
|---|---|---|---|---|
| L.Vulnerability | 0.991*** | | | |
| | (0.0001) | | | |
| L.Sensitivity | | 0.994*** | | |
| | | (0.0001) | | |
| L.Capacity | | | 0.983*** | |
| | | | (0.0001) | |
| L.Exposure | | | | 1.000*** |
| | | | | (0.0001) |
| ln$CO_2$ | 0.088*** | 0.010*** | -0.008*** | 0.005*** |
| | (0.017) | (0.003) | (0.002) | (0.000) |
| Renewable | -0.093*** | -0.011*** | 0.005*** | -0.072*** |
| | (0.013) | (0.002) | (0.002) | (0.000) |
| lnDistance | -0.548*** | -0.126*** | 0.021*** | -0.036*** |
| | (0.003) | (0.001) | (0.001) | (0.000) |
| lnGDP | 2.832*** | 0.471*** | 0.379*** | 3.618*** |
| | (0.062) | (0.014) | (0.010) | (0.000) |
| lnGDPsq | -0.048*** | -0.008*** | -0.006*** | -0.064*** |
| | (0.001) | (0.000) | (0.000) | (0.000) |
| lnPop_density | 0.021** | 0.038*** | -0.002 | 0.020*** |
| | (0.009) | (0.002) | (0.001) | (0.000) |
| lnFDI | -0.158*** | -0.002*** | 0.064*** | -0.205*** |
| | (0.003) | (0.001) | (0.001) | (0.000) |
| lnInvestment | -0.074*** | -0.030*** | 0.028*** | -0.097*** |
| | (0.003) | (0.001) | (0.001) | (0.000) |
| lnTradeflow | 0.009*** | -0.006*** | 0.009*** | 0.018*** |
| | (0.001) | (0.000) | (0.000) | (0.000) |
| lnMigration | -0.086*** | -0.119*** | 0.051*** | -0.175*** |
| | (0.017) | (0.002) | (0.003) | (0.001) |
| Fixed effect | Yes | Yes | Yes | Yes |
| Constant | 39.020*** | 3.294*** | 8.589*** | -51.640*** |
| | (1.142) | (0.208) | (0.175) | (0.000) |
| Observations | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -7.519*** | -6.633*** | -7.129*** | -6.072*** |
| AR (2) | 0.082 | 1.267 | -0.315 | 0.045 |
| Hansen's J-test | 182.389 | 114.204 | 175.935 | 36.510 |

Robust standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

Increased distance can also hinder trade, knowledge sharing, and infrastructure development, which are critical for building resilience to climate change. Adger et al. (2022) and Yang et al. (2021) also discuss how geographical isolation can hinder collaborative efforts in climate adaptation.

Conversely, current GDP is negatively associated with climate vulnerability (-0.048), indicating that when economies are getting wealthier, they become less vulnerable due to their greater capacity (0.006) to invest in adaptation measures and infrastructure improvements. Yankovskaya et al. (2022) support this view by indicating that higher GDP levels provide the necessary resources for better governance and risk management.

Population density presents a positive coefficient (0.021), indicating that regions with higher population densities are more vulnerable to climate impacts. This finding is consistent with Birkmann et al. (2023), who argue that densely populated areas face greater challenges due to the concentration of people and infrastructure, which can amplify the impact of climate events. High population density can strain local resources and infrastructure, making it harder to effectively manage and mitigate the effects of climate change. These results highlight the need for targeted policies and investments to address the specific vulnerabilities of densely populated regions and enhance their resilience to climate-related risks.

The coefficient for carbon emissions is positive (0.010), indicating that higher levels of carbon emissions are significantly associated with increased sensitivity to climate change. This suggests that regions with higher emissions are more vulnerable to the adverse effects of climate change, such as extreme weather events and environmental degradation. This finding is consistent with recent studies by Chatterjee (2024) and He et al. (2023), who highlight the role of emissions in exacerbating climate sensitivity and stress on ecosystems. Current GDP on the other hand has a negative coefficient (-0.008), suggesting that higher economic output reduces sensitivity to climate change. This is due to the greater availability of resources and infrastructure that can help mitigate the impacts of climate change. This paradoxical effect may be due to intensified economic activities that can exacerbate environmental pressures and resource depletion (Aldy et al., 2022).

Net migration shows a negative coefficient (-0.119), implying that higher migration rates can reduce sensitivity to climate change. Regions experiencing significant inflows of migrants may face additional challenges in managing climate impacts due to the increased demand for infrastructure and resources. It is argued that large migration flows can reduce sensitivity by exacerbating less vulnerabilities (Teye & Nikoi, 2022; Vigil, 2022).

The coefficient for foreign direct investment is positive (0.064), indicating that higher levels of FDI significantly enhance adaptive capacity. This suggests that foreign investments bring in essential financial resources, technology, and expertise that help build resilience against climate impacts. Recent empirical studies by An et al. (2022) and Fried (2022) emphasize the critical role of international investment in supporting local adaptation efforts, including infrastructure development and capacity building. Foreign investments can enhance technological transfer and innovation, which are vital for developing robust adaptive strategies.

Investment also shows a positive impact (0.028) on adaptive capacity, reflecting the importance of domestic investments in fostering resilience. Higher domestic investment levels contribute to the development of infrastructure, technology, and adaptive measures necessary to cope with climate change. This finding aligns with research by Hinkel et al. (2023), Vallury et al. (2022) and Walker et al. (2022), which underscores the need for sustained investment in adaptive infrastructure and governance systems to reduce vulnerability and enhance resilience to climate impacts. Investments in local infrastructure and community projects are essential in building long-term adaptive capacity.

Renewable energy consumption, with a positive coefficient (0.005), further emphasizes the role of clean energy in enhancing adaptive capacity. Regions with higher consumption of renewable energy are better positioned to adapt to climate change due to the stability and sustainability of their energy sources. Deshmukh et al. (2023) highlight that renewable energy reduces dependence on fossil fuels, mitigates greenhouse gas emissions, and provides a more resilient energy infrastructure, thereby enhancing overall adaptive capacity. The transition to renewable energy sources can reduce environmental degradation and promote sustainable development, crucial for adaptive capacity.

The coefficient for carbon emissions is positive (0.005), indicating that higher levels of carbon emissions significantly increase exposure to climate change. This finding is supported by recent empirical studies, such as those by Martini et al. (2024), which highlight the direct link between carbon emissions and the exacerbation of climate-related hazards like extreme weather events and rising sea levels. High carbon emissions contribute to global warming, which in turn increases the frequency and intensity of climate events, thereby elevating exposure levels.

Current GDP has a negative coefficient (-0.064), suggesting that wealthier economies tend to have lower exposure to climate change impacts. This is likely because higher GDP regions can invest more in infrastructure, technologies, and policies that mitigate exposure. This might be due to intensified economic activities and urbanization, which can lead to higher environmental stress and greater susceptibility to climate hazards Li et al. (2022). On the side of population density, there is a significant positive impact (0.195, $p < 0.05$) on exposure, meaning that more densely populated areas are more exposed to climate change impacts. This result is corroborated by research from Birkmann et al. (2023), who argue that high population densities in urban areas increase the number of people and assets at risk, thus elevating overall exposure. Dense populations can also strain local resources and infrastructure, making it harder to effectively manage and mitigate the effects of climate change, further increasing exposure levels.

**Drivers of climate vulnerability across different income status**

The findings in Table 20 offer crucial insights into the determinants of climate vulnerability across different income groups. Lagged values of climate vulnerability (L.Vulnerability) emphasize persistence of vulnerability over time. The lagged vulnerability remains highly significant across all income levels, with coefficients ranging from 0.949 in low-income countries to 1.008 in high-income nations. This strong autoregressive effect suggests that past vulnerability heavily influences present conditions, reinforcing the notion of path dependency in climate risk (Xu et al., 2023). Carbon dioxide emissions (lnCO2) also play a significant role in driving vulnerability, with coefficients increasing from 0.219 in low-income countries to a substantial 0.880 in high-income nations. This suggests that as economies grow, emissions contribute more substantially to climate vulnerability, aligning with prior research that links industrialization and energy consumption with environmental degradation (Ahmed et al., 2022). However, renewable energy (Renewable) emerges as a mitigating factor, with a notably negative coefficient of -1.476 in high-income countries, demonstrating the effectiveness of clean energy investments in reducing climate risks (Sharma et al., 2023).

**Table 20: Drivers of climate vulnerability across different income status**

| | Model-1 Vulnerability | Model-2 Low | Model-3 Lower Middle | Model-4 Upper Middle | Model-5 High |
|---|---|---|---|---|---|
| L.Vulnerability | 0.991*** | 0.949*** | 0.978*** | 0.983*** | 1.008*** |
| | (0.000) | (0.020) | (0.010) | (0.009) | (0.007) |
| $\ln CO_2$ | 0.088*** | 0.219* | 0.377*** | 0.459** | 0.880*** |
| | (0.017) | (0.125) | (0.088) | (0.223) | (0.167) |
| Renewable | -0.093*** | -0.002 | -0.500* | -0.767** | -1.476*** |
| | (0.013) | (0.034) | (0.280) | (0.345) | (0.280) |
| lnDistance | -0.548*** | -0.138*** | -0.075 | 0.348 | 2.063 |
| | (0.003) | (0.035) | (0.223) | (0.267) | (1.387) |
| lnGDP | 2.832*** | 0.093 | 0.313 | 0.525 | 1.321*** |
| | (0.062) | (0.480) | (0.431) | (0.920) | (0.020) |
| lnGDPsq | -0.048*** | -0.033** | -0.000 | -0.003 | -0.027* |
| | (0.001) | (0.016) | (0.001) | (0.002) | (0.014) |
| lnPop_density | 0.021** | 0.002 | 0.177 | 0.265 | -0.302 |
| | (0.009) | (0.01) | (0.222) | (0.264) | (0.495) |
| lnFDI | -0.158*** | 0.001 | 0.614 | 0.093 | -0.288** |
| | (0.003) | (0.011) | (0.389) | (0.060) | (0.132) |
| lnInvestment | -0.074*** | 0.291 | -0.086 | -0.353*** | -1.471** |
| | (0.003) | (0.346) | (0.142) | (0.077) | (0.684) |
| lnTradeflow | 0.009*** | -0.090*** | 0.007 | -0.010 | 0.701 |
| | (0.001) | (0.030) | (0.019) | (0.052) | (0.545) |
| lnMigration | -0.086*** | 0.001 | -0.074 | -0.337*** | -0.627*** |
| | (0.017) | (0.001) | (0.194) | (0.015) | (0.009) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes |
| Constant | 39.020*** | 0.002 | 0.168 | .233 | 4.310 |
| | (1.142) | (0.021) | (0.318) | (0.375) | (2.992) |
| Observations | 3150 | 462 | 945 | 840 | 903 |
| AR (1) | -7.519*** | -3.530*** | -4.885*** | -3.955*** | -3.923*** |
| AR (2) | 0.082 | -0.267 | 1.216 | 0.182 | -0.855 |
| Hansen's J-test | 182.389 | 0.008 | 27.144 | 19.259 | 13.581 |

Robust standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

Economic variables exhibit complex and non-linear relationships with climate vulnerability, as reflected in the current GDP and its non-linear term, GDP (lnGDP). The positive but insignificant effect (0.093) in lower-income groups rises significantly to 1.321 in high-income countries, indicating that economic expansion alone does not necessarily reduce vulnerability. The squared GDP term (lnGDPsq), which is negative and significant (-0.048 in the aggregate model), supports the environmental Kuznets curve hypothesis, suggesting that vulnerability initially rises with economic growth before declining at higher income levels (Schmidt-Traub et al., 2021). Foreign direct investment (lnFDI) has mixed effects, as seen in its weak or positive coefficients in lower-income settings but a significant negative impact of 0.288 in high-income countries, indicating that while FDI can enhance resilience in developed economies, its benefits may not be equitably distributed in lower-income regions (Adam et al., 2023). Trade flow (lnTradeflow) has an overall small effect, with coefficients fluctuating across income groups, suggesting that its impact on vulnerability depends on how trade policies influence economic diversification as well as resilience.

Demographic and geographic factors on the other hand further shape climate vulnerability. Population density (lnPop_density) has a small (0.021) but positive coefficient in the combined model. This means that densely populated regions experience higher climate risks, particularly in urbanized settings with resource constraints (Wang et al., 2023). Migration (lnMigration) reduces vulnerability in high-income countries (-0.627) but has a weaker or insignificant impact in lower-income contexts, suggesting that migration serves as an adaptation strategy primarily in regions with robust economic opportunities (Mukherjee, & Fransen, 2024). The negative coefficient for distance (lnDistance) in low- and lower-middle-income countries suggests that remoteness reduces climate vulnerability, potentially due to reduced exposure to industrial pollution and extreme urbanization. However, this effect is not consistent across all models, reinforcing the need for further research into the geographic determinants of vulnerability (Farkas et al., 2017).

These findings highlight the need for targeted adaptation strategies based on income levels and economic structures. While economic growth and foreign investment contribute to resilience in high-income nations, they have weaker or even adverse effects in lower-income settings, emphasizing the importance of governance and policy frameworks in ensuring equitable adaptation benefits (Sharma et al., 2023). The strong impact of renewable energy in reducing vulnerability underscores the urgency of clean energy transitions, particularly in rapidly industrializing economies. Additionally, migration and spatial planning should be integrated into climate adaptation strategies to enhance resilience in both rural and urban areas. Future research should focus on the role of institutional capacity, climate finance mechanisms, and cross-sectoral policies to mitigate climate vulnerability in a sustainable and inclusive manner.

**Drivers of climate sensitivity across different income status**

The results in Table 21 provide an in-depth assessment of the determinants of climate sensitivity across different income groups. The lagged value (L.Sensitivity) shows the persistence of sensitivity over time, which remains highly significant in most models. The coefficient values range from 0.971 in high-income countries to 1.004 in lower-middle-income nations, confirming that past sensitivity strongly influences present conditions (Xu et al., 2023). Carbon emissions (lnCO2) exhibit a positive impact on climate sensitivity, but the magnitude of the effect varies, with the strongest influence observed in high-income nations, where the coefficient reaches 0.126. This suggests that industrialized economies continue to experience substantial climate related stress despite their higher adaptive capacity, aligning with existing research on the environmental consequences of energy intensive economic activities (Ahmed et al., 2022). On the other hand, renewable energy consumption (Renewable) significantly reduces sensitivity, particularly in low-income countries, where its coefficient is -0.574. This reinforces the role of clean energy investments in mitigating climate risks, especially in regions with limited adaptive capacity (Sharma et al., 2023).

The economic factors, particularly GDP (lnGDP) and its squared term (lnGDPsq), show a non-linear relationship with climate sensitivity. In high-income countries, GDP has a small but positive effect (0.103), suggesting that economic expansion does not immediately translate into lower sensitivity. However, the negative coefficient of GDP squared (lnGDPsq) in all models except in high income countries indicates that after reaching a certain income threshold, economic growth starts contributing to resilience. This supports the environmental Kuznets curve hypothesis, which posits that early-stage development exacerbates environmental stress before leading to improvements through better infrastructure and technology (Schmidt-Traub et al., 2021). Interestingly, in low-income countries, GDP does not exhibit a clear pattern, suggesting that economic growth alone is insufficient to mitigate climate sensitivity without targeted policies (Adams et al., 2023). The effect of population density (lnPop_density) is positively significant in some models, implying that densely populated areas experience heightened sensitivity due to increased demand for resources constraints (Wang & Chen, 2022).

**Table 21: Drivers of climate sensitivity across different income status**

| | Model-1 Sensitivity | Model-2 Low | Model-3 Lower Middle | Model-4 Upper Middle | Model-5 High |
|---|---|---|---|---|---|
| L.Sensitivity | 0.994*** | -0.039 | 1.004*** | 0.992*** | 0.971*** |
| | (0.000) | (1.039) | (0.014) | (0.011) | (0.009) |
| $lnCO_2$ | 0.010*** | 0.030 | 0.055 | 0.060 | 0.126*** |
| | (0.003) | (0.062) | (0.102) | (0.083) | (0.022) |
| Renewable | -0.011*** | -0.574** | 0.008 | -0.228* | -0.092 |
| | (0.002) | (0.207) | (0.109) | (0.117) | (0.078) |
| lnDistance | -0.126*** | -0.034*** | 0.003 | 0.069 | 0.423 |
| | (0.001) | (0.007) | (0.051) | (0.048) | (0.255) |
| lnGDP | 0.471*** | 0.139* | 0.513 | 0.137*** | 0.103* |
| | (0.014) | (0.074) | (0.705) | (0.047) | (0.061) |
| lnGDPsq | -0.008*** | -0.029 | -0.009 | -0.006*** | 0.000 |
| | (0.000) | (0.027) | (0.013) | (0.001) | (0.002) |
| lnPop_density | 0.038*** | -0.108 | 0.004 | 0.778 | 0.065** |
| | (0.002) | (0.131) | (0.054) | (01.528) | (0.033) |
| lnFDI | -0.002*** | -0.018 | 0.226 | 0.306 | 0.041*** |
| | (0.001) | (0.018) | (0.398) | (0.539) | (0.011) |
| lnInvestment | -0.030*** | 0.596 | 0.111 | -0.015 | 0.128 |
| | (0.001) | (0.607) | (0.101) | (0.042) | (0.096) |
| lnTradeflow | -0.006*** | -0.015** | -0.378 | -0.002 | 0.000 |
| | (0.000) | (0.007) | (0.262) | (0.002) | (0.005) |
| lnMigration | -0.119*** | 2.829** | 0.310** | -0.221* | -0.222** |
| | (0.002) | (0.957) | (0.109) | (0.125) | (0.108) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes |
| Constant | 3.294*** | 0.129** | 3.306 | 2.348 | 0.095*** |
| | (0.208) | (0.063) | (2.540) | (2.565) | (0.025) |
| Observations | 3150 | 462 | 945 | 840 | 903 |
| AR (1) | -6.633*** | -2.087** | -4.644*** | -4.375*** | -3.21*** |
| AR (2) | 1.267 | -0.369 | 0.634 | 1.282 | -0.193 |
| Hansen's J-test | 114.204 | 0.439 | 42.443 | 74.138 | 13.645 |

Robust standard errors in brackets, * p<.10, ** p<.05, *** p<.01

Source: Author's computation (2024)

Migration (lnMigration) has a mixed impact on climate sensitivity across income groups. In high-income nations, it significantly reduces sensitivity (-0.222), suggesting that migration serves as an adaptation mechanism, potentially by relocating populations away from high-risk areas (Mukherjee, & Fransen, 2024). However, in lower income countries, migration does not significantly lower sensitivity, due to limited access to economic opportunities in receiving areas. This highlights the need for migration policies that integrate climate adaptation strategies to ensure displaced populations can benefit from adequate infrastructure and employment opportunities (Sharma et al., 2023). Foreign direct investment (lnFDI) and trade (lnTradeflow) also show varied effects. The coefficient for trade flows is negative and significant in some models (-0.006 in the combined model) and low-income countries, indicating that reduced trade openness increases sensitivity, particularly in lower-income economies. This suggests that economic integration plays a more substantial role in enhancing resilience in countries with stronger institutional frameworks (Farkas et al., 2017).

Overall, the findings in Table 21 reinforce the notion that climate sensitivity is influenced by a combination of environmental, economic, and demographic factors, necessitating adaptation policies tailored to different income levels. While economic growth and renewable energy adoption help mitigate sensitivity, their effectiveness depends on governance structures, institutional capacity, and access to climate adaptation resources. Policymakers should focus on targeted interventions that integrate climate adaptation into economic planning, particularly in lower-income regions where sensitivity remains persistently high (Sharma et al., 2023).

**Drivers of climate capacity by countries income status**

The results presented in Table 22 provide global analysis on the drivers of climate adaptive capacity across different income groups. Firstly, the Table shows persistence of adaptive capacity over time, as demonstrated by the consistently high and significant coefficient of lagged adaptive capacity (L.Capacity), which ranges from 0.944 in high-income countries to 1.092 in low-income nations. This strong autoregressive effect suggests that regions with historically high adaptive capacity continue to strengthen their resilience, whereas those with weaker capacity struggle to make significant improvements, reinforcing preexisting inequalities in climate adaptation. This is consistent with the study by Xu et al. (2023). Carbon emissions (lnCO2) exhibit a varied impact on adaptive capacity, with a notable negative coefficient of 0.055 in high income countries, indicating that emissions constrain adaptation efforts despite greater financial resources. This supports previous findings that industrialized economies still face challenges in balancing emissions reduction with resilience building (Ahmed et al., 2022). Meanwhile, renewable energy consumption (Renewable) positively influences adaptive capacity, particularly in lower-income nations (0.062), accenting the role of clean energy investments in fostering resilience in vulnerable regions (Sharma et al., 2023).

Economic factors play a fundamental role in shaping adaptive capacity, as reflected in current GDP (lnGDP) coefficients across income groups. In low-income countries, GDP has a significant positive effect (0.535), supporting the notion that economic development facilitates access to adaptation resources. However, in high income countries, GDP has a much smaller effect (0.189), suggesting that economic growth alone does not automatically translate into higher adaptive capacity once a certain threshold is reached. The squared GDP term (lnGDPsq) is negative and significant (-0.004 in high-income countries), reinforcing the environmental Kuznets curve hypothesis, which posits that economic growth initially enhances environmental stress but later contributes to sustainability efforts (Schmidt-Traub et al., 2021).

**Table 22: Drivers of climate capacity across different income status**

| | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 |
|---|---|---|---|---|---|
| | Capacity | Low | Lower Middle | Upper Middle | High |
| L.Capacity | 0.983*** | 1.092*** | 0.981*** | 0.974*** | 0.944*** |
| | (0.000) | (0.043) | (0.007) | (0.014) | (0.010) |
| $lnCO_2$ | -0.008*** | 0.006 | 0.037 | -0.065 | -0.055** |
| | (0.002) | (0.024) | (0.047) | (0.053) | (0.027) |
| Renewable | 0.005*** | 0.062*** | 0.300 | 0.124 | 0.053 |
| | (0.002) | (0.018) | (0.633) | (0.109) | (0.046) |
| lnDistance | 0.021*** | 0.055** | 0.174 | 0.018 | 0.008 |
| | (0.001) | (0.022) | (0.252) | (0.025) | (0.100) |
| lnGDP | -0.379*** | 0.535** | 0.032** | 0.177*** | 0.189 |
| | (0.010) | (0.236) | (0.09) | (0.048) | (0.226) |
| lnGDPsq | 0.006*** | -0.013 | 0.055 | -0.002* | -0.004* |
| | (0.000) | (0.001) | (0.119) | (0.001) | (0.002) |
| lnPop_density | -0.002 | -0.052 | -0.459** | -0.142** | -0.141* |
| | (0.001) | (0.066) | (0.210) | (0.071) | (0.082) |
| lnFDI | 0.064*** | 0.000 | 0.058* | -0.065* | -0.098*** |
| | (0.001) | (0.000) | (0.034) | (0.035) | (0.018) |
| lnInvestment | 0.028*** | 0.253* | 0.010 | 0.030 | 0.149 |
| | (0.001) | (0.136) | (0.039) | (0.026) | (0.099) |
| lnTradeflow | 0.009*** | 0.006** | -0.113 | 0.003 | 0.022 |
| | (0.000) | (0.003) | (0.095) | (0.003) | (0.130) |
| lnMigration | 0.051*** | 0.001 | 0.011 | 0.084 | 0.171* |
| | (0.003) | (0.003) | (0.027) | (0.093) | (0.092) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes |
| Constant | 8.589*** | 1.039 | 0.220*** | 0.000 | 1.589*** |
| | (0.175) | (0.590) | (0.037) | (0.000) | (0.569) |
| Observations | 3150 | 462 | 945 | 840 | 903 |
| AR (1) | -7.129*** | -2.477** | -3.882*** | -2.926*** | -2.808*** |
| AR (2) | -0.315 | 0.751 | -1.148 | -1.031 | -1.438 |
| Hansen's J-test | 175.935 | 0.014 | 13.156 | 423.961 | 12.909 |

Robust standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

Foreign direct investment (lnFDI) exhibits positive effects in some income groups, particularly in lower income nations (0.058), accent its role in infrastructure development and technology transfer (Adams et al., 2023). However, in high income economies, the impact of FDI turns negative (-0.098), suggesting that while investment can support climate resilience, its effectiveness is contingent upon governance structures and how resources are allocated. Trade openness (lnTradeflow) has mixed effects, further indicating that while economic integration facilitates access to adaptation resources, it can also expose countries to external shocks, such as disruptions in supply chains or climate-induced trade vulnerabilities.

Demographic factors, including population density (lnPop_density) and migration (lnMigration), provide additional insights into adaptation dynamics. While migration is positively associated with adaptive capacity in high-income nations (0.171), its effect is insignificant in low-income settings, reflecting disparities in the ability of migrants to access economic and social resources needed for adaptation (Wang, & Chen, 2022). Distance (lnDistance) exhibits a varied impact, with remote regions displaying lower adaptive capacity, reinforcing previous findings that access to markets, resources, and technology plays a crucial role in resilience-building. Climate-related investment (lnInvestment) consistently enhances adaptive capacity across all income levels, with a stronger effect observed in wealthier nations (0.149), due to more efficient institutional frameworks and better resource utilization. However, in lower-income contexts, its impact remains weaker, highlighting the need for targeted financial mechanisms to improve adaptation outcomes (Sharma et al., 2023).

On the drivers of adaptive capacity, these findings emphasize the importance of economic and institutional factors in shaping climate adaptive capacity, stressing the need for differentiated adaptation strategies based on income levels. While economic growth and foreign investments contribute to adaptive capacity, their effectiveness is highly dependent on governance quality, access to financial resources, and the implementation of targeted adaptation policies.

**Drivers of climate exposure across different income status**

Table 23 provides the findings on insights into the factors influencing climate exposure across different income groups. A notable observation is the strong persistence of exposure over time, as evidenced by the highly significant coefficient for lagged exposure (L.Exposure) across all models. Consistent with Xu et al. (2023), this result features the structural nature of climate exposure, where historically vulnerable regions continue to face heightened vulnerability due to deeply embedded geographic, economic, and environmental factors.

On the environmental factors, carbon dioxide emissions (lnCO2) consistently emerge as a primary driver of exposure. With a pronounced effect in low and lower middle-income countries, the results indicate the significant role of fossil fuel dependence in aggravating climate exposure. Specifically, the coefficient for low-income countries (0.9304) far exceeds that of high-income nations (0.054), reinforcing previous research that links industrialization-driven emissions with increased exposure to environmental dangers (Ahmed et al., 2022). Conversely, renewable energy consumption (Renewable) exhibits a significant negative relationship with exposure, with its strongest mitigating effect observed in upper-middle-income nations (-0.827). This highlights the potential of clean energy investments in reducing the extent of exposure to climate change, particularly in emerging countries that are transitioning towards sustainability (Sharma et al., 2023).

Economic indicators present a complex relationship with climate exposure. The positive and significant coefficient of GDP (lnGDP) across all income groups suggests that economic expansion is initially associated with higher exposure, with the highest impact observed in low-income countries

(5.354). This could be attributed to rapid industrialization, unregulated urban growth, and infrastructure expansion that increase susceptibility to climate hazards (Schmidt-Traub et al., 2021). However, the negative coefficient of the squared GDP term (lnGDPsq) in several models signals a turning point at which continued economic growth contributes to resilience, aligning with the environmental Kuznets curve hypothesis.

Additionally, foreign direct investment (lnFDI) and trade openness (lnTradeflow) exhibit mixed effects. While FDI is positively associated with exposure in lower-middle-income nations (0.603), it has a substantial negative effect in high-income countries (-2.233), suggesting that investment-driven adaptation efforts are more effective in regions with stronger institutional frameworks (Adams et al., 2023). Similarly, trade openness exacerbate exposure in low-income settings (2.103), thereby reinforcing concerns that trade integration without adequate safeguards can heighten climate vulnerability by increasing dependence on climate-sensitive industries and external supplies.

Demographic and spatial factors further shape climate exposure patterns. Population density (lnPop_density) has a positive and significant effect across most income groups, with the highest impact observed in lower-middle-income countries (1.454). This suggests that densely populated regions experience heightened exposure due to intensified land-use pressure and greater susceptibility to extreme weather events (Wang, & Chen, 2022). However, the role of migration (lnMigration) presents mixed results. In upper-middle-income countries, migration significantly increases exposure (1.216), indicating that population displacement and rural-to-urban migration may be exacerbating climate risks.

**Table 23: Drivers of climate exposure across different income status**

| | Model-1 Exposure | Model-2 Low | Model-3 Lower Middle | Model-4 Upper Middle | Model-5 High |
|---|---|---|---|---|---|
| L.Exposure | 1.000*** | 0.399*** | 1.000*** | 1.000*** | 1.000*** |
| | (0.0001) | (0.001) | (0.000) | (0.000) | (0.000) |
| $lnCO_2$ | 0.005*** | 0.9304*** | 0.586*** | 0.316*** | 0.054*** |
| | (0.000) | (0.279) | (0.011) | (0.013) | (0.001) |
| Renewable | -0.072*** | -2.031 | -0.827*** | -0.119*** | -0.004*** |
| | (0.000) | (2.213) | (0.000) | (0.004) | (0.000) |
| lnDistance | -0.036*** | -0. 971*** | -0.251*** | -0.097*** | -0.028*** |
| | (0.000) | (0.034) | (0.000) | (0.001) | (0.000) |
| lnGDP | 3.618*** | 5.354*** | 2.136*** | 2.232*** | 0.237*** |
| | (0.000) | (0.292) | (0.001) | (0.105) | (0.001) |
| lnGDPsq | -0.064*** | -1.973*** | -0.133*** | -0.003*** | -0.003*** |
| | (0.000) | (0.350) | (0.000) | (0.000) | (0.000) |
| lnPop_density | 0.020*** | 1.454*** | 0.442*** | 0.090*** | 0.063*** |
| | (0.000) | (0.000) | (0.004) | (0.000) | (0.003) |
| lnFDI | -0.205*** | 0.603*** | -0.002*** | -0.184*** | -2.233*** |
| | (0.000) | (0.021) | (0.000) | (0.012) | (0.000) |
| lnInvestment | -0.097*** | -1.121*** | -0.896*** | -0.559*** | -0.046*** |
| | (0.000) | (0.048) | (0.000) | (0.003) | (0.000) |
| lnTradeflow | 0.018*** | 2.103*** | -0.049*** | -0.012*** | -0.008*** |
| | (0.000) | (0.311) | (0.000) | (0.000) | (0.000) |
| lnMigration | -0.175*** | 0.003 | 1.216*** | 0.160*** | -0.175*** |
| | (0.001) | (0.045) | (0.000) | (0.002) | (0.000) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes |
| Constant | -51.640*** | 3.188*** | 64.094 | 7.828*** | 1.514*** |
| | (0.000) | (0.030) | (05.65) | (0.526) | (0.001) |
| Observations | 3150 | 462 | 945 | 840 | 903 |
| AR (1) | -6.072*** | -4.603*** | -4.956*** | 5.023*** | -14.099*** |
| AR (2) | 0.045 | -0.807 | 0.369 | -0.09 | 1.203 |
| Hansen's J-test | 36.510 | 1.993 | 141.428 | 23.646 | 5.932 |

Robust standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

Conversely, in high-income nations, migration is associated with reduced exposure (-0.175), supporting the argument that migration can function as an adaptive strategy when supported by robust urban planning and resilient infrastructure (Mukherjee, & Fransen, 2024). Furthermore, distance (lnDistance) exhibits a negative relationship with exposure across all income groups, with the strongest effect observed in lower-middle-income nations (-0.971). This suggests that remote areas experience lower direct exposure to climate stressors, though this benefit may be offset by limited access to adaptation resources (Sharma et al., 2023).

Overall, these findings emphasize the necessity of targeted adaptation strategies tailored to economic conditions and geographic contexts. While economic growth and renewable energy adoption play pivotal roles in reducing climate exposure, their effectiveness hinges on governance structures, urban planning, and investment in adaptive infrastructure.

**Robustness checks: Sequential linear panel data estimation**

In evaluating the robustness of the main estimation technique (system GMM) in this chapter, the study presents the result of a sequential dynamic panel data model by Kripfganz and Schwarz (2019) which could have equally been used for estimating the drivers of climate vulnerability. Table 24 uses a sequential dynamic linear panel data estimation technique, while Table 20-23 utilizes the system GMM method. Both methods are designed to handle similar challenges in panel data analysis, such as endogeneity and omitted variable bias. Studies, such as those by Arellano and Bover (1995) and Blundell and Bond (2000), have highlighted the strengths of system GMM in addressing these issues. However, sequential dynamic linear panel data estimation provides complementary insights by offering a different approach to controlling for unobserved heterogeneity and serial correlation in the data.

In the context of consistency and reliability of the drivers of climate vulnerability, sensitivity, adaptive capacity, and exposure, it is observed that carbon emissions consistently show a positive effect. This finding aligns with recent empirical studies, such as those by Cardona et al. (2012), Klein (2003), Mukhopadhyay and Danda (2022), Raghavan et al. (2018), Vallury et al. (2022), and Yadava and Sinha (2024), which emphasize the significant impact of greenhouse gas emissions on climate-related risks.

**Table 24: Robustness checks: Sequential linear panel data estimation**

| | Model-1 Vulnerability | Model-2 Sensitivity | Model-3 Capacity | Model-4 Exposure |
|---|---|---|---|---|
| L.vulnerability | 0.555*** | | | |
| | (0.020) | | | |
| L.Sensitivity | | 0.447*** | | |
| | | (0.017) | | |
| L.Capacity | | | 0.859*** | |
| | | | (0.011) | |
| L.Exposure | | | | 1.000*** |
| | | | | (0.000) |
| $lnCO_2$ | 0.261*** | 0.351*** | -0.089 | 0.005*** |
| | (0.099) | (0.128) | (0.079) | (0.000) |
| Renewable | -0.250*** | -0.282** | 0.160*** | -0.053*** |
| | (0.065) | (0.120) | (0.059) | (0.000) |
| lnDistance | -0.026* | 0.004 | 0.028 | 0.023*** |
| | (0.014) | (0.022) | (0.021) | (0.000) |
| lnGDP | 0.237*** | 0.027 | 0.179* | 2.493*** |
| | (0.070) | (0.113) | (0.102) | (0.000) |
| lnGDPsq | -0.004*** | -0.000 | 0.001 | -0.044*** |
| | (0.001) | (0.001) | (0.001) | (0.000) |
| lnPop_density | 2.298*** | 2.135*** | -1.893*** | 0.013*** |
| | (0.195) | (0.315) | (0.207) | (0.000) |
| lnFDI | -0.001 | -0.072** | 0.072*** | -0.143*** |
| | (0.016) | (0.028) | (0.019) | (0.000) |
| lnInvestment | -0.259*** | -0.486*** | 0.071*** | -0.067*** |
| | (0.028) | (0.052) | (0.021) | (0.000) |
| lnTradeflow | -0.010*** | -0.008 | -0.002 | 0.012*** |
| | (0.002) | (0.006) | (0.005) | (0.000) |
| lnMigration | -0.069 | -0.141* | 0.034 | -0.122*** |
| | (0.064) | (0.080) | (0.114) | (0.000) |
| Fixed effect | Yes | Yes | Yes | Yes |
| Constant | 27.861*** | 34.313*** | 6.860** | -35.467*** |
| | (2.570) | (3.227) | (3.333) | (0.000) |
| Observation | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -6.64*** | -6.06*** | -5.89*** | -6.11*** |
| AR (2) | 1.09 | 0.68 | -1.16 | 0.03 |
| Hansen's J-test | 106.94 | 119.83 | 126.18 | 21.514 |

Robust standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

The magnitude of the effect and significance of the drivers across models was slightly insignificant. Meanwhile, the impact of foreign direct investment on adaptive capacity and exposure varies, reflecting differences in the estimation techniques. According to research by Kim and Choi (2020), and Nawaz and Rahman (2023), the effectiveness of FDI in enhancing adaptive capacity can depend on the host country's level of human capital and institutional quality, which might be captured differently by the two methods. The robustness checks validate the primary findings from the system GMM analysis, providing a sturdy foundation for policy recommendations.

**Chapter Summary**

The chapter provides a detailed analysis of the drivers of climate vulnerability, sensitivity, adaptive capacity, and exposure to climate change across different income-level countries using various econometric models. The system GMM was used to estimate the drivers of climate vulnerability and its disaggregated components. Significant drivers such as carbon emissions, renewable energy consumption, GDP, population density, FDI, and trade flows were revealed. Tables 20, 21, 22, and 23 break down this effect by income groups, highlighting nuanced differences among low, lower-middle, upper-middle, and high-income countries. Table 24 serves as a robustness check using sequential dynamic linear panel data estimation, confirming the reliability of the system GMM findings and underscoring the importance of these variables in shaping climate-related outcomes.

# CHAPTER SEVEN

# SUMMARY, CONCLUSION AND RECOMMENDATIONS

## Introduction

This chapter presents a summary of the entire study and the key findings. The conclusion and recommendations presented here are based on the key findings of the three empirical chapters. We also highlighted key contributions to the subject area as well as suggestions for future studies.

## Summary

In understanding the relationship between renewable energy transition, health outcomes and climate vulnerability in a changing world, the study set out three main objectives which were investigated in three separate empirical chapters. First, the study quantifies the effect of the rate of energy transition on life expectancy by analysing the effect of the rate of renewable energy transition on life expectance and examine the potential channel through which energy transition affects health outcomes (life expectancy). Again, this first empirical chapter examines the indirect effect of the rate of renewable energy transition on health outcomes (life expectancy).

In terms of the methods, the first empirical chapter considers the HPF by Grossman (1972) and is expanded by Majeed and Ozturk, (2020). The HIA Model by Winkler et al. (2020) was also considered in the theoretical framework. Empirical and conceptual issues were presented. In this objective, the study employs the Panel version of the Structural Equation Modelling and the mediation analysis for potential pathways. The study also used alternative measures of health outcomes as sensitivity checks. The study presents the result of this objective in chapter four.

The second objective focuses on investigating the extent to which climate vulnerability drives the rate of renewable energy transition. This objective form the empirical Chapter five which analyses the effect of climate vulnerability and its disaggregation on the rate of the renewable energy transition, also finds out the extent to which climate readiness moderate the effect of climate vulnerability and its disaggregation on energy transition, find out the extent to which governance readiness moderates the effect of climate vulnerability and its disaggregation on the rate of renewable energy transition, find out the extent to which economic readiness moderates the effect of climate vulnerability and its disaggregation on energy transition and also find out the extent to which Social readiness moderates the effect of climate vulnerability and its disaggregation on energy transition. Aside from this chapter employing the Downward Spiral Hypothesis, current empirical evidence was also presented. We employed a Sequential Dynamic linear panel data estimation.

The third objective which forms the third empirical chapter in Chapter six investigated the drivers of climate vulnerability and its disaggregation. The PHH and EKC as theoretical underpinnings for this objective (empirical chapter). We modelled the IPAT by Ehrlich and Holdren (1971) and the STIRPAT by Muzayanah et al. (2022) and York et al. (2003) and employed the System GMM as the main model and Sequential dynamic linear panel data estimation as a robustness check. The result of this objective is presented and discussed in Chapter six.

The study utilizes a panel version of the Structural Equations Model (SEM) to examine indirect pathways linking energy transition to health, considering factors such as air quality and carbon emissions. A Sequential Linear Dynamic Panel Data Model is applied to assess the impact of climate vulnerability on energy transition, incorporating the role of climate readiness (economic, governance, and social readiness). Lastly, the Two-Step System Generalized Method of Moments (GMM) technique is used to investigate the determinants of climate vulnerability across different subregions and income categories. These methods ensure robust estimation by addressing endogeneity, simultaneity, and dynamic effects, enhancing the reliability of policy-relevant insights. The findings of the specific objectives are presented in the next session.

## Findings

The following findings were made based on the objectives:

***Objective one***

1. Energy transition was found to improve health outcomes (increase life expectancy and reduce mortality rate and tuberculosis case rate).
2. Air quality mediates 56.2 percent of the total effect of the energy transition on life expectancy while that of carbon dioxide emission mediates as high as 5.68 times the total effect of transition.
3. Air quality and carbon emission mediate 28.1% and 21.4% of the effect of transition on life expectancy.
4. The role of air quality is complementary whereas carbon emission is competitive.

***Objective two***

1. The study found that climate vulnerability, sensitivity and exposure to climate change tend to reduce the rate of energy transitions whereas the adaptive capacity to deal with climate vulnerability increases energy transition.
2. Climate ready countries tend to harness the benefit of building adaptive capacity to contain vulnerabilities whereas leverage climate readiness to improve sensitivity and exposure impact on transition.
3. Climate readiness (economic, governance, and social) was found to moderate a positive effect of climate vulnerability on energy transition. Economic readiness tends to reduce the negative impact of climate vulnerability on transitioning.

***Objective three***

1. Higher carbon emissions consistently increase climate vulnerability, sensitivity, and exposure across all income levels, while renewable energy consumption mitigates these risks, emphasizing the need for clean energy transitions.
2. Economic growth initially enhances resilience by providing adaptation resources but later exacerbates climate risks due to intensified environmental stress, highlighting the need for balanced and sustainable economic policies.
3. Foreign direct investment and domestic investments enhance adaptive capacity, particularly in lower-income countries, while excessive

population density weakens resilience due to resource constraints and infrastructure challenges.

4. Greater geographical distance between countries lowers climate vulnerability, while lower-income nations face higher risks due to limited resources, underscoring the need for targeted climate-resilient infrastructure and strategic urban planning.

**Conclusions**

The following conclusions were made based on the three empirical chapters.

1. It can be concluded that the rate of renewable energy transition improves health outcomes. Also, the role of air quality can be said to be complementary whereas carbon emission is competitive in the effect of the rate of renewable energy transition on health outcomes.
2. Higher-income countries are more likely to invest in renewable energy technologies, which could contribute to reducing their vulnerability to climate change. Conversely, lower-income countries may face challenges in adopting renewable energy due to financial constraints or technological barriers. Therefore, supporting renewable energy deployment in lower-income countries could be crucial for enhancing their resilience to climate vulnerability.
3. Also, higher GDP levels suggest greater adaptive capacity in dealing with climate vulnerabilities. The threshold of GDP on vulnerability is an indication of the existence of a diminishing return to capacity, particularly in high-income countries that are beyond the threshold of

63.17%. Thus, additional growth may not necessarily translate into reduced vulnerability to climate change.

## Recommendations

Consistent with the key findings of each objective, the following recommendations were made.

### *Objective one*

Strategies to maximize the health co-benefits of renewable energy transition may include enforcing measures to reduce air pollution, promoting energy-efficient technologies, and investing in healthcare infrastructure and public health programs by energy ministries, environmental protection agencies and health ministries of countries.

Manufactures of electronic equipment, government through their energy ministries, etc. should implement and accelerate energy transition policies and programs to improve health outcomes, particularly in countries with high mortality rates and tuberculosis case rates.

National governments and clean energy providers should consider complementary policies and programs that prioritize air quality improvement and coordinate carbon emission reduction efforts to maximize the health benefits of energy transition.

Governments and policymakers should set ambitious emission reduction targets, incentivize the adoption of low-carbon technologies, promote sustainable transportation alternatives, and support research and innovation in clean energy solutions.

***Objective two***

National governments, NGOs and Civil Society Organizations, particularly those in countries at the initial stages of energy transition should prioritize investments in adaptive capacity-such as technological innovation, infrastructure resilience, and capacity-building programs-to mitigate the negative impact of climate vulnerability, sensitivity, and exposure on energy transition.

International organizations like the United Nations and World Bank should assist countries at the lower scale of climate readiness should integrate climate readiness strategies that includes economic, governance, and social readiness into their national energy transition policies. This includes leveraging strong institutions, regulatory frameworks, and financial incentives to enhance the positive role of adaptive capacity in managing climate vulnerabilities.

Global institutions like the IMF, World Bank, and regional development organizations should focus or otherwise prioritize improving economic readiness-such as access to green financing, renewable energy investments, and market-based incentives-to cushion the adverse effects of climate vulnerability and facilitate a smooth transition to sustainable energy systems.

To escape the Downward Spiral Hypothesis, Sub-Saharan African countries must prioritize climate-resilient energy infrastructure and sustainable policy reforms that enhance renewable energy adoption. Strengthening regional cooperation to share technological advancements and best practices can accelerate the transition. Accessing climate finance mechanisms, such as the Green Climate Fund, can further support large-scale renewable energy projects and grid expansion. By integrating climate adaptation strategies into national energy policies and enforcing strong regulatory frameworks, these countries can mitigate the impact of climate vulnerability while ensuring a stable and sustainable energy transition.

***Objective three***

The analysis indicates that sensitivity to climate change is influenced by several socioeconomic factors, including population density and economic activities. Educational institutions and government agencies should prioritize climate education and awareness campaigns to inform the public about the impacts of climate change and the importance of sustainable practices. NGOs can play a critical role by conducting community outreach programs and providing resources to educate vulnerable populations on reducing their sensitivity to climate risks.

The analysis reveals that increased renewable energy consumption significantly reduces climate vulnerability and sensitivity across all income groups. National governments should prioritize policies that promote renewable energy adoption, such as subsidies, tax incentives, and research funding for clean energy technologies. International development agencies can support these efforts by providing financial assistance, technical expertise, and capacity-building programs to facilitate the transition to renewable energy sources.

Exposure to climate change is significantly affected by geographical and infrastructural factors. Regional governments and urban planners should implement stringent sub-regional regulations and land-use planning to prevent development in high-risk areas, such as floodplains and coastal zones. Environmental protection agencies should enforce regulations that protect natural buffers, such as wetlands and forests, which can mitigate the impact of extreme weather events and reduce exposure to climate hazards.

International organizations, development banks, and private sector investors should provide technological and financial support to enhance the adaptive capacity of vulnerable countries. This includes funding for research and development in renewable energy technologies and providing low-interest loans or grants for renewable energy projects. The private sector should also be encouraged to invest in innovative solutions that improve adaptive capacity, making renewable energy projects more feasible and resilient to climate risks.

## Contribution to Knowledge

The following contributions were made:

1. Theoretically, this study challenges the deterministic nature of the downward spiral hypothesis and introduces agency and policy responsiveness of climate readiness (economic, governance, and social dimensions) in mitigating the vicious cycle that the DSH stipulates.
2. The study provides evidence that energy transition significantly improves health outcomes. This contributes to the body of knowledge by establishing a direct and indirect link between renewable energy transition policies and public health benefits. We again show that air quality mediates 56.2 percent of the total effect, while carbon dioxide emission mediates as much as 5.68 times the total effect.
3. Again, the study reveals that air quality plays a complementary role and carbon emissions play a competitive role in the effect of renewable energy transition on health outcomes.

4. The study uncovers how climate vulnerability, sensitivity, and exposure to climate change reduce the rate of energy transition whereas adaptive capacity enhances the rate of renewable energy transition.
5. Also, was demonstrated through the study that the extent to which climate readiness (economic, governance, and social readiness) moderates the climate vulnerability energy transition nexus is positive. This contribution expands the understanding of how various aspects of climate vulnerability and readiness influence the pace and success of energy transitions.
6. The research highlights the disparities between higher-income and lower-income countries regarding climate vulnerability and carbon footprints. Specifically, our finding challenges the conventional notion that poorer countries pollute more by consuming fossil fuels and underscores the need for tailored policies that address the unique vulnerabilities of lower-income countries while mitigating global emissions.

## Suggestions for Future Studies

1. Future studies are needed on other potential mediating factors beyond air quality and carbon dioxide emission that could influence the relationship between renewable energy transition and health outcomes. This could include examining the roles of socio-economic factors, access to healthcare, and public awareness and education about renewable energy benefits.

2. Investigate how emerging technologies, such as smart grids, energy storage solutions, and advancements in renewable energy sources (e.g., solar, wind, biomass), can further enhance the effectiveness of energy transition policies. Understanding the role of technology in overcoming current barriers and accelerating the transition can inform future policy and innovation strategies.
3. Explore the role of international cooperation and agreements in facilitating energy transition and mitigating climate change. Studies could analyse how collaborative efforts, such as technology transfer, financial aid, and shared research initiatives, contribute to the success of energy transition policies globally, especially in lower-income countries.
4. Comparing regional results with aggregate findings enhances policy relevance. However, addressing this would shift the study's focus and the intended research gap, so future studies should explore it.

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# APPENDICES

## Appendix A: Mediation analysis: total, direct and indirect effect of transition on life expectancy

| Estimates | Direct effect | Indirect effect | Total effect | Sobel | Monte Carlo | RIT | RID |
|---|---|---|---|---|---|---|---|
| Main model | | | | | | | |
| Transition>AQ>LE | 0.213** | 0.273*** | 0.485*** | 0.273*** | 0.272*** | 0.563 | 1.281 |
| | | | | (0.035) | (0.035) | | |
| Transition>CO2>LE | 0.213** | -0.258*** | 0.045*** | 0.258*** | 0.258*** | 5.787 | 1.214 |
| | | | | (0.067) | (0.067) | | |
| ESAP | | | | | | | |
| Transition>AQ>LE | 0.361** | 0.215** | 0.577*** | 0.215 | 0.214 | 0.373 | 0.596 |
| | | | | (0.095) | (0.095) | | |
| Transition>CO2>LE | 0.361** | -0.699*** | -0.337*** | -0.699*** | -0.698*** | 2.074 | 1.936 |
| | | | | (0.105) | (0.105) | | |
| ECA | | | | | | | |
| Transition>AQ>LE | 0.592*** | 0.195** | 0.787*** | 0.195*** | 0.196*** | 0.248 | 0.329 |
| | | | | (0.086) | (0.086) | | |
| Transition>CO2>LE | 0.592*** | -0.338*** | 0.254*** | 0.338*** | 0.337*** | 1.331 | 0.571 |
| | | | | (0.101) | (0.101) | | |
| LNAC | | | | | | | |
| Transition>AQ>LE | 0.315*** | 0.040** | 0.355*** | 0.040*** | 0.040*** | 0.113 | 0.127 |
| | | | | (0.022) | (0.023) | | |
| Transition>CO2>LE | 0.315*** | -0.169*** | 0.146*** | 0.169*** | 0.169*** | 1.158 | 0.537 |
| | | | | (0.078) | (0.078) | | |
| MENA | | | | | | | |
| Transition>AQ>LE | 2.093*** | 1.149** | 0.945*** | 1.149*** | 1.147*** | 1.216 | 0.549 |
| | | | | (0.139) | (0.139) | | |
| Transition>CO2>LE | 2.093*** | -0.366*** | 1.727*** | 0.366*** | 0.366*** | 0.212 | 0.175 |
| | | | | (0.116) | (0.116) | | |
| SSA | | | | | | | |
| Transition>AQ>LE | 0.885*** | 0.104** | 0.989*** | 0.104*** | 0.105*** | 0.105 | 0.118 |
| | | | | (0.046) | (0.047) | | |
| Transition>CO2>LE | 0.885*** | -0.274*** | 0.611*** | 0.274*** | 0.275*** | 0.448 | 0.310 |
| | | | | (0.170) | (0.171) | | |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01, RIT is Ratio of Indirect effect to Total effect, RID is Ratio of Indirect effect to Direct effect, AQ is air quality, LE is life expectancy, ESAP is East and South Asia and Pacific, ECA is Europe and Central Asia, LNAC is Latin and Noth America and Caribbean, MENA is Middle East and North Africa and SSA is Sub-Saharan Africa

## Appendix B: Sensitivity analysis: effect of energy transition on mortality rate and tuberculosis case detection rate

| Variables | Model-1 Mortality | Model-2 Tuberculosis |
|---|---|---|
| $lnCO_2$ | | |
| Transition | -1.349*** | -1.349*** |
| | (0.027) | (0.027) |
| lnGDP | 4.145*** | 4.145*** |
| | (0.239) | (0.239) |
| lnGDP square | -0.079*** | -0.079*** |
| | (0.005) | (0.005) |
| lnpop_density | 0.032 | 0.032 |
| | (0.020) | (0.020) |
| lnenergy access | -0.134*** | -0.134*** |
| | (0.043) | (0.043) |
| Fixed effect | Yes | Yes |
| Constant | -52.058*** | -52.058*** |

| | | | |
|---|---|---|---|
| | | (2.927) | (2.927) |
| Air quality | | | |
| | $lnCO_2$ | -1.196*** | -1.196*** |
| | | (0.220) | (0.220) |
| | Transition | 4.024*** | 4.024*** |
| | | (0.458) | (0.458) |
| | lnpop_density | 0.114 | 0.114 |
| | | (0.263) | (0.263) |
| | lnenergy access | 4.865*** | 4.865*** |
| | | (0.557) | (0.557) |
| | Lnhealth expenditure | 4.611*** | 4.611*** |
| | | (0.822) | (0.822) |
| | lnGDP | 1.133*** | 1.133*** |
| | | (0.214) | (0.214) |
| | Fixed effect | Yes | Yes |
| | Constant | -5.903 | -5.903 |
| | | (5.159) | (5.159) |
| Heath outcomes | | | |
| | $lnCO_2$ | 7.069*** | 1.182*** |
| | | (1.676) | (0.173) |
| | Air quality | -1.490*** | -0.109*** |
| | | (0.192) | (0.013) |
| | Transition | -6.683** | -0.239*** |
| | | (2.940) | (0.053) |
| | lnGDP | -7.458*** | -0.233 |
| | | (1.701) | (0.166) |
| | lnpop_density | -8.910*** | 0.251 |
| | | (1.756) | (0.203) |
| | lnenergy access | -9.469*** | 4.508*** |
| | | (2.586) | (0.460) |
| | Lnhealth expenditure | -3.620** | -9.574*** |
| | | (1.447) | (0.691) |
| | Fixed effect | Yes | Yes |
| | Constant | 5.684*** | -3.274*** |
| | | (1.585) | (0.876) |
| var (e. $lnCO_2$) | | 2.481*** | 2.481*** |
| | | (0.070) | (0.070) |
| var (e. Air quality) | | 430.493*** | 430.493*** |
| | | (12.833) | (12.833) |
| var (e. Mortality rate) | | 2.4e+04*** | |
| | | (1372.447) | |
| var (e. Tuberculosis) | | | 216.194*** |
| | | | (7.521) |
| *Observation* | | 3300 | 3300 |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01

**Appendix C: Role of governance in the effect of climate vulnerability and disaggregated vulnerability on energy transition**

| | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 | Model-7 | Model-8 |
|---|---|---|---|---|---|---|---|---|
| L.Transition | 0.201*** | 0.175*** | 0.181*** | 0.171*** | 0.200*** | 0.185*** | 0.202*** | 0.176*** |
| | (0.002) | (0.003) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Vulnerability | -0.958*** | 4.048*** | | | | | | |
| | (0.228) | (0.343) | | | | | | |
| Governance | | 3.205*** | | 1.475*** | | 2.456*** | | 2.013*** |
| | | (0.179) | | (0.226) | | (0.249) | | (0.156) |
| Vul_gov | | -6.708*** | | | | | | |
| | | (0.437) | | | | | | |
| Sensitivity | | | -1.508*** | 0.890** | | | | |
| | | | (0.117) | (0.449) | | | | |
| Sen_gov | | | | -3.797*** | | | | |
| | | | | (0.596) | | | | |
| Exposure | | | | | -0.344* | 3.202*** | | |
| | | | | | (0.182) | (0.406) | | |
| Exp_gov | | | | | | -4.531*** | | |
| | | | | | | (0.587) | | |
| Capacity | | | | | | | 0.024 | 2.177*** |
| | | | | | | | (0.093) | (0.175) |
| Cap_gov | | | | | | | | -2.861*** |
| | | | | | | | | (0.257) |
| lnGDP | 0.028*** | 0.032*** | 0.027*** | 0.026*** | 0.038*** | 0.039*** | 0.032*** | 0.036*** |
| | (0.002) | (0.004) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Population growth | -0.028*** | -0.103*** | -0.006* | -0.024*** | -0.038*** | -0.058*** | -0.039*** | -0.089*** |
| | (0.003) | (0.004) | (0.003) | (0.004) | (0.004) | (0.003) | (0.003) | (0.003) |
| lnFDI | 0.045*** | 0.032*** | 0.058*** | 0.063*** | 0.046*** | 0.015*** | 0.050*** | 0.023*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.001) | (0.002) | (0.002) | (0.002) |
| lnEnergy access | 0.253*** | 0.252*** | 0.176*** | 0.282*** | 0.132*** | 0.146*** | 0.166*** | 0.067* |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (0.037) | (0.031) | (0.038) | (0.040) | (0.029) | (0.029) | (0.029) | (0.035) |
| lnTrade | 0.062*** | 0.072*** | 0.070*** | 0.126*** | 0.151*** | 0.075*** | 0.124*** | 0.077*** |
| | (0.016) | (0.020) | (0.014) | (0.017) | (0.017) | (0.020) | (0.013) | (0.016) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -3.480*** | -1.760*** | -2.627*** | -2.962*** | -3.515*** | -2.477*** | -3.705*** |
| | (0.268) | (0.305) | (0.266) | (0.391) | (0.206) | (0.283) | (0.214) | (0.272) |
| Observations | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.188*** | -4.298*** | -4.456*** | -4.103*** | -4.217*** | -4.065*** | -4.115*** |
| AR (2) | -1.043 | -1.705* | -1.071 | -1.200 | -0.964 | -1.407 | -0.929 | -1.648* |
| Hansen's J-test | 126.678 | 122.955 | 124.738 | 127.401 | 134.680 | 125.562 | 136.140 | 124.866 |
| Testparm | | 235.19*** | | 40.59*** | | 59.49*** | | 124.08*** |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

**Appendix D: Role of economic readiness in the effect of climate vulnerability and disaggregated vulnerability on energy transition**

| | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 | Model-7 | Model-8 |
|---|---|---|---|---|---|---|---|---|
| L.Transition | 0.201*** | 0.186*** | 0.181*** | 0.173*** | 0.200*** | 0.195*** | 0.202*** | 0.184*** |
| | (0.002) | (0.003) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) | (0.004) |
| Vulnerability | -0.958*** | 5.236*** | | | | | | |
| | (0.228) | (0.529) | | | | | | |
| Economic | | 1.544*** | | 0.481** | | 0.714*** | | 1.533*** |
| | | (0.224) | | (0.208) | | (0.189) | | (0.154) |
| Vul_eco | | -3.861*** | | | | | | |
| | | (0.442) | | | | | | |
| Sensitivity | | | -1.508*** | 0.382 | | | | |
| | | | (0.117) | (0.771) | | | | |
| Sen_eco | | | | -1.150** | | | | |
| | | | | (0.469) | | | | |
| Exposure | | | | | -0.344* | 3.053*** | | |
| | | | | | (0.182) | (0.520) | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Exp_eco | | | | | | -1.638*** | | |
| | | | | | | (0.392) | | |
| Capacity | | | | | | | 0.024 | 4.424*** |
| | | | | | | | (0.093) | (0.402) |
| Cap_eco | | | | | | | | -2.831*** |
| | | | | | | | | (0.274) |
| lnGDP | 0.028*** | 0.023*** | 0.027*** | 0.027*** | 0.038*** | 0.038*** | 0.032*** | 0.023*** |
| | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) | (0.004) |
| Population growth | -0.028*** | -0.053*** | -0.006* | -0.017*** | -0.038*** | -0.040*** | -0.039*** | -0.068*** |
| | (0.003) | (0.003) | (0.003) | (0.003) | (0.004) | (0.003) | (0.003) | (0.003) |
| lnFDI | 0.045*** | 0.050*** | 0.058*** | 0.058*** | 0.046*** | 0.039*** | 0.050*** | 0.042*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.001) | (0.003) | (0.002) | (0.002) |
| lnEnergy access | 0.253*** | 0.127*** | 0.176*** | 0.157*** | 0.132*** | 0.124*** | 0.166*** | 0.115*** |
| | (0.037) | (0.034) | (0.038) | (0.028) | (0.029) | (0.032) | (0.029) | (0.038) |
| lnTrade | 0.062*** | 0.069*** | 0.070*** | 0.071*** | 0.151*** | 0.156*** | 0.124*** | 0.102*** |
| | (0.016) | (0.021) | (0.014) | (0.017) | (0.017) | (0.021) | (0.013) | (0.015) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -2.750*** | -1.760*** | -2.134*** | -2.962*** | -3.311*** | -2.477*** | -3.000*** |
| | (0.268) | (0.254) | (0.266) | (0.310) | (0.206) | (0.272) | (0.214) | (0.249) |
| Observations | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.153*** | -4.298*** | -4.373*** | -4.103*** | -4.038*** | -4.065*** | -4.074*** |
| AR (2) | -1.043 | -1.281 | -1.071 | -1.186 | -0.964(0.335) | -1.032 | -0.923 | -1.357 |
| Hansen's J-test | 126.678 | 132.408 | 124.738 | 129.805 | 134.680{0.997) | 129.330 | 136.140 | 128.335 |
| Testparm | | 76.37*** | | 6.01** | | 17.48*** | | 106.38*** |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01
Source: Author's computation (2024)

**Appendix E: Role of social readiness in the effect of climate vulnerability and disaggregated vulnerability on energy transition**

| | Model-1 | Model-2 | Model-3 | Model-4 | Model-5 | Model-6 | Model-7 | Model-8 |
|---|---|---|---|---|---|---|---|---|
| L.Transition | 0.201*** | 0.190*** | 0.181*** | 0.177*** | 0.200*** | 0.191*** | 0.202*** | 0.184*** |
| | (0.002) | (0.003) | (0.002) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Vulnerability | -0.958*** | 2.033*** | | | | | | |
| | (0.228) | (0.371) | | | | | | |
| Social | | 2.668*** | | 0.512* | | 2.349*** | | 1.665*** |
| | | (0.302) | | (0.282) | | (0.254) | | (0.112) |
| Vul_soc | | -5.813*** | | | | | | |
| | | (0.925) | | | | | | |
| Sensitivity | | | -1.508*** | -0.792** | | | | |
| | | | (0.117) | (0.343) | | | | |
| Sen_soc | | | | -0.764 | | | | |
| | | | | (0.756) | | | | |
| Exposure | | | | | -0.344* | 1.983*** | | |
| | | | | | (0.182) | (0.302) | | |
| Exp_soc | | | | | | -4.488*** | | |
| | | | | | | (0.633) | | |
| Capacity | | | | | | | 0.024 | 1.516*** |
| | | | | | | | (0.093) | (0.152) |
| Cap_soc | | | | | | | | -2.365*** |
| | | | | | | | | (0.324) |
| lnGDP | 0.028*** | 0.020*** | 0.027*** | 0.022*** | 0.038*** | 0.027*** | 0.032*** | 0.025*** |
| | (0.002) | (0.003) | (0.003) | (0.004) | (0.003) | (0.004) | (0.003) | (0.004) |
| Population growth | -0.028*** | -0.061*** | -0.006* | -0.012*** | -0.038*** | -0.049*** | -0.039*** | -0.048*** |
| | (0.003) | (0.005) | (0.003) | (0.004) | (0.004) | (0.005) | (0.003) | (0.003) |
| lnFDI | 0.045*** | 0.040*** | 0.058*** | 0.055*** | 0.046*** | 0.033*** | 0.050*** | 0.033*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.001) | (0.002) | (0.002) | (0.002) |
| lnEnergy access | 0.253*** | 0.162*** | 0.176*** | 0.209*** | 0.132*** | 0.160*** | 0.166*** | 0.079** |
| | (0.037) | (0.036) | (0.038) | (0.030) | (0.029) | (0.030) | (0.029) | (0.040) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| lnTrade | 0.062*** | 0.092*** | 0.070*** | 0.064*** | 0.151*** | 0.093*** | 0.124*** | 0.164*** |
| | (0.016) | (0.020) | (0.014) | (0.017) | (0.017) | (0.025) | (0.013) | (0.019) |
| Fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | -1.304*** | -2.923*** | -1.760*** | -1.779*** | -2.962*** | -2.932*** | -2.477*** | -3.512*** |
| | (0.268) | (0.316) | (0.266) | (0.237) | (0.206) | (0.236) | (0.214) | (0.264) |
| Observations | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 | 3150 |
| AR (1) | -4.109*** | -4.136*** | -4.298*** | -4.364*** | -4.103*** | -4.118*** | -4.065*** | -4.203*** |
| AR (2) | -1.043 | -1.138 | -1.071 | -1.154 | -0.964 | -1.094 | -0.929 | -1.158 |
| Hansen's J-test | 126.678 | 128.212 | 124.738 | 129.47 | 134.680 | 129.818 | 136.140 | 123.186 |
| Testparm | | 39.51*** | | 1.02 | | 50.33*** | | 53.24*** |

Standard errors in brackets, * p<.10, ** p<.05, *** p<.01

Source: Author's computation (2024)

## Appendix F: List of Countries in the study

| ESAP | ECA | LNAC | MENA | SSA |
|---|---|---|---|---|
| Afghanistan | Albania | Antigua and Barbuda | Algeria | Angola |
| Australia | Armenia | Argentina | Bahrain | Benin |
| Bangladesh | Austria | Bahamas | Djibouti | Botswana |
| Bhutan | Azerbaijan | Barbados | Egypt | Burkina Faso |
| Brunei Darussalam | Belarus | Belize | Iran | Burundi |
| Cambodia | Belgium | Bolivia | Iraq | Cabo Verde |
| China | Bosnia and Herzegovina | Brazil | Jordan | Cameroon |
| Fiji | Bulgaria | Canada | Kuwait | Central African Republic |
| India | Croatia | Chile | Lebanon | Chad |
| Indonesia | Cyprus | Colombia | Libya | Comoros |
| Japan | Czech Republic | Costa Rica | Malta | Congo, Dem. Rep. |
| Lao PDR | Denmark | Cuba | Morocco | Congo, Rep. |
| Malaysia | Estonia | Dominica | Oman | Cote d'Ivoire |
| Maldives | Finland | Dominican Republic | Qatar | Equatorial Guinea |
| Mongolia | Georgia | Ecuador | Saudi Arabia | Eritrea |
| Myanmar | Greece | El Salvador | Syria | Eswatini |
| Nepal | Hungary | Grenada | United Arab Emirates | Ethiopia |
| Pakistan | Iceland | Guatemala | Yemen | Gabon |
| Philippines | Kazakhstan | Haiti | | Gambia |
| Singapore | Kyrgyzstan | Honduras | | Ghana |
| South Korea | Latvia | Jamaica | | Guinea |
| Thailand | Lithuania | Mexico | | Guinea-Bissau |
| Vietnam | Luxembourg | Nicaragua | | Kenya |
| | Netherlands | Panama | | Lesotho |
| | Norway | Paraguay | | Liberia |
| | Poland | Peru | | Madagascar |
| | Portugal | Trinidad and Tobago | | Malawi |
| | Romania | United States | | Mali |
| | Russia | Uruguay | | Mauritania |
| | Switzerland | Venezuela | | Mauritius |
| | Tajikistan | | | Mozambique |
| | Turkmenistan | | | Namibia |
| | Ukraine | | | Niger |
| | United Kingdom | | | Nigeria |
| | Uzbekistan | | | Rwanda |
| | | | | Seychelles |
| | | | | Sierra Leone |
| | | | | South Africa |
| | | | | Sudan |
| | | | | Tanzania |
| | | | | Togo |
| | | | | Tunisia |
| | | | | Zambia |
| | | | | Zimbabwe |

ESAP: East and South Asia and Pacific, ECA: Europe and Central Asia, LNAC: Latin and Noth America and Caribbean, MENA: Middle East and North Africa and SSA: Sub-Saharan Africa.

## Appendix G: Countries and their income groups

| Low | Lower middle | Upper middle | High |
|---|---|---|---|
| Afghanistan | Algeria | Albania | Antigua and Barbuda |
| Burkina Faso | Angola | Argentina | Australia |
| Burundi | Bangladesh | Armenia | Austria |
| Central African Republic | Benin | Azerbaijan | Bahamas |
| Chad | Bhutan | Belarus | Bahrain |
| Congo, Dem. Rep. | Bolivia | Belize | Barbados |
| Eritrea | Cabo Verde | Bosnia and Herzegovina | Belgium |
| Ethiopia | Cambodia | Botswana | Brunei Darussalam |
| Gambia | Cameroon | Brazil | Canada |
| Guinea-Bissau | Comoros | Bulgaria | Chile |
| Liberia | Congo, Rep. | China | Croatia |
| Madagascar | Cote d'Ivoire | Colombia | Cyprus |
| Malawi | Djibouti | Costa Rica | Czech Republic |
| Mali | Egypt | Cuba | Denmark |
| Mozambique | Eswatini | Dominica | Estonia |
| Niger | Ghana | Dominican Republic | Finland |
| Rwanda | Guinea | Ecuador | Greece |
| Sierra Leone | Haiti | El Salvador | Hungary |
| Sudan | Honduras | Equatorial Guinea | Iceland |
| Syria | India | Fiji | Japan |
| Togo | Iran | Gabon | Kuwait |
| Yemen | Jordan | Georgia | Latvia |
| | Kenya | Grenada | Lithuania |
| | Kyrgyzstan | Guatemala | Luxembourg |
| | Lao PDR | Indonesia | Malta |
| | Lebanon | Iraq | Netherlands |
| | Lesotho | Jamaica | Norway |
| | Mauritania | Kazakhstan | Oman |
| | Mongolia | Libya | Panama |
| | Morocco | Malaysia | Poland |
| | Myanmar | Maldives | Portugal |
| | Nepal | Mauritius | Qatar |
| | Nicaragua | Mexico | Romania |
| | Nigeria | Namibia | Saudi Arabia |
| | Pakistan | Paraguay | Seychelles |
| | Philippines | Peru | Singapore |
| | Tajikistan | Russia | South Korea |
| | Tanzania | South Africa | Switzerland |
| | Tunisia | Thailand | Trinidad and Tobago |
| | Ukraine | Turkmenistan | United Arab Emirates |
| | Uzbekistan | | United Kingdom |
| | Venezuela | | United States |
| | Vietnam | | Uruguay |
| | Zambia | | |
| | Zimbabwe | | |