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Master in Monetary and Financial Economics

Greenhouse Gas Emissions and GDP Growth: Assessing the Economic Impact of Climate Change and Renewable Energy Transitions

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Table of Contents

Abstract

Climate change represents a significant global challenge as rising Greenhouse Gas (GHG) emissions lead to increasing temperatures and shifts in precipitation patterns, directly impacting economic outcomes. This thesis examines the effects of Carbon Dioxide (CO_2) emissions on Gross Domestic Product (GDP) growth, as well as the economic response to transitions to renewable energy. The study utilizes fixed effects and random effects panel regressions to analyse data from 23 countries between 1990 and 2020. The Hausman test determined that the fixed effects models are the most suitable for this dataset. The results indicate that a 1°C increase in mean temperature reduces GDP growth by 0.46 percentage points, while there is not statistically enough evidence that mean precipitation affects GDP growth. Additionally, a 1 percentage point increase in renewable energy consumption results in a 0.091 percentage points decrease in GDP growth. These findings underscore the importance of adaptive policies that balance economic growth with environmental sustainability.

1. Introduction

Climate change is a critical global challenge that directly influences economic outcomes, affecting everything from output and investment to productivity. As Greenhouse Gas (GHG) emissions continue to rise, primarily from the burning of fossil fuels, the planet experiences increasing temperatures and shifts in precipitation patterns. These climatic changes are already having tangible effects on global economic stability, impacting diverse sectors such as agriculture and industry. Recently, the issue has gained significant recognition, underscored by central banks beginning to incorporate climate considerations into their economic models. This reflects a growing awareness of the short and long-term economic impacts of climate change restrictions, highlighting its importance and urgency.

Recent years have seen numerous work-related deaths attributed to heat stress, and many workers have suffered from decreased productivity due to climate-related health risks. Such developments highlight the urgent need for not just climate economists but a broad spectrum of economic professionals to address and understand the economic consequences of climate change. It's not just about adapting to these changes, there's a pressing need to harness technological advancements like renewable energy sources and carbon capture technologies, which could play a crucial role in mitigating the severe effects of global warming.

The severity of the situation was underscored by the Cerberus Heatwave in 2023, which brought temperatures above 45°C across several European countries, including Cyprus, Greece, Italy, Spain and Croatia. According to BBC news, this extreme weather caused significant disruptions, with people collapsing in the heat and businesses forced to close. One poignant incident involved a worker in Italy who tragically died due to the heat while working outdoors. Events like these not only point to the increasing frequency and intensity of extreme weather but also their profound impact on the economy. They disrupt economic activities, lead to productivity losses, and necessitate business closures.

If current trends continue, climate change is expected to bring more frequent and widespread extreme weather events. This will increasingly demand that adaptations in agriculture and other sectors be attuned not only to gradual changes in climate but to the harsh realities of these acute climatic disruptions. The economic strategies and policies of the future must, therefore, account for these challenges, paving the way for a proactive approach to global climate policy that incorporates both mitigation and adaptation strategies.

Building on the broad implications of climate change, this thesis delves into how variations in key climatic variables such as temperature and precipitation influence economic growth. It further explores the impact of mitigation efforts, including the adoption of renewable energy technologies, on economic stability and growth. By focusing on these critical areas, the thesis aims to provide a detailed analysis of the pathways through which climate change affects economic performance, offering insights that enhance the understanding of the importance of incorporating climate considerations into economic and environmental policies.

The choice of this topic was driven by the escalating global concern over climate change and its wide-reaching effects, which now require urgent and effective responses. This thesis analyses data from 23 countries, representing both developed and developing countries including Australia, Austria, Bangladesh, Belgium, Bulgaria, Croatia, Cyprus, Denmark, Germany, Greece, Hungary, India, Kenya, Lebanon, Luxembourg, Malta, Mexico, Norway, Romania, Spain, Sri Lanka, Sweden and Switzerland, over the period from 1990 to 2020. The data, sourced from the World Bank provides a robust basis for detailed econometric modelling using panel data analysis to understand the relationships between climatic changes and economic growth. The estimation techniques employed, included fixed effects and random effects panel regressions and then a Hausman test to select the most suitable models for the analysis.

This thesis explores several theoretical frameworks that link climate change to economic impacts, providing a foundation for understanding the complex interactions between the environment and economic growth. Central to this exploration is the role of Carbon Dioxide (CO_2) and its impact through the greenhouse effect, which significantly alters temperature and precipitation patterns worldwide. These changes in climate conditions directly influence various economic sectors by altering productivity, resource availability, and overall economic stability. Furthermore, the physical risks associated with climate change include both acute and chronic impacts, such as natural disasters and long-term environmental changes that pose significant financial challenges. Additionally, transition risks arise from the shift towards a low-carbon economy, involving technological, market, and regulatory changes that industries must navigate to remain viable. Understanding these interconnected risks is crucial for developing effective strategies to mitigate the adverse effects of climate change.

Furthermore, the theories explore the Environmental Kuznets Curve (EKC), which suggests a pattern where economic growth initially leads to greater environmental degradation, but as income levels rise, technological advancements eventually result in environmental improvements, forming an inverted U-shaped relationship. The theory of externalities underscores the global impact of individual countries' emissions, highlighting the need for international cooperation to manage climate change. Negative externalities include increased natural disasters, while positive externalities arise from sustainable practices benefiting society. Additionally, the theory of renewable energy transition emphasizes the need for a shift from fossil fuels to renewable energy, balancing economic growth with sustainable development, despite initial costs.

Furthermore, the thesis provides a clear explanation on different key climate related models and offers an overview of the impacts of climate change on various economic sectors, including agriculture, supply chain and logistics, industry and energy, labour, tourism and hospitality, banking and financial services, and insurance. These sectors are affected by climate change and directly contribute to Gross Domestic Product (GDP) growth. Finally, the discussion covers the implications of adaptation and mitigation policies, focusing on key international frameworks and strategies such as Green Growth, Kyoto Protocol, Paris Agreement and carbon taxes. These policies collectively interact to shape global efforts in mitigating climate change, highlighting the importance of international agreements and economic strategies in achieving environmental goals.

The main questions that motivate this thesis are:

1) How do increases in CO_2 emissions, which lead to rising temperatures and changes in precipitation patterns impact GDP growth?
2) What is the impact of renewable energy consumption on economic outcomes?

2. Literature Review

2.1 Historical Overview

The issue of climate change didn't really gain attention until the late 1980s. However, scientists had already started studying this threat as early as the beginning of the 20th century and continued their research efforts for many years. They understood that when we burn carbon-based substances like coal, oil and wood it releases CO_2 into the atmosphere. This CO_2 then disrupts the Earth’s surface temperatures by trapping heat from the sun. During the Industrial Revolution there was an increase in CO_2 levels due to the use of these carbon containing fuels. Initially scientists believed that the oceans were absorbing this CO_2, so they didn't pay attention to it. However, in the century they decided to reassess their understanding. By conducting measurements on top of a volcano from pollution sources they discovered a rise in CO_2 levels in the air. This discovery prompted them to give climate change consideration and dedicate themselves to further research, for many years.

It wasn’t until the early 1990s that economists began to focus on how climate change affects the economy. In 1991, research frameworks based on data related to increased global average temperatures and the concentration of greenhouse gases highlighted the severity of climate change. They demonstrated the potential costs, including damage to infrastructure, loss of agricultural productivity, and increased risk of extreme weather events. These studies also suggested that transitioning to a low-carbon economy could reduce pollution and create new jobs, laying the foundation for ongoing research and raising awareness among economists and policymakers.

Although, in order for these policies to actually have an impact in addressing the climate change, it was necessary to have global cooperation. Most of the countries acknowledged the science of climate change and made significant discussions on how to act against its negative impacts. As a result, they created several international agreements, two significant pivotal accords were named the Kyoto Protocol (1997) and the Paris Agreement (2015). The Kyoto Protocol was in force prior the Paris Agreement. The Kyoto Protocol was established in 1997 and resolved several challenging matters, particularly focusing on the schedule for reducing emissions to a percentage below the emissions prior 1990. However, the suggested protocol had a number of design flows and that resulted to the newest accord named the Paris Agreement in 2015. Johannesson (2017) states that while the Kyoto Protocol focused on how to avoid climate change, the Paris Agreement takes a different approach by recognizing that climate change already exists and we need to adapt to it. The Agreements goal is to decrease the increase in global warming below two degrees Celsius and it is flexible for each country to assign its own goals on the emissions targets, a concept referred to as National Determined Contributions (NDCs).

Over the past decades, the world has witnessed a series of significant environmental events, raising global concerns and highlighting the enormous impact such events can have on the ecosystem. As it is widely known climate change has been linked with the increase of high temperatures. Some stark examples related to that global phenomenon was the European heatwaves of 2003, 2006, 2010, 2015, 2017, 2018, 2022, 2023 where Europe experienced hot weathers causing drought, forest fires, negativities in agriculture and other significant problems to the countries contributing a decline in their GDP. In most countries the daily maximum temperature exceeded 40°C causing drought problems and low water availability, creating negative impact on their vegetation productivity with an estimation of 30% lower gross productivity (Ciais et al, 2005). A crucial contributing element of productivity is the working capacity of individuals which is sensitive to extreme weathers like the increase in the temperature that summer. With their results Leon et al (2021) suggested that nowadays the primary effects of high temperatures on labor efficiency predominantly occur in outdoor sectors, but still have an impact to the whole economy primarily via the mechanism of intermediate goods. They took their research a step further and found future projections that until the year 2060 the consequences of phenomena like this one will increase in Europe if no further mitigation or adaption strategies are taken.

Between the years 2012-2016 California suffered with one of the worst droughts in history making a loss of $21 billion in the industry of Agriculture making significant loses for the economy of the state. The magnitude of the losses incurred was substantial, given the fact that it brought multiple native species closer to extinction, brought difficulties and expenses on households and businesses and had a negative impact on forests as it killed millions of trees. The biggest impact on the economy came from agriculture and hydropower losses. According to Howitt et al. (2014), the total estimation of agriculture losses was $3.8 billion between the five-year period, including losses of net revenue coming from production, dairy and livestock and supplementary expenses for groundwater pumping. The drought reduced by 50% the hydropower production making the state to replace it with costlier gas-turbine electricity generation that amounted $2 billion, which caused increase in market prices and emissions of air pollutants and GHG (Gleick, 2016). In addition to these aspects, it also yielded a positive effect as it helped to bring attention to these issues and prompted innovations and enhancements in water management to be prepared for future droughts in California (Lund et al. 2018).

A specific case of natural disasters that shows the clear consequences of environmental events to the economy is the case of Hurricane Katrina. The event in question took place in August 2005 in New Orleans and has been called the hurricane with the greatest financial consequences in terms of real monetary value in the United States history in more than 75 years (Peterson et al. 2006). The main reason of the huge size of the disaster is the location of New Orleans, which is near the Mississippi River and the hurricane along with the wind and storm brought also flooding that lasted for quite a few days. While safety measures against wind and storms existed in the city of New Orleans, there were not many for flooding. The negative impact on the housing market was estimated between $97.4 billion to $145.5 billion due to the huge catastrophe on all the properties. It also caused more than 1,800 fatalities, a lot of injuries and reduction in population who lived in New Orleans. However, the decline in property supply was greater than the population reduction leading to a sharp increase in housing prices (Vigdor, 2008). Lastly, the negative impact of the hurricane on the labor market was also noticeable with the reduction of the number of workers and the operating firms in New Orleans with a loss of about 70,000 jobs. On the whole, Hurricane Katrina affected several sectors of the economy, including energy, finance, construction, housing, gaming and commercial fishing.

Another example, that is worth mentioning is the Tōhoku earthquake and tsunami that happened in 2011 in Japan that completely obliterated everything in its path, affected businesses and consumers and caused an estimated physical damage of more than $300 billion. To gain a comprehensive prospective of the magnitude of the impact, consider that Cypriot GDP at the moment is $32 billion, thus the damage was 10 times higher. Almost 200,000 citizens had to abandon their place and live to inhospitable places without electricity and with daily minimum temperatures of 0°C (Shibahara, 2011). This environmental disaster not only had a negative impact on the economy of Japan but also affected global financial markets and trade. It reduced the worldwide economic growth by 0.5% as it damaged foreign companies that were established in Japan, caused disruptions in trade and supply chains and created fluctuations on the interest rate and on yen-dollar exchange rate. Japan's economy is very important for the worldwide economic stability as it is famed as one of the world's largest economies where the GDP back then was $5.5 trillion and had a contribution of almost 10% on the global GDP (Shibehara, 2011).

An illustrative case demonstrating the consequences of wildfires resulting from drought, high temperatures and low rainfall is evident in the wildfires that occurred in Australia during the period of 2019-2020. The fires destroyed properties, businesses and many more making approximately $100 billions of economic losses. Based on the article of Wittwer and Waschik (2021), the net present value of the national welfare loss from bushfires was $10 billion, the cost of rehabilitating the burned farmland was approximately $600 million, other replacements cost almost $3 billion, while an amount of $18 million was necessary for all the injuries of citizens and firefighters. The Australian tourism, one of the country's top exports, significantly contributes to the nation's revenue, also felt the impact of the fires. Tourism shut down all over Australia during the tourist peak seasons, even in areas unaffected by the fires physically, created large direct and indirect negativities to the country's income coming from the specific sector.

2.2 Theoretical Background

The Environmental Kuznets Curve (EKC) depicts a U-shaped relationship between environmental degradation, such as CO_2 emissions, and GDP growth. This hypothesis, derived from Simon Kuznets's (1955) theory on the connection between income inequality and economic development, gained prominence after Grossman and Krueger's (1991) analysis of the North American Free Trade Agreement's effects on pollution. The concept was further popularized by the World Bank's 1992 Development Report, which suggested that while economic growth initially exacerbates environmental harm, increasing incomes eventually lead to higher public demand for a cleaner environment. This demand, in turn, spurs investments in environmental protection and technological advancements.

While EKC can be beneficial to address environmental problems resulting from economic growth there are different viewpoints in the literature. Stern (2004) found that there is not enough evidence that EKC holds because of weaknesses in the econometrical framework. They found that most studies assume that the existence of an EKC relationship can be concluded simply based on the nominal significance and expected direction of regression coefficients and overlook factors like serial dependence and stochastic trends in time-series data. When taking into consideration of these factors they found that the EKC does not hold. On the other hand, Panayiotou (1997) gave evidence that for specific environmental problems such as pollutants in the atmosphere, a U-shaped relationship becomes evident with economic development.

A significant concept for the promotion of economic growth and environmental sustainability named “green growth” was innovated in Seoul, South Korea in 2005 at the fifth Ministerial Conference on Environment and Development (MCED). Jacobs (2012), defined the meaning of green growth as a policy that simultaneously brings growth to GDP and achieves significant environmental protection and it is now adopted by international economic and development institutions such as the World Bank, the Organization for Economic Co-operation and Development (OECD), the Global Green Growth Institute and the United Nations Environment Program. Their econometric overview on green growth is based on two claims. Firstly, the costs of identifying all environmental damage are not so high as to reduce the natural growth rate of a well-performing economy to zero. Secondly, if you don't identify this environmental damage, the economic consequences will be worse.

Stern (2007), argued on these claims and reported that the costs of tackling the climate crisis are considerable related to economic growth but they can be controllable and a lot less than the costs of not acting at all. Nordhaus (2007), presented different opinions with both on the policy of green growth, as they claimed that in the long-term countries would be richer because of economic growth and have innovative technologies to adapt or prevent climate crises.

2.3 Evidence Base

From the historical and theoretical background, one can observe the importance of the ever-evolving landscape of climate change and understand the impact of its shifts on economic growth by disrupting supply chains, damaging infrastructure among other critical factors. The evidence presented by various papers highlights the complex ways climate change affects the global economy. From global GDP projections to sector-specific vulnerabilities, the following studies show how important the effects of climate change on the economy are. The findings underscore the need for urgent policy measures to counteract potential disruptions to key components.

Dellink (2014) investigated how climate change affects economic growth globally. They used simulations with the OECD's ENV-Linkages model for macro-level analysis, incorporating long-term implications through the AD-RICE model. Their projections indicated a significant negative impact on annual global GDP due to climate change, estimating a potential loss between 0.7 and 2.5 percentage points by 2060. The impact varied across regions and sectors, with the Agricultural sector being particularly vulnerable, especially to damages from sea level rise. International trade played a role in mitigating impacts in some regions. Regarding CO_2 emissions, they foresaw a substantial future impact, potentially increasing annual global GDP damages to a range of 1.5 to 4.8 percentage points. Notably, they didn't consider certain extreme weather events in their model, which could intensify the negative effects on economic growth. In conclusion, these findings emphasize the need for immediate policy action to tackle the climate crisis. Policies should focus on reducing emissions now to prevent potential damages and preparing for unexpected events to minimize risks.

Transitioning from the global perspective provided by Dellink (2014), Burke (2015) delves into the specific economic impacts of climate change adaption on the agriculture sector in the United States, through variables like temperature and precipitation between the years of 1950-2005. They projected future economic effects on agriculture, with a focus on long-term outcomes for corn and soy production, two vital products in the United States (U.S.) economy. Their model considered farmers' decision-making under different climate conditions and used a production technology model to illustrate climate change's impact on production. Farmer adaptation was factored in through Bayesian learning. Using the long difference approach, they observed limited farmer adaptation, possibly influenced by government insurance programs covering significant losses and discouraging investment in adaptation measures. The projection results indicated that consistent adaptation policies could halve the negative impacts of climate change in the long run compared to the short run. Without such policies and international trade support, the adverse effects on the agricultural sector could be substantial. Specifically, their findings show that an increase in temperature by 1°C reduces agricultural production by 0.56 percentage points at 1% significance level, while changes in precipitation do not show a significant effect.

Dogan (2016) analyzed the impact of renewable energy consumption on economic growth in OECD countries from 1990 to 2010. Using advanced econometric methods to address heterogeneity in renewable energy and economic growth across these countries, the study found that the effects of renewable energy consumption vary across different economic levels. The panel quantile regression results revealed that renewable energy consumption positively affects economic growth in lower and lower-middle quantiles but negatively impacts middle, high-middle, and higher quantiles when measured by absolute value. Furthermore, when renewable energy consumption is considered as a share of total energy consumption, it shows a negative impact on economic growth across nearly all quantiles. Specifically, Dogan found that an increase of one additional kiloton of oil equivalent in renewable energy consumption is estimated to reduce GDP per capita by $3.152 (constant US$ 2005). These findings provide a detailed view of the relationship between renewable energy and economic growth, highlighting the complexity of this dynamic.

Batten (2018), similarly to Dellink (2014), expands this sector-specific analysis to model and forecast macroeconomic variables. This shift allows for a broader analysis of the negative impact of climate change on various important economic variables. Batten (2018) addressed the importance of modelling and forecasting macroeconomic variables to comprehend the adverse effects of climate change on crucial economic factors like output, investment and productivity. The main motivation behind their work was the belief that climate change should concern not only those directly involved in green economy design but also individuals in government, central banks, international organizations and beyond. In their study, they examined the impact of climate change damage on the macroeconomy through physical and transition risk channels following various climatic shocks. Integrated Assessment Models (IAMs) were employed to measure transmission risk, and growth theory was used to explore trade-offs in transitioning to a green economy amid climate change restrictions. Their findings revealed a negative impact of climate change on the economy, with both physical and transmission risks being significant. However, they highlighted that physical risk is likely to pose a more severe threat to the economy in the future. Consequently, they concluded that investing in climate-friendly infrastructure, developing new technologies to reduce atmospheric carbon, and providing support to vulnerable countries are crucial steps.

Kahn (2021) extends the discussion of the macro-level analysis, exploring how climate change impacts economic activity across numerous countries between 1960-2014. They utilized panel data and a stochastic growth model to demonstrate how deviations in temperature and precipitation from historical averages affect long-term productivity. The findings revealed a negative influence on per capita real output growth with changes in temperature, but no significant impact from precipitation. Specifically, they found that an increase in temperature by 1°C reduces GDP per capita growth by 0.58 percentage points at the 1% significance level, while precipitation changes do not show a significant effect.

Moving from a global perspective, Ashizawa (2022) examined the impact of climate change on the economy, focusing on the Japanese Flood as a case study of physical disasters. Natural disasters can harm the economy directly by damaging assets and indirectly through changes in production inputs. Using prefectural accounts and flood statistics, they estimated the indirect negative economic impacts of floods in different sectors, with a fixed-effects model revealing varying effects across Japan. The most negative impacts were observed in manufacturing, wholesale, and retail sectors, but interestingly floods had a positive effect on the construction sector. The economic impact of floods not only varies by sector but also by the type of damage to assets, facilities, and equipment. Notably, the largest impact on the economy occurs when public sector infrastructure, such as roads and public services, is damaged, underscoring the significance of public sector damages in the overall economic impact of climate change. Finally, it was observed that a year after the flood, the long-term effect on the economy became statistically insignificant, indicating a diminishing impact over time.

3. Theoretical and Operational Framework

3.1 Introduction to the Theoretical and Operational Framework

The study of climate change's impact on the economy highlights its complexity and the critical global challenges it presents, affecting all economic sectors. Understanding this impact is crucial due to its potential to disrupt global economic stability through changes in productivity and resource availability, demanding informed decision-making from policymakers and businesses.

This section will present economic theories that illustrate the interconnectedness between climatic crises and economic activities, exploring the effects of variables such as GHG emissions. It will also explore the specific roles of CO_2 in climate change, detailing how increased CO_2 levels enhance the greenhouse effect that warms the planet and alters global weather patterns. Additionally, this section will address the risks associated with climate change, categorized into physical risks and transition risks. Emphasizing the need for robust policies and technologies, this discussion underscores the importance of informed decision-making by policymakers, businesses, and societies. The aim is to enhance understanding of how climate variations affect productivity, resource availability, and economic growth.

This section serves as a foundation for the thesis by outlining economic theories and key models that support the empirical analysis to follow. These insights are crucial for comprehending the broad economic repercussions of climate change and developing effective strategic responses.

3.2 CO_2's Role in Climate Change and the Economy

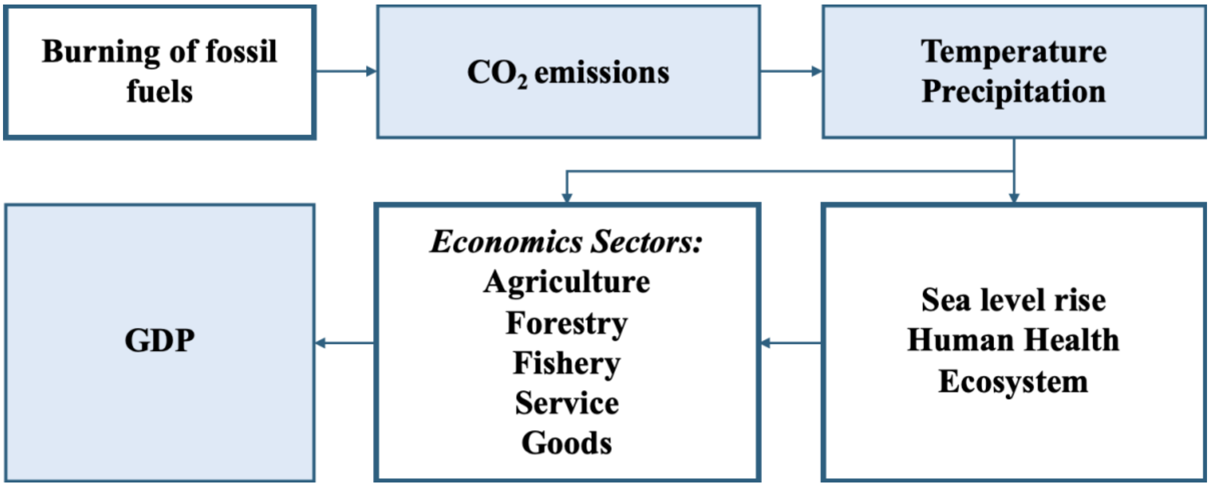
CO_2 plays a crucial role in regulating Earth's temperature, acting much like a blanket that traps heat. This phenomenon, commonly known as the greenhouse effect, is vital for keeping the planet warm enough to sustain life, but an increase in CO_2 from human activities is affecting the balance of this.

The way that this works is when sunlight reaches Earth, the ground absorbs some of this solar energy and heats up. Earth's surface then radiates this heat back towards space as infrared energy. Normally, some of this heat escapes into space, keeping the planet's climate in balance. However, with higher concentrations of CO_2 in the atmosphere, primarily added through the burning of fossil fuels like coal and oil, more heat gets trapped. This is because CO_2 molecules absorb the infrared energy and reradiate it in all directions, including back down towards Earth, which increases the planet's surface temperature.

This enhanced greenhouse effect is causing global temperatures to rise, leading to several changes in weather patterns, including precipitation. As temperatures increase, more water evaporates from the surface of oceans, lakes, and rivers and from soil. This extra water vapor then gets carried into the atmosphere, where it can form clouds and, eventually, precipitation. Hence, some regions experience more rainfall and more intense weather events, like storms and hurricanes, while others may face droughts due to shifting climate patterns.

Understanding this connection between CO_2 emissions and changes in temperature and precipitation is crucial as it affects the economy. Figure 1 explains the relationship between CO_2 emissions and GDP. The increased CO_2 emissions in the atmosphere, coming from the burning of fossil fuels, affect the climate, which in turn will directly and immediately impact important economic sectors such as agriculture, forestry, fishery, service, and goods sectors. Additionally, the resulting climate changes will indirectly affect these sectors in the long term, with more significant effects through sea level rise, which will increase the risk of floods, changes in human health, and ecosystem collapse. The negative effects on these sectors will then directly impact GDP.

Figure 1 – How CO_2 emissions affect GDP



3.3 Risks Associated with Climate Change

3.3.1 Physical Risks

Physical risks are associated with the impacts of climate change and can be categorized into acute and chronic types. Acute physical risks refer to immediate catastrophes triggered by events such as extreme weather conditions, hurricanes, heatwaves, cold snaps, or floods. These are sudden disasters that have a direct and immediate effect. On the other hand, chronic physical risks involve long-term changes in climate that gradually create conditions detrimental to environments and economies, such as rising temperatures, sea-level rise, and shifts in precipitation patterns. These physical risks have significant financial implications as they can directly damage assets and indirectly cause disruptions in the supply chain. For instance, infrastructure like roads and bridges may be destroyed or severely damaged by flooding, requiring costly repairs or replacements. Similarly, businesses may face operational interruptions when key resources are affected by unseasonal weather patterns.

3.3.2 Transition Risks

Transition risks are the challenges and uncertainties faced when shifting towards a low-carbon economy. This shift involves significant changes in technology, market dynamics, and governmental policies. As new technologies emerge to reduce carbon emissions, industries may need to invest heavily in updating equipment and processes, which can be costly and disruptive in the short term. Markets may also fluctuate during this transition period, as demand increases for green products and services while declining for those associated with high emissions. Policy changes can introduce additional risks. New regulations, such as carbon pricing or emissions caps, can affect profitability and operational practices. Companies must adapt quickly to comply with these regulations, potentially facing financial penalties or lost market share if they fail to meet new standards.

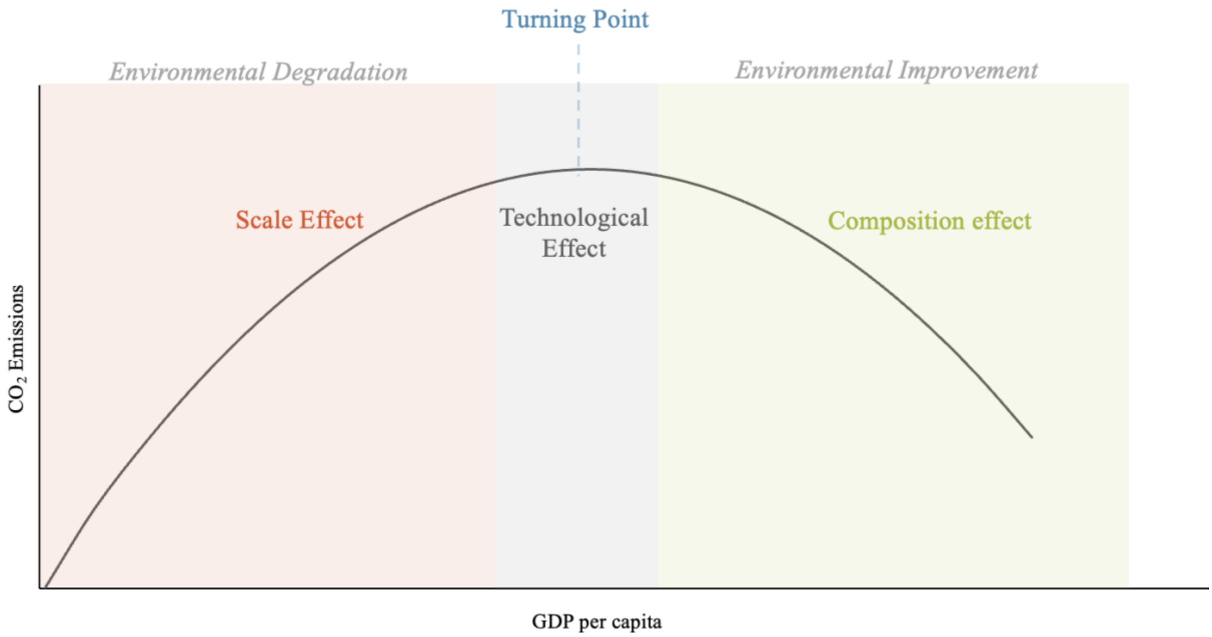
3.4 Economic Theories of Climate Impact

3.4.1 Environmental Kuznets Curve (EKC)

Rooted in Simon Kuznet's work from the 1950s, the Environmental Kuznets Curve (EKC) theory was brought to prominence in the realm of environmental economics by Grossman and Krueger in the 1990s. It postulates an inverted U-shaped relationship between economic development and environmental degradation, suggesting that an economy's increasing emissions and energy use, which initially degrade environmental quality, will eventually lead to improvements at higher income levels.

This curve has been a main approach for economists since the early 1990s to understand the connection between GHG emissions and economic expansion. Figure 2 shows the positive correlation between GDP per capita and CO_2 emissions up to a tipping point, after which the relationship becomes inverse. The EKC hypothesis is founded on three primary effects: the scale effect, the technological effect, and the composition effect. The scale effect describes the initial rise in environmental damage as economies expand and resource use intensifies. The technological effect accounts for the curve's peak, where investments in efficiency and research lead to decreased resource inputs for greater outputs, marking a turning point in the curve. As companies prosper and the service sector grows, the composition effect takes hold, leading to greater wealth without proportional increases in pollution.

Figure 2 – Environmental Kuznets Curve (EKC)



3.4.2 Negative and Positive Externalities with Climate Change

The concept of externalities becomes globally significant when the actions of a single country have worldwide impacts. This is exemplified by the theory of externalities, which underscores the importance of national actions globally. In the context of climate change, the emissions from one country can influence global warming, affecting every nation either negatively or positively. This dynamic illustrates the crucial role of international cooperation, as each country's contributions to climate change demonstrate how interconnected the planet truly is.

As GHG concentrations rise, the mean atmospheric temperature is expected to increase, potentially increasing the frequency of natural disasters that affect the economic activity worldwide. Entities often decide based on decreased costs and profit benefits from increased production, failing to acknowledge the real cost of their actions assuming that their contribution is too minor to the wider climatic impact and as a result the social costs exceed their private costs. This logic mirrors the "Prisoner's Dilemma" in game theory, where individual rational choices result in collectively irrational outcomes, due to a failure in coordination to reduce emissions.

Positive externalities emerge when organizational actions benefit society at large. For example, investment in R&D may yield new technologies and innovations that benefit the wider society beyond the originating entity. Specifically, organizations that adhere to regulations and prioritize sustainability can generate broad environmental and public health benefits while realizing energy efficiency and cost savings themselves, leading to social returns exceeding private gains.

3.4.3 Theory of Renewable Energy Transition

Through the years, energy consumption has grown at a rate surpassing that of population growth. This rise, coupled with the escalating frequency of climate disasters, underscoring the urgent shift towards renewable energy sources. Table 1 presents a clear image on different renewable energy sources, how they are derived from natural sources to understand their pivotal role in sustainable development by impacting social, economic and political sectors. It not only offers a limitless supply but also minimizes carbon emissions, contributing to a zero-carbon footprint.

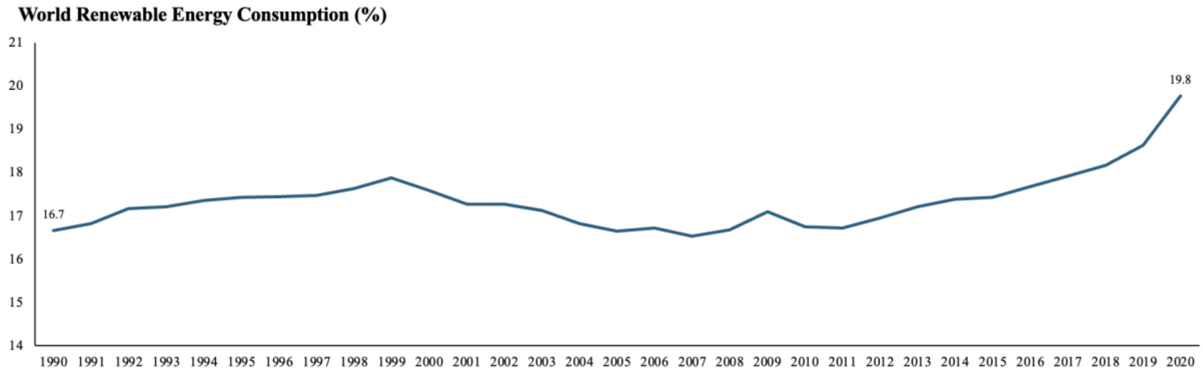
Table 1 – Types of renewable energy sources and mechanisms

	Mechanism	Usage
Solar Energy	Solar panels create electricity by capturing sunlight and converting it into an electrical current through the absorption of photons.	Homes, businesses
Wind Energy	Wind turbines convert wind energy into electrical energy by rotating blades connected to a rotor, which drives a generator to produce electricity.	Commonly deployed in extensive wind farms to supply electricity to national grids, as well as in single turbines for personal or localized use.
Hydropower	Utilizes moving water to turn a turbine linked to a generator. This water movement can originate from natural river flows or controlled releases from reservoirs.	Primarily utilized for large-scale electricity production, it is one of the oldest and most established renewable energy technologies.
Geothermal Energy	Utilizes heat from beneath the earth's surface to generate electricity or to heat and cool buildings directly.	Generates electricity and provides direct heating by accessing steam and hot water from underground reservoirs.
Biomass Energy	Harnesses geothermal energy from beneath the Earth's surface to produce electricity or to directly regulate the temperature in buildings.	Can substitute traditional fuels such as coal for heating and electricity generation, and is also employed in the production of biofuels.
Ocean Energy	Tidal power transforms the energy of ocean tides into electricity through the use of turbines or barrages. Wave energy captures the movement of surface waves to generate power. Ocean Thermal Energy Conversion (OTEC) exploits the temperature gradient between warm surface water and cold deep water to operate a heat engine.	Currently in the developmental phase, but holds significant promise for large-scale energy production in coastal regions.

The adaption of renewable energy presents a viable alternative to fossil fuels, crucial for reducing CO_2 emissions. However, transitioning to these energy sources needs substantial initial investment in new technologies and the restructuring of production methods, which is very costly. Countries must therefore find a way to balance between mitigating climate impacts, fostering economic growth and investing in sustainable practices. While the transition to renewable energy is both time-intensive and expensive creating a negative impact to the short-term GDP growth, it is essential for achieving long-term economic stability and environmental health. Countries have begun to invest in renewable energy and the shift is evident from Figure

3, which shows a considerable positive trend in the share of renewable energy consumption to the total energy consumption over the years.

Figure 3 – Increasing trend of Renewable Energy Consumption as a part of total energy consumption.



Source: World Bank Open Data

3.5 Review of Key Economic Models of Climate Change

There are a lot of prominent economic models that have been instrumental in assessing and interpreting the economic impacts of climate change. Table 2 presents the foundational models that have shaped the theory of climate economics. For each model there is a specification of the year of introduction, the developer or institution responsible if available and a description for each model's structure. The table further introduce the key contributions each model has made, its practical applications and its influence on policy.

Theoretical models help in understanding the complex relationship between climate and economic dynamics as they are crucial for predicting future economic outcomes and for planning effective responses.

Table 2 – Key Economic Models of Climate Change

Model	Year Introduc	Developer(s)	Detailed Description	Key Contribution	Applications	Influence on Policy
Strategic environmental assessment (SEA) Environmental Impact Assessment (EIA) & Climate risk assessmnent (CRA)	Late 20th century	European Commission	The European Commission has developed these three models to guide environmental assessments at different stages of a project's lifecycle. SEA assesses the environmental implications of policies or programs, EIA evaluates the environmental impacts of specific projects, and CRA anticipates and mitigates climate-related risks of projects.	Facilitates comprehensive environmental management by integrating considerations at all project stages.	Used in policy formation, project management, and environmental regulation.	Shapes EU environmental legislation and project approval processes by emphasizing preemptive risk assessment and sustainability.
Dynamic integrated climate-economy (DICE)	1992	William Nordhaus	A pioneering model that combines climate science with economics to estimate the costs of climate change and the benefits of reducing greenhouse gas emissions.	One of the earliest tools to evaluate the economic impacts of climate policies.	Economic policy formulation, climate change economics education.	Has influenced discussions on carbon taxes and international agreements.
Regionally aggregated climate-economy (RICE)	1996	William Nordhaus & Zili Yang	An extension of the DICE model that provides a regionalized analysis of climate-economy interactions, allowing for differentiated regional approaches to policy-making.	Enhances the DICE model by incorporating regional data for more localized policy analysis.	Regional economic planning, climate policy analysis.	Used to advocate for differentiated responsibilities in climate agreements.
Integrated Assessment Models (IAMs)	1970s-1980s	Multiple developers across disciplines	Integrated Assessment Models that bring together knowledge from various fields to assess the relationships between human activities, climate change, and policy responses.	Facilitates interdisciplinary research and comprehensive climate policy analysis.	Policy-making, academic research, environmental economics.	Central to the formulation of Intergovernmental Panel on Climate Change (IPCC) reports and national climate policies.
Computable general equilibrium (CGE)	1960s	Various economists	Computable General Equilibrium models simulate how an economy might react to external changes, including environmental policies, by using actual economic data.	Allows for detailed analysis of economic sectors and the impacts of environmental policy.	Economic forecasting, evaluation of tax policies, trade agreements.	Influences environmental tax reform and trade negotiations.
Stochastic dynamic programming (SDP)	1950s	Richard Bellman and others	Stochastic dynamic programming models account for randomness and uncertainty in data to optimize decision-making over time.	Addresses uncertainty in climate predictions and economic planning.	Natural resource management, financial planning.	Supports adaptive management policies in resource-dependent sectors.
Risk-based decision-making (RBDM)	1980s	Decision theorists and economists	Risk-based decision-making models are used to make informed choices under uncertainty, considering the probability and impact of risks, particularly climate-related ones.	Enhances the capacity to make decisions that are robust under a wide range of possible future states.	Infrastructure development, business strategy, public policy.	Informs regulatory frameworks for climate risk management.

3.5.1 SEA, EIA and CRA

European Commission has developed three models for application during various stages of a project's lifecycle, including Strategic environmental assessment (SEA), Environmental Impact Assessment (EIA) and Climate Risk Assessment (CRA). SEA serves to evaluate the environmental consequences of proposed policies or programs, integrating environmental considerations early in the decision-making process. EIA is concerned with identifying and assessing the environmental effects of specific projects across their entire duration. Meanwhile, CRA focuses on anticipating a project's climate-related risks, offering recommendations to mitigate these risks and enhance the project's contribution to sustainable economic development.

A screening process is required to determine the appropriate model for a given project, as recognized by the European Union (EU). Following this, a Climate Risk Management Plan (CRMP) is formulated to mitigate climate risks. The data required for such a model is comprehensive and detailed project information and forecasts of climate change variables like temperature and precipitation, as well as other location-specific climate impacts. This structured methodology facilitates a thorough understanding and management of climate – related risks.

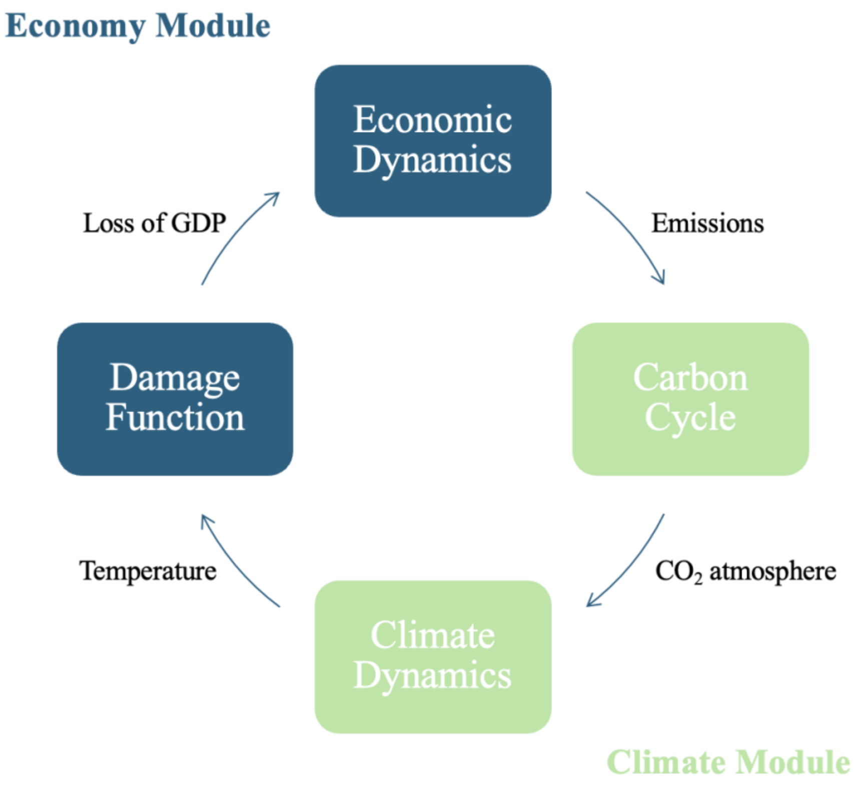
3.5.2 DICE and RICE

The DICE model, developed by Nordhaus, is one of the earliest global tools used to evaluate the economic impact of climate change. It integrates climate economics to estimate the costs of climate change and the benefits of reducing GHG emissions. The model plays a crucial role in shaping economic policies and has significantly influenced discussions on carbon taxes and international agreements. It emphasizes the need to reduce current consumption to mitigate future climate damages, thereby increasing the potential for future consumption growth. This approach supports the theory that investments made today in emission reductions can decrease current consumption but ultimately lead to reduced climate damage and increased future consumption possibilities.

The DICE model consists of two main modules: the Economy Module and the Climate Module. The Economy Module includes Economic Dynamics and a Damage Function. Economic Dynamics encompass the fundamental economic activities such as production, consumption and investment, which determine the overall economic growth and output. The Damage Function calculates the economic losses caused by climate change impacts. The Climate Module addresses emissions by tracking GHG from economic activities. It also covers the Carbon Cycle, where emissions are absorbed by oceans and affect the climate and Climate Dynamics, which describe how atmospheric GHG lead to changes in climate conditions, primarily temperature increases.

Interactions between the modules occur as Economic Dynamics directly influence emissions through industrial activity and energy use. These emissions then feed into Carbon Cycle and affect Climate Dynamics, such as temperature increases. Rising temperatures impact the Economy Module's Damage Function, potentially causing greater economic damage due to factors like extreme weather conditions or sea-level rise affecting Economic Dynamics by reducing GDP. This creates a feedback loop where economic activities lead to increased emissions and these emissions then impact the climate which circles back to affect the economy through physical and structural damages.

Figure 4 – DICE Model Interaction Flowchart



While the DICE model adopts a global approach using aggregated world data, the RICE model extends this framework to incorporate regional data, allowing for more localized policy analysis. It segments the global economy into multiple regions, providing a more detailed analysis of how climate change affects different parts of the world. By utilizing specific regional data, the RICE model can account for regional variations in economic impacts related to climate and assist in the development of targeted mitigation policies. This approach proves especially useful in the context of international climate agreements, as it is tailored to consider and address region-specific factors.

3.6 Impact of Climate on Economic Sectors

Climate change influences various economic sectors, each facing unique challenges and undergoing significant transformations. This section examines the different impacts of climate change across diverse areas including agriculture, supply chain and logistics, industry and energy, labour, tourism and hospitality, banking and financial services and insurance. Understanding these impacts helps policy makers to develop adaptive strategies and policies to mitigate risks and provide positive impact on the environment.

3.6.1 Agriculture Sector

Agriculture plays an important role in society, not only by providing food and raw materials but also by fuelling economic growth through job creation and trade. Agriculture begins with the production of raw materials, which are essential for manufacturing and contribute significantly to the global supply chain and economic development. Without these raw materials, manufacturers would be unable to produce goods. Moreover, the import and export of agricultural products are vital for global trade, enhancing the sector’s impact on the economy. Agriculture also drives economic development by creating employment opportunities. In regions with high agricultural productivity, there tends to be higher per capita income, as producers invest in innovative technology to enhance productivity and profitability.

However, the agriculture sector is one of the main and first sector affected by climate change, experiencing direct impacts from climatic factors which then influence the broader economy. Over time, climate change could alter agriculture in various way, altering crop quality and quantity, affecting growth rates, photosynthesis, transpiration rates, and moisture availability. For example, an increase in temperature could reduce crop production or degrade quality, directly impacting food availability worldwide. Events like droughts and floods can disrupt agricultural production, leading to supply shocks that potentially increase food prices and cause cost-push inflation, affecting both domestic and international markets.

The greenhouse effect, which creates a warmer environment, can lead to droughts, severely affecting agricultural output. While increased CO_2 levels can initially boost photosynthesis and reduce water usage, making plants temporarily more efficient, the long-term consequences include a rise in sea levels and changes in temperature and precipitation patterns. Sea-level rise can result in the loss of arable land, coastal erosion, and the salinization of groundwater, whereas temperature changes can lead to droughts, diminishing the quality and quantity of crops. This reduces the supply available to markets, impacting farmers' livelihoods and leading to economic losses.

The last years, the agriculture sector is undergoing significant transformations due to socioeconomic development, technological change, population growth, and shifting commodity demands. There is also a growing need for sustainability within the sector to address both current needs and future challenges posed by climate change.

3.6.2 Supply Chain and Logistics

Climate change significantly impacts supply chains and logistics, influencing the whole process from manufacturing to consumption. Manufacturing processes are substantial contributors to GHG emissions, prompting carbon mitigation regulations. Similarly, transportation, a major component of global warming, faces disruptions due to extreme weather events like hurricanes, floods, and heavy snowfalls. These disruptions can lead to delays or damage to goods in transit, directly affecting shipment schedules.

Storage and warehousing contribute both directly and indirectly to pollution, utilizing large land areas and substantial energy, which also heightens their vulnerability to climate-induced physical damage. Trading is sensitive to climate risks as goods need to go from one region to another, often disrupted by natural disasters blocking key transport routes like roads and ports.

Furthermore, consumer behavior impacts climate change through the consumption of products and the subsequent disposal of packaging and waste, adding to environmental strain. The demand for more sustainable products is influencing market changes, requiring adjustments in supply chain practices to accommodate greener alternatives.

The supply chain is also affected by the vulnerability of suppliers, particularly those reliant on natural resources or located in areas prone to climate impacts. This vulnerability can affect their production capacity and ability to meet demands. Uncertainties in climate conditions lead companies to increase inventory levels as a buffer, which in turn raises their costs.

Infrastructure critical to logistics, such as ports, warehouses, and roads, may suffer damage from climate-related events, leading to additional repair costs and delays. Regulatory changes aimed at reducing emissions and mitigating environmental impact further affect how products are transported and managed.

Lastly, economic impacts such as fluctuations in consumer demand, fuel prices, and the cost of raw materials are influenced by climate change, affecting the overall stability and efficiency of supply chains.

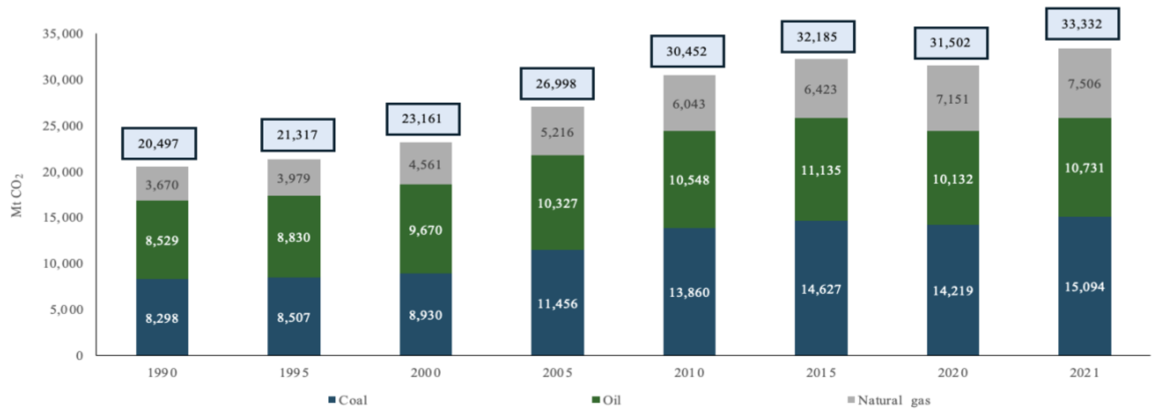
3.6.3 Industry and Energy

Industry contributes directly and indirectly to climate change through energy consumption, accounting for a significant amount of global GHG emissions, largely from energy use. The combustion of coal, oil, and natural gas is the main source of the world's GHG emissions. However, the sales of these fuels also drive economic growth in resource-rich countries and bring revenues to global firms.

Since the early 2000s, there has been a significant growth in GHG associated with energy use. Yet, industries have already started improving energy efficiency and are increasingly focusing on replacing traditional energy sources with alternative options to reduce GHG emissions. Specifically, CO_2 emissions primarily come from three sources: the direct use of fossil fuels for heat and power within the industry, indirectly through the generation of purchased electricity and steam, and through non-energy uses such as chemical processing and metal smelting. Additionally, processes like cement and lime manufacture contribute to emissions from non-fossil fuel sources. Industrial activities, especially in chemical manufacturing and metal smelting, are also significant sources of other GHG.

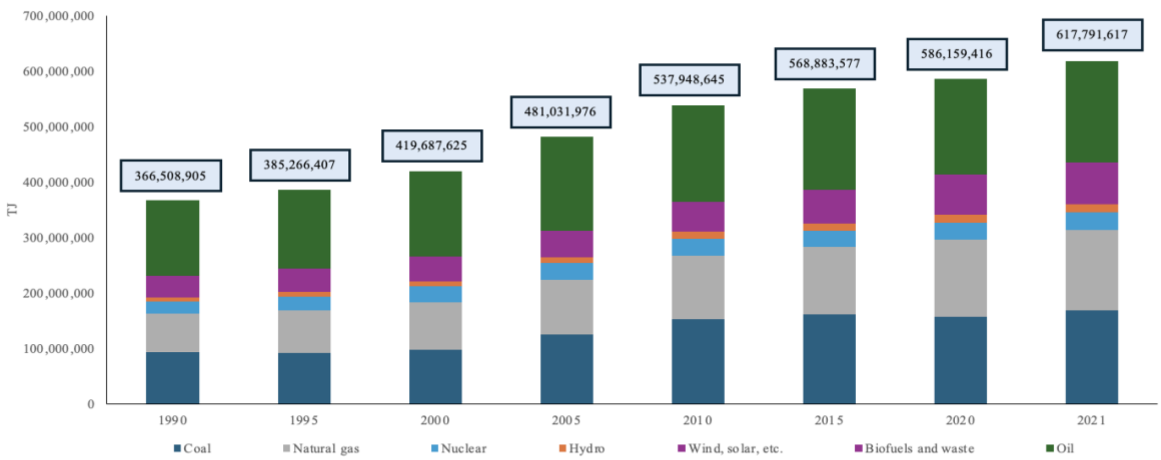
Figures 5 and 6 illustrate the trends in total energy supply and CO_2 emissions by energy source over recent years worldwide, showcasing a consistent increase. This ongoing rise in both underlies the pressing need for continued improvements. Efforts to reduce CO_2 emissions related to energy use can benefit significantly from a variety of technologies aimed at increasing energy efficiency, switching fuels, enhancing material potential to mitigate the environmental impact of industrial energy use.

Figure 5 – CO_2 per energy source



Source: IEA- International Energy Agency database

Figure 6 – Total Energy supply by source



Source: IEA- International Energy Agency database

3.6.4 Labour

Climate Change affects labour with both direct and indirect impacts that are often immediate and observable. Extreme weather conditions, such as heat waves, directly affect the physical capabilities of workers, mostly affecting sectors like agriculture and construction. It is important to understand that climate change influences labour not only through climatic changes like extreme weather but also through natural disasters such as earthquakes, droughts, storms, hurricanes, wildfires, floods and pollution.

Labour supply and productivity are expected to decline under climate change conditions, especially in tropical regions. While outdoor workers are directly affected by the changing environmental conditions, indoor workers can also be indirectly affected. Indirect effects include health problems caused by bad air quality and diseases carried by insects. Additionally, natural disasters can cause substantial damage to buildings and other business assets, transport routes and industrial and agricultural infrastructure, leading to significant job losses.

For instance, increased daily temperatures and humidity levels, forcing workers to reduce work intensity or take more frequent short breaks, which slows down productivity. It is important to note that if a body temperature goes above 39°C will lead to heatstroke, and temperatures exceeding 41°C may be life-threatening. As temperatures and humidity rise, the human body adapts by increasing blood flow to the skin's surface and sweating to regulate temperature. However, these adaptations make sustained physical activity more challenging and reduce workers' productivity.

Additionally, as mentioned earlier, climate change has a direct impact on agricultural production. In developing economies, where agriculture is a central economic pillar, the impact of climate change on agriculture can have broader effects on aggregate income and employment. This interconnection underlines the wider economic implications of climate impacts on the labor force in these regions.

These impacts of climate change on labour highlight the critical need for adaptive strategies in the workforce to mitigate these effects. Employers and policymakers must prioritize creating work environments that can withstand the challenges posed by climate change, ensuring safety and sustainability in the face of these evolving threats.

3.6.5 Tourism and Hospitality

Tourism and hospitality are linked to climate change, both influencing and being influenced by it. As tourists travel from one place to another, their transportation contributes to GHG emissions, directly impacting the atmosphere. Hotels, as fixed assets, are particularly vulnerable to climate change, with natural disasters such as floods and wildfires causing significant damage to properties and leading to substantial losses in tourism revenue.

The impact of climate change on tourism is both direct and indirect, affecting natural and cultural environments and putting weather-dependent tourism activities at risk. Changes in climate conditions influence tourists' choice of destinations and the types of holidays they prefer, making them be attracted to locations that are safer from climate impacts.

In response, many hotels in various countries have begun investing in energy-efficient technologies and adopting practices to reduce their carbon footprints. This shift is partly driven by the need to manage potential increases in costs related to property damage and stricter pollution mitigation regulations. Moreover, changes in tourist flows and behaviours due to climate concerns are prompting the hospitality industry to adapt to new customer preferences.

Hot weather can significantly alter tourist preferences, with travellers seeking cooler or more comfortable climates, especially during heatwaves. These conditions pose health risks such as heat strokes and dehydration, not letting tourists from engaging in outdoor activities. For the hospitality sector, extreme warmth increases operational costs as the need for air conditioning and refrigeration grows, necessitating higher operational budgets and increase needs for new investments.

Through these adaptations and investments, the tourism and hospitality sectors are evolving to face the challenges posed by climate change, aiming to sustain their viability and continue attracting tourists despite environmental changes.

3.6.6 Banking and Financial Services

Central banks, responsible for financial and macroeconomic stability, are increasingly recognizing the necessity to address climate-related and environmental risks at a systemic level. In response, they are adapting the models used by commercial banks for loan considerations to include climate change factors. This integration ensures that climate-related risks are considered in their controls over commercial banks, highlighting the importance of climate considerations in central banking decisions and supervision.

Banks now need to assess the climate change exposure of borrowers when determining eligibility for loans and setting interest rates. This assessment includes evaluating physical risks to collateral in disaster-prone areas, such as properties located in regions that are most likely to suffer from flooding, droughts, or earthquakes. Additionally, banks consider the operational adjustments companies must make to comply with climate change mitigation policies, such as CO_2 emission reductions. For example, a manufacturing facility required to reduce emissions might experience decreased production capacity, which can impact profitability and increase their probability to default their loan. Consequently, businesses with high exposure to climate change regulations might face higher interest rates due to the increased risk of default.

The broader financial system also faces increased systemic risk due to climate change. Extreme weather events and the transition to a low-carbon economy can cause significant asset volatility, mostly affecting real estate and commodities. This volatility increases the risks for banks holding these assets or having significant exposure to affected sectors, potentially leading to greater financial instability.

In response to these challenges, central banks are promoting the development of green finance models through regulatory supervision. These models aim to address environmental risks and promote sustainable finance, contributing to the stability and development of the financial sector. Moreover, climate change's impact on sectors such as agriculture influences supply and prices, contributing to inflation. This necessitates monetary policy adjustments by central banks. They must consider climate-related effects on food and energy prices, alongside the impacts of climate mitigation policies. However, focusing primarily on inflationary impacts without considering broader economic effects of climate policies may result in output losses.

3.6.7 Insurance Service

The insurance industry plays a crucial role in making society and economy more resilience to climate change. This sector faces significant challenges in accurately measuring and predicting climate-related risks because these involve uncertainties about future events that have not yet occurred, such as natural disasters driven by climate changes.

Insurance companies traditionally manage risks by setting premiums that are supposed to cover potential future claims resulting from catastrophic events. However, the increasing frequency and severity of these events, such as floods, droughts, and wildfires, complicate this. As these disasters become more common, insurance providers may need to raise premiums to cover the increasing costs. Yet, continuously increasing premiums is not a feasible long-term strategy, as excessively high rates could lead to higher numbers of uninsured individuals and businesses.

In addition to property and infrastructure damage, climate change significantly impacts life insurance sectors. The industry must now consider the health implications of climate change, which can cause health issues, particularly among vulnerable groups like the elderly or those with chronic conditions, during extreme hot weather events. Moreover, some of the responses to climate change, such as increased energy taxes and other regulatory costs could challenge the ability of companies and private individuals to fulfil their financial obligations to insurers.

These dynamics underscore the pressing need for the insurance industry to develop new strategies and models that can accommodate the unpredictable impacts of climate change, ensuring both affordability for consumers and financial sustainability for insurers.

3.7 Policy and Economic Strategies against Climate Change

As policy makers have grown increasingly aware of the critical importance of climate change, they have developed some policy and economic strategies to address this global challenge. This section will explore several important approaches including the Green Growth concept, the Kyoto Protocol, the Paris Agreement and carbon taxes. Each represents a strategic response to the urgent need for sustainable development and carbon management, aiming to align economic progress with environmental preservation. These policies will be detailed further, providing a clearer understanding of how each contributes to tackling the profound impact of climate change on a global scale.

3.7.1 Green Growth Concept

The concept of green growth was innovated in Seoul, South Korea in 2005 at the fifth Ministerial Conference on Environment and Development (MCED). The MCED introduced the Seoul Initiative Network on Green Growth (SINGG), which advocates for economic development that promotes environmental sustainability and economic growth at the same time. This approach has gained international attention, significantly from organizations such as the OECD, which adopted a Green Growth Declaration in 2009, and the United Nations Environment Programme (UNEP) in 2012. Together with the World Bank and the Global Green Growth Institute (GGGI), these bodies have developed the Green Growth Knowledge Platform (GGKP) to support research and assist countries in implementing green growth strategies.

Green growth is recognized as a leading concept for sustainable economy and development because it addresses both economic and environmental sustainability. Unlike other approaches that may focus only on environmental protection without considering economic costs, or economic models that overlook environmental impact, green growth emphasizes the importance of balancing sustainable development with economic expansion.

The rationale behind green growth is grounded in the comparison of the costs of addressing versus ignoring environmental damage. It suggests that while there are immediate costs associated with mitigating environmental damage, these are substantially lower than the long-term costs of inaction. Green growth strategies promote investment in sustainable practices and technologies that, although initially costly, lead to benefits such as reduced pollution, job creation in new green industries, lower taxes, and higher profits from cleaner alternatives.

This model suggests that the long-term costs of ignoring environmental damage, such as limitations on resources, climate change, ecosystem collapse, and temperature fluctuations, will far exceed the costs of proactive investments in sustainability. The potential for severe economic consequences from natural disasters and necessary adjustments further underscores the economic viability of green growth. By investing in sustainable technologies now, it can prevent much greater future expenses and foster economic growth that is both substantial and sustainable.

3.7.2 Adaptation and Mitigation Policies

Adaptation and mitigation represent two fundamental strategies in the global approach to climate change. Adaptation policies aim to reduce the impact of expected climate change effects, while mitigation policies seek to reduce the emission of GHG. These strategies suggest actions designed to address both the causes and impacts of climate change. This section delves into the Kyoto Protocol and the Paris Agreement as key international efforts to implement these policies, examining their evolution and approaches.

3.7.2.1 Kyoto Protocol

The Kyoto Protocol, adopted by the UN Climate Change Conference in Kyoto, Japan in 1997, marked a significant milestone in global efforts to address climate change, although it did not enter into force until 2005. This international concept was designed to target industrialized nations to transition to low-carbon economies by setting legally binding limits on their GHG emissions. These countries, recognized as the primary contributors to global emissions, had to reduce their emissions by an average of 5% below 1990 levels during the first commitment period from 2008 to 2012.

Under the Protocol, participating nations were required to not only meet their emissions targets but also to regularly report their emissions data. The focus was primarily on developed countries, under the principle that they bear the larger responsibility for current levels of GHG in the atmosphere due to their longer history of industrial activity.

The Protocol was further amended in 2012 by the UN Climate Change Conference at Doha, Qatar, leading to the Doha Amendment which introduced a second commitment period running from 2013 to 2020. However, this period saw reduced participation from member countries, reflecting shifting dynamics and criticisms of the Protocol's effectiveness and fairness. At the end of 2015, the Paris Agreement was adopted in Paris, effectively replacing the Kyoto Protocol beyond 2020 with a new global framework to reduce GHG emissions.

3.7.2.2 Paris Agreement

In 2015, the Paris Agreement was adopted at the UN Climate Change Conference in Paris, France, and it came into force in 2016. This agreement's long-term goal is to maintain the global average temperature rise well below 2°C above pre-industrial levels, while aiming to further limit the increase to 1.5°C. This target is crucial as it significantly reduces the risk of severe climate impacts, including extreme droughts, heatwaves, and heavy rainfall.

The Paris Agreement is a landmark because it unites all participating countries both developed and developing in an ongoing effort to fight climate change. This inclusiveness ensures a broad approach to mitigating global warming and its effects. The agreement specifies that global emissions should peak before 2025 and aims for almost half reduction by 2030.

Under the Paris Agreement, countries operate within a dynamic five-year cycle of commitment and review. This framework demands substantial economic and social transformations. Each country is required to prepare, communicate, and maintain successive Nationally Determined Contributions (NDCs) to achieve the main goal. These NDCs must be updated every five years, reflecting increasing levels of ambition over time.

As it stands, almost all nations have signed the Paris Agreement, illustrating global commitment to this comprehensive plan. This approach not only underscores the universal recognition of the climate challenge but also amplifies the collective resolve to pursue sustainable development while reducing GHG emissions globally.

3.7.2.3 Kyoto Protocol vs Paris Agreement

Table 3 highlights the key differences between the Kyoto Protocol and the Paris Agreement, illustrating how global adaption and mitigation policies have evolved to address the pressing issue of climate change more effectively.

Table 3 – Main differences of Kyoto Protocol and Paris Agreement

	Kyoto Protocol	Paris Agreement
Target Parties	Developed countries	All countries
Task	All countries reduce greenhouse gas emissions to a specific threshold.	Each countries set their own national targets for reducing emissions.
Long-Term Goals	Set specific targets for emission reductions by certain deadlines.	To maintain the global average temperature rise well below a specific degree Celcius above pre-industrial levels.
Mechanisms for Compliance	Penalties when non-compliance.	Relying on transparency and international peer presure to encourage compliance.
Adaptation Efforts	Focused mainly on mitigation with less emphasis on adaptation to climate change.	Places equal emphasis on adaptation and mitigation, recognizing the importance of strengthening resilience and reducing vulnerability to climate change.
Update and Review	Had commitment periods for which targets were set in advance (e.g., 2008-2012, 2013-2020).	Establishes a five-year cycle for updating NDCs, with each successive national plan expected to be more ambitious than the last.

GHG emissions from one country can significantly impact the global climate, leading to consequences that affect all nations. This global externality demands international effort collaborations and poses substantial challenges for international relations and policy governance. The Kyoto Protocol and the Paris Agreement represent pivotal attempts by the international community to tackle climate change collectively. However, the success of such frameworks largely depends on the commitment of participating countries to adhere to agreed targets and the effectiveness of mechanisms established to monitor and enforce these commitments.

3.7.3 Addressing Climate Change through Carbon Taxes

In response to rising GHG emissions and their profound impact on global climates, governments have increasingly adopted carbon taxes as a strategy to promote reductions in emissions. Unlike specific emission reduction policies and agreements, a carbon tax does not limit the amount of emissions but imposes a cost on them, encouraging emitters to reduce their output to avoid high fees. This financial mechanism operates either as an emissions tax directly on the quantity of GHG emitted or as a tax on goods and services that are intensive in GHG production, such as gasoline.

Carbon taxes apply to a range of carbon-based fuels like coal, oil products, and natural gas, impacting fuel suppliers who, in turn, may pass these costs onto consumers through higher prices for electricity, gasoline, and heating oil. This system aims to reduce emissions by making it economically unfavorable to continue high levels of GHG production. The revenue generated from carbon taxes provides governments with funds that can be reinvested in renewable energy projects and other environmental initiatives, supporting a transition to a low-carbon economy.

The relationship between carbon taxes and the 2015 Paris Agreement is significant. Carbon taxes play a crucial role in enabling countries to meet their Nationally Determined Contributions (NDCs) under the Paris Agreement, which are reviewed and updated every five years. These taxes help align national efforts with their commitments to reduce emissions, demonstrating their potential as a tool for global climate change mitigation. For heavily coal-dependent countries, even moderate carbon taxes can lead to significant emissions reductions, underscoring their effectiveness. However, in nations with more stringent environmental targets, even higher rates of carbon taxation might not suffice, emphasizing the need for policies tailored to specific national contexts and environmental goals.

Customers are increasingly seeking alternatives to traditional energy sources and production methods. Motivated by both the rising cost of carbon taxes and environmental considerations, they want to invest in new sustainable technologies to reduce their emissions. This shift not only helps them avoid the financial burden of carbon taxes but also aligns their operations with broader environmental sustainability goals.

3.8 Challenges in Current Policies and Economic Strategies

Countries sometimes minimize their efforts to mitigate climate change due to the Free Rider Problem, where they can benefit from the mitigation efforts of others without making significant contributions themselves. Since the reduction of emissions by any one country benefits the global community, some nations may exploit this dynamic, continuing to produce higher emissions while relying on others to adhere to stricter standards. This leads to an imbalance and perceived unfairness in international climate efforts.

Additionally, climate change mitigation policies, such as carbon taxes, can pose economic challenges. These policies may influence inflation by affecting energy production and prices, leading to fluctuations in inflation rates. Transition risks associated with shifting to a low-carbon economy also present significant challenges. These risks include disruptions caused by technological advances, shifts in market demand towards greener options, and policy changes. As the economy transitions, existing jobs and technologies may become obsolete, replaced by new roles and innovations designed to reduce environmental impact. This transformative process, while necessary for sustainable development, can create short-term economic disturbances and require substantial adjustments within industries and the workforce.

4. Data

4.1 Variable Description

For the analysis, I selected the period from 1990 to 2020. The restriction of the analysis to the year 2020 reflects the data availability. The selection of years starting from 1990 is because it was a period where the significance of climate change impacts on the economy began to be recognized. The year 2020 was chosen as the endpoint because it was the most recent year for which comprehensive data for all the variables and countries included in this thesis were available. This timeframe is significant as it encompasses the early stages of widespread global discourse on climate change, a pivotal era for environmental policy development.

Additionally, the analysis includes data from 23 countries: Australia, Austria, Bangladesh, Belgium, Bulgaria, Croatia, Cyprus, Denmark, Germany, Greece, Hungary, India, Kenya, Lebanon, Luxembourg, Malta, Mexico, Norway, Romania, Spain, Sri Lanka, Sweden, and Switzerland. The group of countries includes both developed and developing economies, providing a diverse range of economic contexts. These countries also represent a variety of climates, both hot and cold, and are spread across different geographical regions. This diversity allows for a more comprehensive analysis of the economic impacts of climate change across different economic and environmental settings.

The variables chosen for this study are intended to explore potential causal effects on the primary variable of interest, the dependent variable, which is Gross Domestic Product (GDP) per capita growth. The independent variables include Renewable Energy Consumption, Mean Temperature, Mean Precipitation, Inflation, Net Trade, Population Growth, Military Expenditure, and Education Expenditure. Here’s a brief overview of each:

- **GDP per capita growth (%):** This metric indicates the overall increase in the value generated by all domestic producers in the economy, including the addition of any product taxes and the subtraction of any subsidies not reflected in product values. It is determined by dividing the total GDP by the population at midyear to derive a per capita amount.
- **Renewable Energy Consumption (%):** This measures the amount of energy generated from renewable sources. It reflects a country's shift towards sustainable energy solutions. Data represent the percentage of consumption coming from renewable sources.
- **Mean Temperature (°C) and Mean Precipitation (mm):** These climatic variables are included to assess the impacts of atmospheric CO_2 levels on local weather patterns, which in turn affect economic activities. Mean temperature is calculated by obtaining the temperature in Celsius (°C) and Mean Precipitation is the rainfall in millimeters (mm), representing the depth of rainfall over a specific area.
- **Inflation (%):** Represented by the Consumer Price Index (CPI), inflation indicates the rate at which the general level of prices for goods and services is rising, subsequently eroding purchasing power.
- **Net Trade ($):** Calculated as exports minus imports, this variable reflects a country's balance of trade. Data are in U.S. dollars.
- **Population Growth (%):** This is the rate at which the number of individuals in a population increases in a specific year due to natural increase and net migration.
- **Military Expenditure (%):** Represents the part of government expenditure that goes to military expenses.

- **Education ($):** This variable represents the government expenditure on education, reflecting the investment in human capital, which influences productivity and economic performance. Data are in U.S. dollars.

Understanding these variables is crucial for examining how various factors contribute to the economic growth measured by GDP per capita. This set of variables provides a comprehensive framework to analyze the intricate dynamics between economic performance and environmental and societal factors during the period under study.

4.2 Data Source & Collection Method

The data for this study are all quantitative and were sourced from the World Bank Open Data and the World Bank Climate Change Knowledge Portal. The World Bank Open Data initiative utilizes a comprehensive methodology, focusing on global data collection that includes a variety of socio-economic, developmental, and environmental indicators. The World Bank Climate Change Knowledge Portal provides relevant climate data, primarily derived from the observed historical records maintained by the Climatic Research Unit (CRU) at the University of East Anglia. This data offers valuable insights into climatic trends and patterns, crucial for examining the environmental factors influencing economic variables.

These sources were chosen due to their widespread recognition and reliability in the academic and policy-making communities, making them ideal for conducting credible and impactful research. Additionally, their comprehensive databases offer ease of access, which facilitated the downloading and subsequent analysis of the required data.

Table 4 – Each Variable's data source

Variable	Source
GDP per capita growth	World Bank Open Data
Renewable Energy Consumption	World Bank Open Data
Mean Temperature	World Bank Climate Change Knowledge Portal
Mean Precipitation	World Bank Climate Change Knowledge Portal
Inflation	World Bank Open Data
Net Trade	World Bank Open Data
Population Growth	World Bank Open Data
Military Expenditure	World Bank Open Data
Education	World Bank Open Data

The data was downloaded directly from these online portals and prepared for analysis using tools in Excel and Python's Pandas library. This preparation involved cleaning the data to ensure accuracy and organizing it to effectively address the research questions posed, setting the foundation for an empirical analysis.

4.3 Descriptive Statistics

Descriptive statistics help in summarizing statistical information about the dataset. The table of descriptive statistics can include measures such as mean, standard deviation, minimum and maximum value. The mean is the most commonly used type of descriptive statistic and falls under the measures of central tendency, which aim to convey the central or key characteristics of the sample by indicating the average location. Variance, a measure of the variation of the data, falls under the measures of variability. This category helps measure the deviation and spread of the data. The variation indicates the amount of dispersion or scattering of values within the dataset. Standard deviation, defined as the square root of variance, provides a clear measure of the spread of data points.

Table 5 – Descriptive Statistics Table

Variables	Mean	Standard Deviation	Minimum Value	Maximum Value
Dependent Variable				
GDP per capita growth (%)	1.94	3.92	-19.75	46.47
Independent Variables				
Renewable Energy Consumption (%)	23.30	21.79	0.00	82.87
Mean Temperature (°C)	13.85	6.66	0.38	28.08
Mean Precipitation (mm)	891.88	420.69	282.78	2,674.16
Inflation (%)	8.84	46.39	-3.75	1,058.37
Net Trade ($)	3,049,062,000.00	50,121,420,000.00	-201,668,400,000.00	291,485,600,000.00
Population Growth (%)	0.78	1.09	-3.85	9.97
Military Expenditure (%)	5.46	4.32	0.86	28.96
Education ($)	19,222,990,000.00	30,334,860,000.00	64,960,580.00	182,897,000,000.00

Table 5 represents descriptive statistics for the dataset of this thesis, covering the period from 1990 to 2020 for 23 countries. The mean value for GDP per capita growth, the dependent variable, was 1.94%. The maximum GDP per capita growth was an increase of 46.47%, observed in Lebanon in 1991 following the end of the civil war, marked by extensive reconstruction efforts and policy changes. Conversely, the minimum value was a decline of 19.75% in Lebanon in 2020, due to the economic and financial crisis in preceding years, compounded by political instability, the COVID-19 pandemic, and the Beirut port explosion.

The mean value for renewable energy consumption as a percentage of total energy consumption was 23.30%. The maximum value was 82.87%, recorded in Kenya in 2003, reflecting the country's high proportion of renewable energy usage. The minimum value was 0%, noted in Malta for the decade from 1990 to 2000, as the country focused more on other sectors and lacked initiatives promoting renewable energy during that period.

The mean temperature was 13.85°C, with the highest value of 28.08°C recorded in Kenya in 2008, a reflection of the country's typically hot weather. The lowest mean temperature was 0.38°C in Norway in 2010, indicative of its cold climate. The mean precipitation was 891.88

mm, with the highest value of 2,674.16 mm observed in Bangladesh in 2017, a country known for its significant rainfall due to its geographical location. The lowest recorded precipitation was 282.78 mm in Cyprus in 2008, characteristic of its warm Mediterranean climate with limited rainfall.

From the descriptive statistics in this table, it is evident that the dataset includes a diverse range of countries with varying climates, both cold and hot, and economies, both developed and developing.

5. Empirical Framework

This section outlines the methodology used in the analysis, which is essential for addressing the research questions: 1) How do increases in CO_2 emissions, which lead to rising temperatures and changes in precipitation patterns, affect GDP growth? and 2) What is the impact of renewable energy consumption on economic outcomes? To investigate the relationship, and more specifically, the cause-effect dynamics of the climatic variables, regression analysis will be employed to determine whether causality exists. Additionally, this section will describe the models' specification, the estimation techniques used, the software and tools employed, and the procedures for selecting the best model and testing for statistical assumptions such as heteroskedasticity.

5.1 Models Specification

The data for this study consists of panel data, therefore, the appropriate models for the analysis are two panel multiple linear regression models. These models can efficiently handle data that involves multiple measurements over time for the same entities. Model 1 is designed to test the first question of the thesis on how temperature and precipitation affect GDP, while Model 2 is intended to test the second question on how renewable energy transition affects GDP. The models' specifications are as follows:

Model 1:

$$GDPg_{it} = \beta_0 + \beta_1 MnTemp_{it} + \beta_2 MnPrec_{it} + \beta_3 Infl_{it} + \beta_4 NTR_{it} + \beta_5 Popg_{it} + \beta_6 MExp_{it} + \beta_7 Educ_{it} + u_{it} \quad (1)$$

Where:

i represents the country.

t represents the year.

u = error term

Dependent Variable:

$GDPg$ = Gross Domestic Product per capita growth

Independent Variables:

$MnTemp$ = Mean Temperature

$MnPrec$ = Mean Precipitation

Control Variables:

$Infl$ = Inflation

NTR = Net Trade

$Popg$ = Population Growth

$MExp$ = Military Expenditure

$Educ$ = Education

Model 2:

$$GDPg_{it} = \beta_0 + \beta_1 REC_{it} + \beta_2 Infl_{it} + \beta_3 NTR_{it} + \beta_4 Popg_{it} + \beta_5 MExp_{it} + \beta_6 Educ_{it} + u_{it} \quad (2)$$

Where:

i represents the country.

t represents the year.

u = error term

Dependent Variable:

$GDPg$ = Gross Domestic Product per capita growth

Independent Variables:

REC = Renewable Energy Consumption

Control Variables:

$Infl$ = Inflation

NTR = Net Trade

$Popg$ = Population Growth

$MExp$ = Military Expenditure

$Educ$ = Education

5.2 Heteroskedasticity Check: White Test

A White test was conducted to address potential heteroskedasticity concerns within the models. The White test is designed to detect the presence of heteroskedasticity by examining whether the variance of the residuals from a regression model is constant. The Null hypothesis (H_0) of the White test posits homoskedasticity, meaning that the residuals have a constant variance, while the Alternative hypothesis (H_1) suggests heteroskedasticity, indicating that the residual variance changes.

For Model 1, which tests how temperature and precipitation affect GDP, the White test results showed a test statistic of 1.21 and a p-value of 0.99. For Model 2, which examines the impact of renewable energy transition on GDP, the White test results showed a test statistic of 3.77 and a p-value of 0.98. These p-values are greater than all the significance levels of 1%, 5% and 10%, indicating that we fail to reject the null hypothesis of homoskedasticity. Consequently, the test results suggest that there is no evidence of heteroskedasticity in either model, affirming that both models are free from heteroskedasticity and that the assumption of constant variance of residuals holds.

5.3 Estimation Techniques

This section discusses the estimation techniques used in the analysis, including fixed effects and random effects panel regressions. Both techniques are robust tools in econometrics and are particularly useful in panel data analysis, where data is collected over time for the same entities. Fixed effects models control for entity-specific characteristics that do not change over time and are designed to analyze the impact of variables that vary over time within the same entities. This approach captures all time-invariant characteristics of each entity, distinguishing fixed effects from random effects models. In random effects models, differences between entities are assumed to be random, allowing these models to consider variations both within and between entities.

Ordinary Least Squares (OLS) will be employed to identify the significance of the variables. OLS operates under the premise that the sum of the squared residuals, which is the differences between observed and predicted values, is minimized. The objective to OLS is to find the estimates of the coefficients $\beta_0, \beta_1, \ldots, \beta_9$ that minimize the sum of the squared residuals. Therefore, we are looking to minimize the squared differences between the observed dependent variable values and those predicted by the linear model across all entities and time periods.

5.4 Software and Tools

For this analysis, Python was used due to its robustness and extensive library support, making it ideal for research. Python's popularity among researchers is due to its readability, versatility, and powerful capabilities for handling complex data analysis tasks. Several specific libraries were integral to this study:

- pandas: This library was invaluable for data manipulation and preparation, allowing for efficient handling and transformation of large datasets.
- linearmodels: This package provided the necessary tools for performing panel OLS regression, which is crucial for analyzing data that involves multiple entities over time.
- numpy: Used for numerical computations, numpy enabled efficient processing of large arrays and matrices of numerical data.

Together, these libraries enabled a comprehensive and rigorous analysis by providing a wide range of functionalities required for handling, processing, and analyzing the data. The use of these tools ensured that the study was conducted efficiently, with high accuracy and reliability in the results.

5.5 Model Selection: Hausman Test

Choosing the right model, fixed effects, or random effects, is crucial for the analysis, and that's where the Hausman test comes. This test helps to decide which model is more appropriate for the data by checking if the unique errors -the differences that aren't explained by the model- are correlated with the regressors, the variables that are tested on whether they influence the dependent variable.

The hypotheses are the following:

Null Hypothesis: $H_0: \beta_{RE} = \beta_{FE}$

Alternative Hypothesis: $H_1: \beta_{RE} \neq \beta_{FE}$

Where, H_0 states that the coefficient estimates from the Random Effects (RE) model (β_{RE}) are equal to those from the Fixed Effects (FE) model (β_{FE}). It suggests that the random effects estimator is consistent and there are no omitted variable biases related to the individual effects being correlated with other regressors. On the other hand, H_1 states that the coefficient estimates from the RE are not equal to those from FE model, implying that the RE estimator may be inconsistent due to correlations between the individual effects and the regressors.

For Model 1, which tests how temperature and precipitation affect GDP, after running the Hausman test in Python, the following p-value was obtained:

$$p - value = 0.0026 = 0.26\%$$

With the p-value being lower than the significance levels of 1%, 5% and 10% the Null Hypothesis, H_0 is rejected. This outcome suggests using the Fixed Effects model for Model 1 because it indicates that the unique errors correlate with the regressors, thus affecting the consistency of the Random Effects model.

For Model 2, which examines the impact of renewable energy transition on GDP, the Hausman test was also conducted. The results showed the following p-value:

$$p - value = 0.009 = 0.90\%$$

Similarly, with the p-value being lower than the significance levels of 1%, 5% and 10%, the Null Hypothesis, H_0, is rejected for Model 2 as well. This indicates that the Fixed Effects model is more appropriate for Model 2 because the unique errors correlate with the regressors, compromising the consistency of the Random Effects model.

5.6 Results

The estimated fixed effects OLS panel regression models for the two different analyses are as follows:

Model 1:

$$\widehat{GDPg}_{it} = 6.85 - 0.46\widehat{MnTemp}_{it} + 0.0009\widehat{MnPrec}_{it} - 0.018\widehat{Infl}_{it} + 0.66\widehat{Popg}_{it} - 0.021\widehat{MExp}_{it} \quad (3)$$

Model 2:

$$\widehat{GDPg_{\iota t}} = 3.49 - 0.091\widehat{REC_{\iota t}} - 0.019\widehat{Infl_{\iota t}} + 0.74\widehat{Popg_{\iota t}} + 0.029\widehat{MExp_{\iota t}} \quad (4)$$

While the estimated random effects OLS panel regression models for the two different analyses are as follows:

Model 1:

$$\widehat{GDPg_{\iota t}} = - 0.013\widehat{MnTemp_{\iota t}} + 0.0014\widehat{MnPrec_{\iota t}} - 0.016\widehat{Infl_{\iota t}} + 0.76\widehat{Popg_{\iota t}} + 0.088\widehat{MExp_{\iota t}} \quad (5)$$

Model 2:

$$\widehat{GDPg_{\iota t}} = - 0.012\widehat{REC_{\iota t}} - 0.016\widehat{Infl_{\iota t}} + 0.89\widehat{Popg_{\iota t}} + 0.19\widehat{MExp_{\iota t}} \quad (6)$$

Table 6 summarizes the results of the analysis, displaying the coefficients and standard errors for all models. The table is organized into four columns, Column (1) presents the results for Model 1 Fixed Effects, Column (2) details the results for Model 1 Random Effects, Column (3) shows the results for Model 2 Fixed Effects and Column (4) provides the results for Model 2 Random Effects. Each row corresponds to an independent variable, providing insights into its estimated impact on the dependent variable, GDP per capita growth.

Table 6 – Panel Regression Results

Dependent Variable: GDP per capita growth (GDPg)	MODEL 1		MODEL 2	
	(1) FE	(2) RE	(3) FE	(4) RE
Intercept	6.85*** (2.36)	-	3.49* (1.86)	-
Renewable Energy Consumption (REC)	-	-	-0.091** (0.045)	-0.012 (0.012)
Mean Temperature (MnTemp)	-0.46** (0.18)	-0.013 (0.040)	-	-
Mean Precipitation (MnPrec)	0.0009 (0.0008)	0.0014** (0.0006)	-	-
Inflation (Infl)	-0.018*** (0.0016)	-0.016*** (0.0032)	-0.019*** (0.0012)	-0.016*** (0.0032)
Net Trade (NTR)	0.00 (0.00)	0.00** (0.00)	0.00 (0.00)	0.00** (0.00)
Population Growth (Popg)	0.66*** (0.21)	0.76*** (0.18)	0.74*** (0.16)	0.89*** (0.18)
Military Expenditure (MExp)	0.021 (0.19)	0.088 (0.055)	0.029 (0.18)	0.19*** (0.048)
Education (Educ)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
R-squared	0.092	0.15	0.083	0.14
Adjusted R-squared	0.082	0.14	0.074	0.13
N	713	713	713	713

**** Significant at p≤ 0.01, ** Significant at p≤ 0.05, * Significant at p≤ 0.1*

Note 1: Values in parentheses represent the standard errors.

Note 2: In 2nd and 4th columns where RE results for both models are presented, the intercept is not shown because it's automatically included in the overall model calculation.

Note 3: The estimated coefficients for the variables Net Trade and Education in both FE and RE models are not actually 0.00 but are very small numbers that have been rounded. Specifically, for Model 1 FE model: the estimated coefficients for Net Trade and Education are -0.000000000010 and -0.000000000011 respectively, with standard errors of 0.000000000011 and 0.000000000018 respectively. For Model 1 RE model: the estimated coefficients for Net Trade and Education are -0.0000000000093 and -0.00000000000056 respectively, with standard errors of 0.0000000000047 and 0.0000000000086 respectively. For Model 2 FE model: the estimated coefficients for Net Trade and Education are -0.0000000000049 and -0.000000000011 respectively, with standard errors of 0.000000000013 and 0.000000000017 respectively. For Model 2 RE model: the estimated coefficients for Net Trade and Education are -0.0000000000089 and 0.0000000000070 respectively, with standard errors of 0.0000000000046 and 0.0000000000079 respectively.

In the fixed effects OLS panel regression, the observed several significant relationships were the following:

Model 1 – Fixed Effects:

- Mean Temperature is statistically significant at the 5% level, which provides a 95% confidence level that a 1°C increase in temperature will reduce GDP growth by about 0.46 percentage points.
- Mean Precipitation is not statistically significant, indicating that there is not a statistically visible causation effect of this variable on GDP growth.

Among the control variables in the fixed effects OLS panel regression, Inflation (Infl) and Population growth (Popg) were statistically significant, each at the 1% significance level, reflecting a 99% confidence level in these findings. Specifically, a 1 percentage point increase in Inflation is associated with a decrease of 0.018 percentage point in GDP growth, indicating that higher Inflation rates may have a negative effect on economic expansion. Conversely, a 1 percentage point increase in Population growth corresponds to a 0.66 percentage point increase in GDP growth, suggesting that demographic expansion significantly boosts economic activity.

Model 2 – Fixed Effects:

- Renewable Energy Consumption (REC) is statistically significant at the 5% level, indicating that there is a 95% confidence level that a 1 percentage point increase in renewable energy consumption as part of total consumption will lead to a 0.091 percentage points decrease in GDP growth.

Among the control variables in the fixed effects OLS panel regression, Inflation (Infl) and Population growth (Popg) were statistically significant, each at the 1% significance level, reflecting a 99% confidence level in these findings. Specifically, a 1 percentage point increase in Inflation is associated with a decrease of 0.019 percentage points in GDP growth and a 1 percentage point increase in Population growth corresponds to a 0.74 percentage points increase in GDP growth.

In the random effects OLS panel regression, the observed several significant relationships were the following:

Model 1 – Random Effects:

- Mean Temperature is not significant, indicating that there is not a statistically visible causation effect of this variable on GDP growth.
- Mean Precipitation is significant at the 5% level, demonstrating with 95% confidence that a 1mm increase in precipitation will lead to a 0.0014 percentage points increase in GDP growth.

Among the control variables in the random effects OLS panel regression, Inflation (Infl) and Population growth (Popg) were statistically significant. Specifically, with 99% confidence, a 1 percentage point rise in Inflation is associated with a 0.016 percentage points decrease in GDP growth, and a 1 percentage point increase in Population growth leads to a 0.76 percentage points increase in GDP growth. Additionally, at the 95% confidence level, a $1 increase in Net Trade is linked to a decline of 0.0000000000093 percentage points in GDP growth.

Model 2 – Random Effects:

- Renewable Energy Consumption (REC) is not statistically significant, suggesting no observable causation effect of this variable on GDP growth.

Among the control variables in the random effects OLS panel regression, Inflation (Infl), Net Trade (NTR), Population Growth (Popg), and Military Expenditure (MilExp) were statistically significant. Specifically, with 99% confidence, a 1 percentage point rise in Inflation is associated with a 0.016 percentage points decrease in GDP growth, a 1 percentage points increase in Population growth leads to a 0.89 percentage points increase in GDP growth, and a $1 increase in Military Expenditure corresponds to a 0.19 percentage points increase in GDP. Additionally, at the 95% confidence level, a $1 increase in Net Trade corresponds to a decrease of 0.0000000000089 percentage points in GDP.

As mentioned previously, the Hausman test was conducted to determine which model, fixed or random effects, is more appropriate for the dataset. For both models, Model 1, which tests the relationship between temperature, precipitation, and GDP growth, and Model 2, which tests the relationship between renewable energy consumption and GDP growth, the fixed effects models were found to be more appropriate. This finding clearly demonstrates the substantial impact of environmental and climatic variables on GDP growth, reflecting the complex relationships between natural conditions and economic performance.

5.7 F-test

The F-test is conducted to determine the joint significance of multiple independent variables. In this context, it tests the overall significance of all independent variables included in each model. This approach helps to find out whether these variables, as a group, significantly impact the dependent variable, which is GDP growth in this case.

The hypotheses for the test are as follows:

Null Hypothesis: $H_0: \beta_1 = \beta_2 = \cdots = \beta_k = 0$

Alternative Hypothesis: $H_1: \beta_i \neq 0 \ \ where\ i = 1,2 \ldots, k\ and\ k = number\ of\ coefficients$

H_0 suggests that none of the variables are significant and thus, they do not collectively explain the variance in GDP growth. While H_1 indicates that at least one of the parameters is statistically significant. F-statistic measures how well the independent variables, as a group, explain the variability in the dependent variable relative to the variability not explained, scaled by the degrees of freedom associated with the model and the data.

Table 7 – F-test Results

	MODEL 1		MODEL 2	
	(1) FE	(2) RE	(3) FE	(4) RE
F-statistic	8.86	13.35	9.48	15.28
P-value	0.00	0.00	0.00	0.00
Distribution	F(7,683)	F(7,706)	F(6,684)	F(6,707)

Table 7 presents the F-test results for both Fixed Effects and Random Effects panel regression models for each of the two analyses.

For Model 1, which examines the relationship between temperature, precipitation, and GDP growth:

The Fixed Effects F-test yields an F-statistic of 8.86 with a p-value of 0.00, indicating a statistically significant relationship between the independent variables and GDP growth. This suggests that the variables collectively have a substantial impact on explaining the variability in GDP growth. The Random Effects model shows an F-statistic of 13.35 with a p-value of 0.00, also indicating statistical significance. Although this implies a better model fit, the preference for the Fixed Effects model, as indicated by the Hausman test, underscores its suitability for our data.

For Model 2, which explores the impact of renewable energy consumption on GDP growth:

The Fixed Effects F-test results in an F-statistic of 9.48 with a p-value of 0.00, demonstrating a statistically significant relationship between the independent variables and GDP growth.
The Random Effects model yields an even higher F-statistic of 15.28 with a p-value of 0.00, also indicating statistical significance. However, the preference for the Fixed Effects model, as determined by the Hausman test, reaffirms its appropriateness for this dataset.

Overall, these results justify the inclusion of the selected variables in the models, as they significantly influence GDP growth.

6. Conclusion

This final chapter summarizes the objectives of the study, the research hypotheses, and the empirical findings, emphasizing the practical implications of the results and answering the research questions stated at the beginning:

1) How do increases in CO_2 emissions, which lead to rising temperatures and changes in precipitation patterns, affect GDP growth?
2) What is the impact of renewable energy consumption on economic outcomes?

The fixed effects OLS panel regressions, supported by the Hausman test which confirmed its suitability for the dataset, revealed several significant relationships.

Firstly, the analysis showed that a 1°C increase in mean temperature reduces GDP growth by about 0.46 percentage points, while for mean precipitation there is not a statistically visible causation effect on GDP growth. These findings suggest that rising temperatures, likely driven by increased CO_2 emissions, negatively impact economic growth. Secondly, a 1 percentage point increase in renewable energy consumption as part of total consumption results in a 0.091 percentage point decrease in GDP growth, suggesting that the initial costs and adjustments associated with renewable energy adoption might hinder short-term economic performance. The results support the green growth concept, which advocates that the cost of fighting climate change, such as transitioning to renewable energy sources, is significantly lower than the long-term cost of ignoring climate change impacts. This is evident as the decrease in GDP due to an increase in temperature is substantially higher than the decrease in GDP when transitioning to renewable energy sources.

These findings have significant practical implications. They highlight the need for policies that balance economic growth with environmental sustainability, emphasizing the long-term benefits of renewable energy despite its short-term economic costs. The study contributes to existing literature by providing empirical evidence on the economic impacts of climate change-related factors, and it aligns with other research indicating the adverse effects of rising temperatures and poor air quality on economic outcomes. Future research could further investigate the long-term economic benefits of renewable energy and explore strategies to mitigate the negative impacts of temperature increases on GDP growth.

The findings of this study align with and extend the existing literature on the economic impacts of climate change, particularly the works of Kahn (2021) and Dogan (2016). Kahn's research demonstrated that deviations in temperature from historical averages negatively impact long-term productivity and per capita real output growth, with significant implications for economic stability. Similarly, this thesis' results indicate that a 1°C increase in mean temperature reduces GDP growth by about 0.46 percentage points, reinforcing Kahn's assertion of the detrimental effects of rising temperatures on economic performance. Another similarity with Kahn's findings is that there is no significant impact from changes in precipitation patterns. However, the findings on renewable energy consumption provide additional context to the broader discourse on sustainable economic development. Both this thesis' results and Dogan (2016) conclude that an increase in renewable energy consumption will reduce GDP. While Kahn's counterfactual analysis highlighted the importance of policy interventions like the Paris Agreement to mitigate economic losses from climate change, this thesis analyzes renewable energy consumption and finds that it negatively affects GDP growth. Both the Paris Agreement and renewable energy consumption aim for a greener economy in the long run. This underscores the necessity for supportive policies to balance these short-term economic challenges with the long-term environmental and economic benefits envisioned by global agreements like the Paris Agreement.

By highlighting the significant relationships between these factors and GDP growth, the study underscores the critical need for adaptive policies that balance economic growth with environmental sustainability. Experts have started to develop new methods to prevent these disasters, and central banks are creating policies to adapt to climate change, incorporating it into various financial decisions. It is crucial to find ways to adapt to this climatic crisis and leverage natural resources through sustainable energy consumption. The transition to a sustainable economy, supported by the theory of renewable energy transition and green growth, supports long-term economic development. This shift will create the way for new growth paths and create new job opportunities, ultimately leading to a more resilient economy. Future research should continue to explore the long-term benefits of renewable energy and develop strategies to mitigate the negative economic impacts of climate change.

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