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ECONOMIC GROWTH AND ENVIRONMENTAL QUALITY: FROM KUZNTES’ CURVE TO THE NEED FOR IMPLEMENTING ADAPTATION AND MITIGATION TECHNIQUES

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INTRODUCTION

Climate change is of global concern for it threatens ecosystems and biodiversity, affects water resources, human settlements as well as the frequency and magnitude of extreme weather events, the combination of the latter consequently causing great damage to food production, human well-being, socio-economic activities and economic output.

Extreme weather such as frequent droughts, major storms, floods and heavy snow fall opposes a threat to the agricultural sector worldwide, but as growing crops becomes ever more challenging, countries that largely depend on this sector are faced with major loss in terms of GDP. WorldAtlas[1] top three countries that most depend on agriculture are: Liberia (76.9% of GDP), Somalia (60.2% of GDP), Guinea-Bissau (55.8% of GDP), all of which are already low-income countries. The effects on these countries' GDPs would be devastating and could lead to an increase in the population's emigration.

Migration is also another fallout of climate change, as in 2018, extreme weather events such as a severe drought in Afghanistan, the Tropical Cyclone Gita[2] in Samoa, and flooding in the Philippines, have all resulted in acute humanitarian needs. The UNHCR[3] recognizes that the consequences of climate change are extremely serious, including for refugees and other people of concern.

In 2017 alone, the Internal Displacement Monitoring Centre[4] registered 18.8 million new disaster-related internal displacements.

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[1] WorldAtlas is one of the largest publishing resources in geography and other topics it covers, including sociology, demography, environment, economics, politics, and travel.

[2] Severe Tropical Cyclone Gita was the most intense tropical cyclone to impact Tonga since reliable records began. Gita originated from a monsoon trough that was active in the South Pacific in early February 2018.

[3] The UNHCR (United Nations High Commissioner for Refugees) is a global organisation dedicated to saving lives and protecting the rights of refugees.

[4] The IDMC is the world's authoritative source of data and analysis on internal displacement, founded in 1998, it is based in Geneva.

Continued emission of greenhouse gases[5] is bound to cause further rising of temperatures and produce long-lasting changes in all components of the climate system, increasing the likelihood of triggering unprecedented climate damages. Being that the self-organized biosphere is complex and non-linear, it may be inherently impossible for science to discover the limits of the system's resilience.

Even though many aspects of climate change and associated impacts are sure to linger on for centuries, even if anthropogenic emissions of greenhouse gases were to cease, we should seek limiting future risks of abrupt or irreversible changes that increase as the magnitude of the warming increases. Complementary strategies for reducing and managing the risks of climate change are adaptation and mitigation techniques.

This thesis consists of two parts: the first part aims to showcase the correlation between today's economic growth, still largely reliant on the use of fossil fuels as a means of energy, and the consequent degradation of the environment that derives from the change in climate caused by CO_2, a gas that is emitted when burning such fuels. The second part of the thesis analyses possible ways to mitigate the impacts of a climate that is already changing, through the use of renewable energy solutions, alternative to fossil fuels.

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[5] A greenhouse gas is a gas that absorbs and emits radiant energy within the thermal infrared range, causing the greenhouse effect. The primary greenhouse gasses in Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3).

CHAPTER ONE

CLIMATE CHANGE

The Evidence

Earth's climate has changed throughout history, just in the last 650,000 years there have been seven cycles of glacial advance and retreat. Very small variations in Earth's orbit that change the amount of solar energy our planet receives, in the past, have resulted in drastic fluctuations in temperature causing phenomena as the "Little Ice Age[6]" that took place between 1650 and 1850. Today Earth orbiting satellites and more advanced technologies have enabled scientists to study the current warming trend by collecting data that reveals the signals of a climate changing at a rate that is unprecedented over decades to millennia.

Since the late 19th century, the planet's average surface temperature has risen about 1.14 degrees Celsius, causing shrinking ice sheets in Greenland and Antarctica, glacial retreat almost everywhere around the world, including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa, decreased snow cover in the Northern Hemisphere, sea level rise of about 20 cm globally, the decline in Arctic Sea ice, increased occurrence of extreme events and lastly the acidification of oceans.

[6] The Little Ice Age was a period of cooling that occurred after the Medieval Warm Period. Although it was not a true ice age, the term was introduced into scientific literature by François E. Matthes in 1939.

The Causes

The current climate change shows a cooling in the upper atmosphere and a warming at the surface and in the lower parts of the atmosphere, which excludes any connection to solar activity and supports the thesis of a “greenhouse”[7] effect.

The Intergovernmental Panel on Climate Change[8] (IPCC) states that: *“Scientific evidence for warming of the climate system is unequivocal.”*

About half the sunlight reaching Earth's atmosphere passes through the air and clouds to the surface where it is absorbed and then radiated upward in the form of infrared heat. Certain gases in the atmosphere though, trap about 90 percent of this heat and radiate it back toward the surface, resulting in rising temperatures.

The ability of gases such as water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFC) to affect the transfer of infrared energy through the atmosphere was demonstrated in the mid-19th century. It is certain that increased levels of greenhouse gases are what cause Earth to warm in response. In fact, ice cores drawn from Greenland, Antarctica, and tropical mountain glaciers show that Earth’s climate responds to changes in greenhouse gas levels. Paleoclimate evidence found in tree rings, ocean sediments, coral reefs, and layers of sedimentary rocks, reveals that current warming is occurring roughly ten times faster than the average rate of ice-age-recovery warming. The global average atmospheric CO_2 in 2019 was 409.8 ppm (parts per million), with a range of uncertainty of plus or minus 0.1 ppm, making it the highest peak reached in at least the past 800,000 years.

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[7] The "greenhouse effect" of the atmosphere is named by analogy to greenhouses which become warmer in sunlight.

[8] The Intergovernmental Panel on Climate Change is the United Nations body for assessing the science related to climate change. Created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies.

The Role of Human Activity

According to the IPCC: *"There's more than a 95 percent probability that human activities over the past 50 years have warmed our planet."*

The main cause of global warming is to be found in increases in CO_2 levels that have intensified more than 250 times faster than after the last Ice Age[9] due to the industrial activities our modern economic system depends on. As Figure I.1 shows, fossil fuels burnt since the Industrial Revolution have raised atmospheric CO_2 levels of more than 1/3 of pre-industrial eras.

Fossil fuels such as coal and oil contain carbon dioxide that plants have pulled out of the atmosphere, through photosynthesis, over the span of many millions of years, their combustion is returning said carbon to the atmosphere in just a few hundred years.

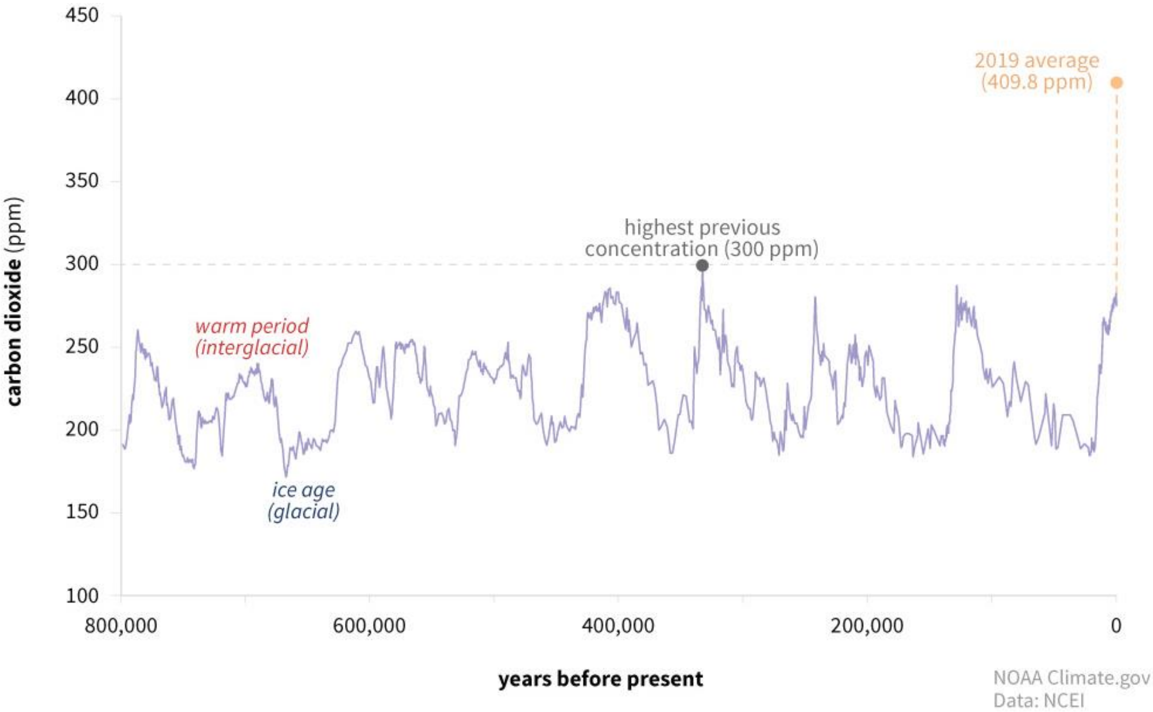

Figure I.1 - Global atmospheric CO_2 concentrations in parts per million (ppm) for the past 800,000 years.
https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

9 An ice age is a long period of reduction in the temperature of the Earth's surface and atmosphere, resulting in the presence or expansion of continental and polar ice sheets and alpine glaciers.

CHAPTER TWO

MACROECONOMIC IMPLICATIONS OF CLIMATE CHANGE

Food Security

Agriculture is strongly influenced by weather and climate, therefore climate change can be expected to threaten established aspects of farming systems, but also provide opportunities for improvements. Global food security is at stake when rising temperatures, changes in rainfall patterns, more frequent extreme weather events are considered. Even if greenhouse gas emissions were abruptly reduced, the climate system is slow to respond fully to imposed changes, due to inertia in the physical climate system itself.

In mid and high latitudes, the suitability and productivity of crops are projected to increase and extend northwards, especially for cereals and cool season seed crops[10]. Maize, sunflower and soya beans, which are all crops prevalent in southern Europe, could also become viable further north and at higher altitudes. In areas where temperatures are already close to the physiological maxima for crops, such as seasonally arid and tropical regions, a rise in temperatures may be more immediately detrimental, causing the increase in heat stress on crops and water loss by evaporation. A hypothetic 2°C local warming in the mid-latitudes could increase wheat production by nearly 10 per cent, whereas at low latitudes the same amount of warming may decrease yields by nearly the same amount.

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[10] Common cool-season vegetables are: asparagus, beets, broccoli, Brussels sprouts, chives, cabbage, carrots, cauliflower, Swiss chard, kale, leek, lettuce, onion, parsnips, peas, radishes, spinach, and turnips.

Since water is vital to plant growth, varying precipitation patterns will have a significant impact on agriculture. In fact, over 80 per cent of total agriculture is rain-fed, projections of future precipitation changes often influence the magnitude and direction of climate impacts on crop production. Even though it is difficult to predict the impact global warming will have on regional precipitation, there is an increasing confidence in projections of a general increase in high-latitude rainfall, especially in winter and an overall decrease in many parts of the tropics and sub-tropics.

While change in long-term mean climate will have significance for global food production, historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events. Europe experienced a particularly extreme climate event during the summer of 2003, as temperatures averaged about 6°C above normal and precipitation dropped of about 300 mm, a record crop yield loss of 36 per cent occurred in Italy for corn grown in the Po valley where extremely high temperatures prevailed.

The definition of what constitutes extreme weather highly depends on geographical location, as for example, temperatures considered extreme for some countries are considered normality in other countries. Though farming may adapt to increases in extreme temperature events, by moving to practices already used in warmer climate, in regions where farming exists at the edge of key thresholds increases in extreme temperatures or drought may move the local climate into a state outside historical human experience. It is precisely in these cases that it is difficult to assess the extent to which adaption will be possible.

Climate Refugees

Climate change is expected to significantly impact the global economy in the coming decades. Rising temperatures and sea levels, changes in rainfall patterns, increases in ocean acidification and more frequent and intense extreme weather events, all translate into significant market impacts, with output losses through effects on climate-sensitive sectors as, for example, agriculture, forestry, coastal real estate and tourism.

The magnitude of consequences on a country's GDP[11] varies considerably across regions, with greater impacts for regions with lower per capita income and higher initial temperatures. As Figure II.1 shows, most vulnerable to negative effects are sub-Saharan Africa (SSA), South East Asia (SEA), and Middle-East and North Africa (MENA), countries that all have climates closer to dangerous physical thresholds. These countries also rely more on outdoor work and natural capital and have fewer financial means to adapt quickly. Northern Europe, on the contrary will mainly benefit from positive impacts on crop productivity and tourism.

This will not just slow global economic growth, but also exacerbate global inequalities, actually hitting the countries which have contributed the least to manmade climate change the hardest.

[11] Gross domestic product

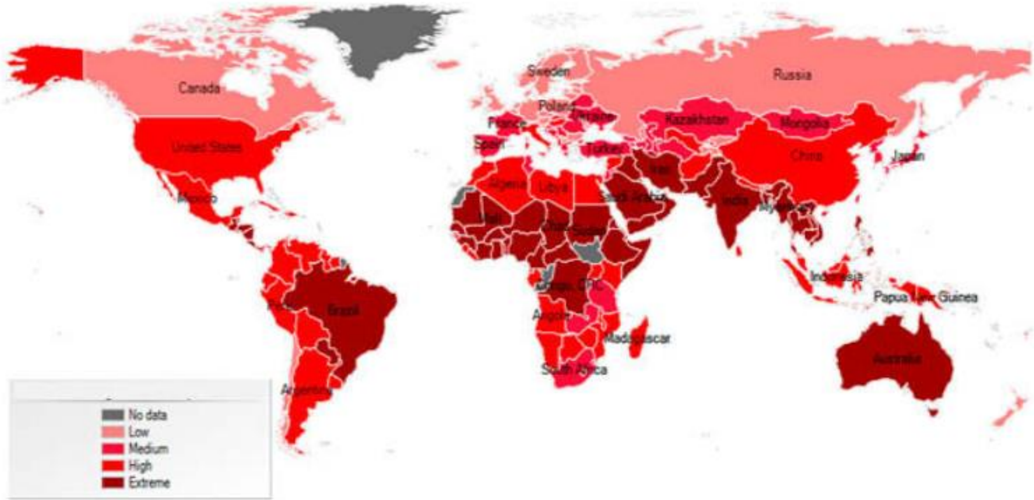

Figure II.1 - Impacts of climate change by geographical location

A study conducted in 2012 by Roson[12] and van der Mensbrugghe[13] states that sea level rise and agriculture are the main channels of impact for SEA; water scarcity for MENA; labor productivity and health for SSA, while in China, net positive effects are mostly due to increased crop productivity. On the contrary, positive effects can be seen in northern European countries, slightly offsetting losses in other regions.

Low income countries and small states are often the hardest hit by natural disasters. Over the period 1985–2015, LICs[14] were hit about one and a half times as often by climate-related disasters such as floods, storms, and droughts. The proportion of the domestic population affected by natural disasters is also higher compared with other countries, particularly for small developing and low-lying coastal states. What is more, within LICs, the poorest 25th percentile of countries faces the highest natural disaster risks of all.

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[12] Roberto Roson is Professor at Cà Foscari University, in Venice, Italy.

[13] Dominique van der Mensbrugghe is Research Professor and Director of the Center for Global Trade Analysis at Purdue University, West Lafayette, Indiana, U.S.A.

[14] Low Income Countries

Climate-related natural disasters combined with higher temperatures harm the growth of developing countries, exacerbating poverty. It is estimated that natural disasters reduce the GDP growth of such countries by 1-3 percentage points, depending on the type of disaster. If temperatures were to rise by 1°C , then economic growth in LICs would be reduced by 1.3 percentage points on average, mainly through the reduction of agricultural output, which is an important growth channel for such countries.

The loss of productive economic assets, combined with limited savings and food vulnerability worsen poverty. As a result, the scale of internal migration is expected to rise, as more and more people search for food security and job stability.

The term “climate refugee” has been given to those displaced and forced to migrate across borders as a result of climate change. Such phenomenon hinders development in at least four ways; by increasing pressure on urban infrastructure and services, undermining economic growth, increasing the risk of conflict and leading to worse health, educational and social indicators among migrants themselves.

The dramatic rural-urban drift in the developing world, caused by growing difficulties of living in rural areas, might lead to unplanned urbanization, which will have serious implications for urban welfare and urban service provision. To date, more than one-third of the world’s urban population lives in slums; about 1 billion people, live with poor quality housing, limited clean water, sanitation and education services. By 2030 it is estimated that this number increase to 1.7 billion people.

CHAPTER THREE

ECONOMIC GROWTH AND THE ENVIRONMENT

Ever more increasingly over the years, the worldwide degradation of the environment has sparked an interest in trying to understand the correlation between economic growth and environmental quality. In the 1970s, debate on the relation between growth and the environment was based on the report "The Limits to Growth", a study conducted at "The Club of Rome"[15] by an international team of researchers from the Massachusetts Institute of Technology on the implications of perpetuated worldwide growth. Having examined basic factors that ultimately limit growth on this planet such as population increase, agricultural production, nonrenewable source depletion, industrial output and pollution generation, they fed data on these five factors into a global computer model.

What emerged from the study was the high improbability of our planet to support current rates of economic growth beyond, if not even before, the year 2100. Common knowledge was that economic growth meant greater environmental impacts, so the only option for a better environment seemed to be refraining growth and reducing consumption.

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[15] The Club of Rome was created in 1970 by Aurelio Peccei, an Italian industrialist, and Alexander King, the Scottish Head of Science at the OECD (Organization for Economic Co-operation and Development) to address the multiple crises facing humanity and the planet.

THE EKC HYPOTHESIS

By the late 1980s, however, a new kind of idea emerged, one that contemplated the possibility to maintain growth at its regular speed. By observing the development path of more advanced economies, what stood out was an apparent correlation between higher income and increased environmental quality. The idea that economic growth could eventually solve the problems it had initially created was ever so engaging.

Most studies have since settled on the assertion that environmental pressure increases faster than income at early stages of development and slows down relative to GDP growth at higher income levels.

The economic theory that mostly stands out for trying to explain this phenomenon is the Environmental Kutznets Curve[16] (EKC) which postulates an inverted-U-shaped curve derived from plotting pollution indicators against per capita income.

When at the early stages of economic growth, the economy changes from rural to urban, or agricultural to industrial, causing environmental deterioration, the curve portrays a positive correlation between GDP and levels of environmental degradation. In reaching a certain turning point, perhaps when energy-intensive industries are substituted with service and knowledge-based technology-intensive industries, the positive correlation turns into a negative one.

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[16] Such hypothesis derives its name from the work of the American economist, Simon Kuznets, who in 1955 postulated a similar correlation between income inequality and economic development.

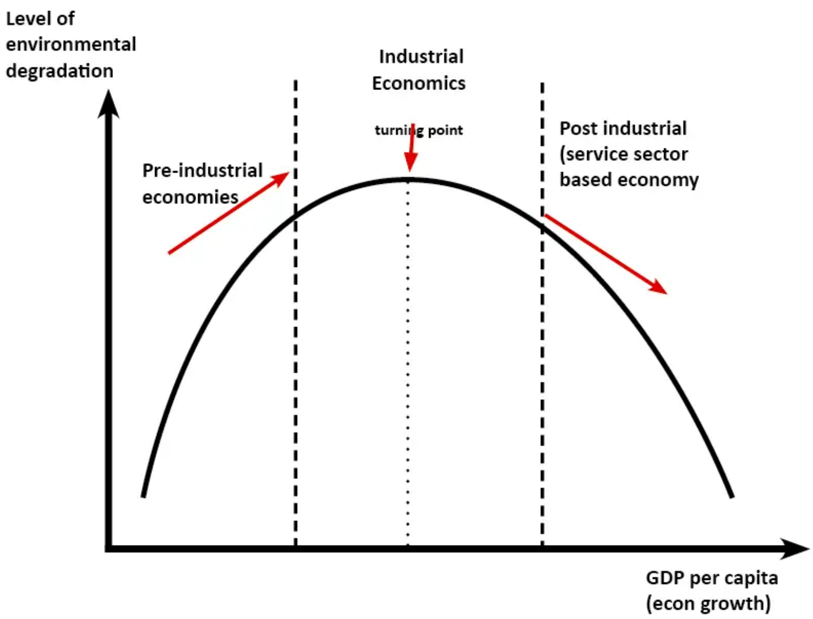

Figure III.1 - Environmental Kutznets Curve
https://www.economicshelp.org/blog/14337/environment/environmental-kuznets-curve/

The following reduced form model has been used by a large number of econometric studies to test for the emergence of an EKC in a wide variety of income based environmental pressure/pollution levels.

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 z_{it} + \varepsilon_{it}$$

If y stands for environmental indicators, x is income and z relates to other variables of influence on environmental degradation, the up mentioned model is used to test the various possible relationships between environmental pressure and income.

Here the subscript i is a country, t is time, a is constant, β_κ is the coefficient of the k explanatory variables. The EKC is one of the possible outcomes of the model, where the inverted-U-shape is given by the following values:

$$\beta_1 > 0,\ \beta_2 < 0,\ \beta_3 = 0$$

An Unrealistic Model

Though it might be true that the demand and concern towards a cleaner environment can be witnessed in countries with higher income per capita, recent evidence revealing that pollution problems are being addressed and remedied in developing economies as well, undermines the idea that higher income is the only reason for an improvement in environmental quality.

International trade may be one of the sources of an EKC-pattern: being open to trade favors the expansion of an economy through an increase in production of exportable goods. Higher production creates pollution therefore, as income and environmental degradation rise substantially, more severe environmental regulations are imposed on the economy which results in a shift of its domestic production of pollution-intensive goods to other, usually low-income countries that have less strict environmental legislation. When a developed country exports goods it generates the upward slope of its EKC, while, consequently, its imports of goods from developing countries generate the downward slope of its EKC. Such theory is reported the "pollution haven hypothesis"[17].

Another possible explanation of an EKC-pattern may rely on improvements in the technologies used. Emissions may have declined over time probably due to technological and structural changes and not due to economic growth. Observed changes in pollution levels over time or across regions can be attributed to shifts in production techniques.

[17] The pollution haven hypothesis posits that, when large, industrialized nations seek to set up factories or offices abroad, they will often look for the cheapest option in terms of resources and labor that offers the land and material access they require. However, this often comes at the cost of environmentally unsound practices.

Furthermore, one must consider the importance of institutional framework and governance in dealing with an increase in environmental quality. In economically developed countries, governments are expected to respond to public awareness on environmental degradation by imposing suitable regulations that prevent pollution from further increasing. The growth of an economy is an essential condition to overcome pollution, but it is a means, not an end.

Lastly some studies consider consumers' preferences as being a partial explanation for an EKC-pattern. In what capacity does an increase in income alter the elasticity of demand for environmental quality? The income elasticity of demand for environmental quality η is defined as:

$$\eta = \frac{(\Delta E)\%}{(\Delta Y)\%} = \frac{\Theta E}{\Theta Y}\frac{Y}{E}$$

Where E is the quantity of environmental quality demanded and Y is income, η is the change in the demanded quantity of environmental quality with respect to a change in income. If $|\eta| > 1$, then E is a luxury good[18]. Several problems emerge in trying to find an EKC-pattern in consumeristic preferences. The lack in exercising enough environmental effort as income per capita rises, will lead to an inevitable increase of pollution, as even the most sophisticated and effective abatement technologies remain incapable of entirely solving the problem. Furthermore, it is difficult to predict the effect of a shift in consumers' preferences, because such shift may depend on various spatial and time conditions.

[18] A luxury good means an increase in income causes a bigger percentage increase in demand. It means that the income elasticity of demand is greater than one.

Poor people, especially rural poor people, are often the most direct dependent on their environment, and its resources, and the most vulnerable to its degradation. Such people do not need to become richer to become concerned about the environment. Thus, income does not appear to be the main determinant for environmental legislation.

"There are some environmental problems where thresholds like survival are at stake. Here the willingness to avert damage is close to infinity and the level of per capita income only affects the capacity, not the willingness, to pay" (Shafik[19] 1994).

[19] Nemat Talaat Shafik, Baroness Shafik is an Egyptian-born British-American economist who served as the Deputy Governor of the Bank of England from August 2014 to February 2017 and has served as the Director of the London School of Economics since September 2017.

CHAPTER FOUR

ADAPTATION, MITIGATION AND SUSTAINABLE DEVELOPMENT

Climate change is seen to be heightening disparities among countries worldwide, as those majorly hit by the consequences of a changing climate are actually the ones that have contributed and contribute little to greenhouse gas emissions. Countries' past and future contributions to the accumulation of greenhouse gas emissions in the atmosphere are different and the same can be said about their capacity to address mitigation and adaptation. Limiting the effects of climate change is essential if we wish to achieve sustainable development and equity, including the eradication of poverty around the Globe.

Adaptation and mitigation are complementary strategies necessary for the reduction and management of risks associated with climate change impacts over different time-scales. While mitigation in the near term and through the century, can significantly reduce climate change impacts in the latter decades of the 21st century and beyond, benefits from adaptation can already be realized while addressing current risks, but can also be implemented in the future for addressing emerging risks. Countries have already put to action such strategies, but it is clear that without additional mitigation efforts beyond those in place today, warming by the end of the 21st century will lead to very high risk of severe, widespread and irreversible impacts globally, leaving little chance for adaptation strategies to alleviate such consequences. Warming of the Earth's surface is more likely than not to exceed 4°C above pre-industrial levels by 2100.

Substantial cuts in greenhouse gas emissions can reduce risks of climate change sensibly, by limiting a rise in temperatures in the second half of the 21st century and beyond. A limit for cumulative CO_2 emissions would have to eventually lead global net emissions to zero, through the annual constraining over the next few decades. Despite this, there is only so much adaptation and mitigation policies can do for our planet; in fact, as the magnitude and rate of climate change increases, the effectiveness of such policies decreases substantially. Delaying additional mitigation increases its own costs in the medium to long term.

Adaptation can contribute to the well-being of populations, the security of assets and the maintenance of ecosystem goods, functions and services now and in the future. It is every National government's place to coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups and by supporting economic diversification, while providing information, policy and legal frameworks and financial support. Bot local governments and the private sector are increasingly recognized as crucial to maintain progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing.

Adaptation

The UNFCCC[20] and its Paris Agreement[21] recognize that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions. It is a key component of the long-term global response to climate change to protect people, livelihoods and ecosystems. Depending on the unique context of a community, business, organization, country or region, adaptation solutions take many shapes and forms. There is no 'one-size-fits-all-solution', as adaptation can range from building flood defenses[22], setting up early warning systems for cyclones and switching to drought-resistant crops, to redesigning communication systems, business operations and government policies. The term "adaptation" refers to ecological, social, or economic adjustments achieved in response to present or future climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change.

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[20] United Nations Framework Convention on Climate Change.

[21] A legally binding international treaty on climate change. Adopted by 196 Parties in Paris, on 12 December 2015 and entered into force on 4 November 2016. Its goal is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels.

[22] The Mose System in Venice, Italy, is an example of a storm surge barrier, that should keep Venice from flooding.

Mitigation

The term "mitigation" refers to the efforts set to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior. Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation. Scenarios in which all countries of the world simultaneously initiate mitigation, for example by setting a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macro-economic mitigation costs.

Under these assumptions mitigation scenarios that are likely to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption of 1 to 4% in 2030, 2 to 6% in 2050 and 3 to 11% in 2100 relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century. These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6 and 3% per year.

Renewable Energy and Biodiversity

Reducing CO_2 emissions while still meeting the growing demand for energy is a challenge countries worldwide have been trying to overcome for years. Early in March 2020, when most countries had undergone national lockdowns due to the Covid-19 pandemic, the population confinement led to drastic changes in energy use, with impacts on fossil fuel emissions. With changes in patterns of energy demand, reduced transport and shifts in consumption patterns, daily global CO_2 emissions decreased by –19% by early April 2020 compared with the mean 2019 levels. At their peak, emissions in individual countries decreased by –27% on average.

As Nations are now coming out of lockdowns, restrictions are being loosened and the economy slowly resumed, we can expect emissions to increase again. Therefore, even temporary reductions of fossil fuel emissions are insufficient in meeting Paris Agreement targets of preventing the globe from warming more than 1.5 ºC above pre-industrial levels.

Alternatives to fossil fuel emissions can be found in renewable sources of energy such as hydropower, solar energy and wind power. Although these sources of energy are generally low in carbon emissions, they are often more land-use intensive, than conventional energy sources and can potentially have large impacts on the environment and biodiversity, particularly in the hyperdiverse tropics where human populations and economies are expanding most rapidly. Until recently, global attention has largely focused on conventional energy sources, with particular regards to fossil fuels, and its impacts on the environment. Now, some recent reviews have compared the impacts among different renewable energy sources and discovered that they are not as “green” as we hoped they might be.

Solar Energy

By harnessing the power of the sun, solar energy generates electricity either directly through photovoltaic (PV) cells[23], or indirectly by means of concentrated solar power (CSP)[24]. This first main difference between the two being the amount of space they take: while PV panels can be mounted on any surface exposed to the sun, making them ideal for integration into urban environments, or manmade structures, CSP generally requires large areas to be effective. The ecological impacts of USSE, such as CSP technologies (Large-scale solar energy generation, usually referred to as Utility Scale Solar Energy) can affect ecosystems in multiple ways throughout its lifecycle, (i.e. construction- operation- decommission).

Most of the well-documented effects solar energy has on the ecosystem can be seen in the loss and change of habitats. With the development of solar energy infrastructure taking up significant amounts of land, this can result in a barrier to the movement of species, hiding places, preying strategies and a compromised availability of food. Supporting infrastructure (e.g. access roads and electrical equipment) and the spacing requirement of the panels, can result in the actual space requirement of solar power installations being around 2.5 times the area of the panels themselves. CSP technologies also use large amounts of water, therefore having a dramatic effect in water-scarce environments.

[23] An electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.
[24] CSP technologies use arrays of mirrors that track the sun and continuously reflect its rays to a point (heliostats) to heat a working liquid, which is then used to generate electricity in a conventional turbine.

On the contrary, solar PVs can counteract some of the negative effects solar energy has on the environment, through its capacity of being mounted on rooftops and building facades in urban areas, with no need for the conversion or fragmentation of habitats. It should be noted that if these solar PV installations were to be combined with green rooftops[25] they could potentially provide habitat for certain plant or insect species, thus providing a number of ecosystem services in urban areas.

Solar energy installations have also been associated with pollution, as in order to keep panel access to the sun, the cleared land is often maintained with dust suppressants and herbicides, increasing runoff and altering key chemical properties of adjoining waterways when washed out. Finally soil temperature changes have been reported around a CSP plant in China (0.5–4 °C lower in spring and summer and higher by the same range in winter), compared to control sites with no collectors.

Wind Power

Generated from turbines powered by large rotating blades, the size of which has increased markedly since their widespread introduction in the 1980s, wind power has been one of the fastest growing energy generation technologies over the last two decades. While wind energy generation can have a number of ecological impacts on avian and aquatic species, some of these negative effects could be minimized using certain mitigation measures. The main threat to biodiversity arises from the collision of birds with the wind generators.

[25] A roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane.

An estimated 234,000 birds are killed annually from wind turbines in the United States alone. Mitigation measures that can resolve negative impacts on ecosystems and biodiversity include: locating wind power installations in areas of little biodiversity, developing biodiversity-friendly operational procedures for wind energy generation or adopting innovative policies.

Hydropower

Hydropower is harnessed from the kinetic energy derived from fresh flowing water to run turbines and generate electricity, depending on specific geographical constraints and human patterns, the different technologies include: conventional hydropower from dams, run-of-river hydropower and pumped-storage hydropower. Apart from being a renewable source of energy, hydropower has other co-benefits such as water supply regulation, flood and drought control and agricultural irrigation. Over the past two decades, hydropower has come into greater demand with global consumption increasing significantly since the early 2000s. In 2019, global installed capacity of renewable power reached roughly 2.6 terawatts, approximately 1.15 terawatts of which were derived from hydropower.

Despite being praised as a clean source of energy, hydropower actually causes substantial emissions of greenhouse gasses such as CO_2, methane (CH_4) and nitrous oxide (N_2O). Globally, hydroelectric reservoirs emissions range from 48–82 Tg of CO_2 and 3–14 Tg of CH_4 per year from their reservoir surfaces. Further emissions are frequently caused by habitat loss and fragmentation associated with networks of roads and power lines needed for dam construction and operation.

What also stands out is the considerable habitat loss to impoundment reservoirs; the Three Gorges Dam[26] on the Yangtze River in China is considered one of the largest hydroelectric dams in the world based on generating capacity. The Three Gorges Dam, completed in 2012 amidst controversy, concerned the displacement of 1.3 million people (critics insisted the figure was actually 1.9 million) living in more than 1,500 cities, towns, and villages along the river, and the destruction of magnificent scenery and countless rare architectural and archaeological sites.

[26] The Three Gorges Dam is a hydroelectric gravity dam that spans the Yangtze River by the town of Sandouping, in Yiling District, Yichang, Hubei province, central China, downstream of the Three Gorges. The dam generates an average 95±20 TWh of electricity per year, depending on annual amount of precipitation in the river basin.

The Tradeoffs of Renewable Energy

In general, all three renewable energy sources are considered environmentally benign because of their crucial role in combating climate change. In truth though, they generate environmental disturbances, especially if they are to be deployed at the large-scale needed to enable a transition towards a Green Economy[27].

Some of these negative impacts have been largely ignored, but many of can be mitigated. A tool recently developed by the Conservation Strategy Fund allows local citizens, scientists and policymakers to calculate projected carbon emissions produced by planned hydropower dams, influencing decisions about future dam construction. The impacts of solar energy can be mitigated by constructing solar installations in areas that lack ecologically sensitive habitats or that are already degraded. The design of wind farms can be improved to limit biodiversity impacts; building wind turbines at the lowest height feasible, possibly far away from important migratory routes.

More research is needed on the long-term impacts all three types of renewables, but for now, wind power seems to be the safest of them all, leaving hydropower at the very end in terms of overall ecological impacts. The fact remains that the large-scale deployment of renewable energy can have some biodiversity tradeoffs.

Given that non-linear effects can emerge during scaling up and that seemingly low impacts could become considerable when renewable energy technologies are deployed at a scale commensurate to achieve a transition towards a Green Economy, the negative impacts renewable energy has on biodiversity need to be considered when developing renewable energy policies.

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[27] The term Green Economy refers to an economy that aims at reducing environmental risks and ecological scarcities, and that aims for sustainable development without degrading the environment.

TRANSITION TO A LOW-CARBON ECONOMY

Net zero CO_2 emissions are required from countries around the globe to limit global warming to 1.5 degrees Celsius and therefore meet the Paris Agreement. Achieving this goal, which has been adopted by major economies such as EU, US and UK, would require a total transformation of the global economy over the next three decades. The International Energy Agency[28], a Paris-based oil watchdog, has mapped out a pathway that it states is "narrow but still achievable". Under the IEA's scenario, this would include ending the sale of conventional petrol cars by 2035, reaching 100 per cent clean energy by 2040 and using heat pumps to meet at least half of all heating needs by 2045. Total energy consumption in 2050 would be less than it is today because of improvements in efficiency, despite a growth of 40 per cent in the global economy. Being that most of the energy would come from renewable sources, the IEA forecasts that solar power will increase 20 times and wind power 11 times by 2050.

Total capital investment in the energy sector would need to rise to $5tn a year, of which investment in transmission and distribution grids would rise to $820bn annually in 2030 from $260bn today. In this scenario fossil fuels such as coal, oil and gas would have a very limited role by 2050, as coal would decline to just 4 per cent of the global energy supply, mostly from power plants that are equipped to capture carbon dioxide before it is released.

[28] The IEA was founded in 1974 by oil-consuming OECD countries, which were concerned about access to supplies after the Arab oil embargo that sent prices surging. Its mandate has subsequently evolved to consider all forms of energy security.

Tax Policy and Climate Change

In April 2021, the IMF[29] and OECD report for the G20[30] Finance Ministers and Central Bank Governors stated that current emissions commitments and policies fall short of the ambitious policy action that is needed to limit global warming to 1.5 degrees Celsius. In order to put the world on an emissions pathway consistent with climate stabilization targets, global carbon dioxide and other greenhouse gases must be cut by a quarter to a half below projected levels in 2030. As Parties of the Paris Agreement find themselves in the process of submitting revised mitigation commitments in their Nationally Determined Contributions (NDCs) ahead of COP26, in November 2021, many are announcing emission neutrality targets by mid-century. At present though, several intermediate emissions targets for 2030 fail in meeting with such longer run neutrality goals.

[29] The International Monetary Fund was established in 1944 and it promotes international financial stability and monetary cooperation.
[30] The G20 is the international forum that brings together the world's major economies.

Carbon Pricing

Carbon pricing has a central role as it is the only instrument that automatically promotes all mitigation opportunities, and strikes a cost-effective balance across these responses. Since many of the cheapest energy sources generate high carbon emissions, charging for the carbon content of fossil fuels or their emissions corrects for this, providing incentives for businesses and households to make production and consumption decisions that support lower emissions.

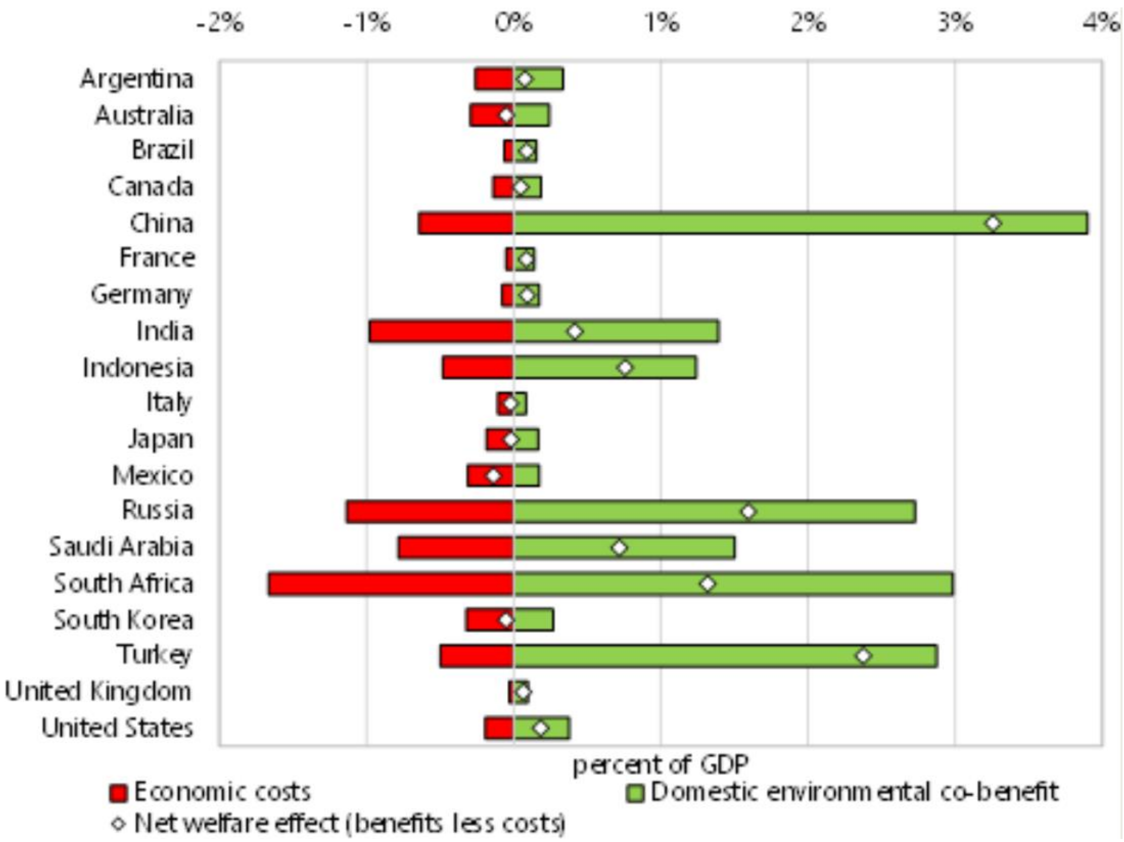

Figure IV.2 1- Efficiency costs and domestic environmental co-benefits for a $50 carbon price, 2030
https://www.oecd.org/tax/tax-policy/tax-policy-and-climate-change-imf-oecd-g20-report-april-2021.pdf

The International Monetary Fund has considered both costs and benefits of carbon pricing globally. The results, that can be seen in Figure IV.2 clearly indicate that domestic environmental benefits can outweigh the economic efficiency costs of pricing. It is in many countries' own domestic interest that there be a price on Carbon, even before counting the global climate benefits. In fact, up to a point, the domestic environmental and health co-benefits can outweigh the economic efficiency costs—this is especially the case for countries with chronic mortality risk from local fossil fuel air pollution.

The potential revenue gains from carbon pricing are significant. For example, a USD 50 per tonne of CO_2 carbon price in 2030 would generate revenue increases of around 1% of GDP for many G20[31] countries and substantially more than that in a few cases.

Unlike most other mitigation instruments, carbon pricing raises government revenues, and administrative costs of revenue collection are much lower than for broader fiscal instruments. Prices in carbon today are well below the required levels, as a recent analysis shows that 55% of CO_2 emissions from energy use across OECD[32] and G20 countries remain completely unpriced.

[31] The members of the G20 are: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States, and the European Union.

[32] The OECD's 37 members are: Austria, Australia, Belgium, Canada, Chile, Colombia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

CONCLUSIONS

Climate Change poses consequences that the current generation and especially future generations will be severely impacted with, despite all efforts on part of the former to mitigate them. The current economic system, based on Capitalism[33] has undoubtley contributed to the breaching of several ecological boundaries, in relation to climate change, biodiversity loss and nutrient enrichment. As the majority of nations worldwide have evolved from primitive types of economic systems to the current, which at first brought benefits to many individuals, it is now clear that the time has come to move on.

Economic growth can only be partial if in its pursuit humanity is altering the environment, causing negative repercussions on itself as well as on other forms of life that all contribute to the ecological balance on planet Earth. The path we have embarked on seems to have come to a dead end, as anthropogenic climate forcing has very likely increased the economic inequality between countries. A parabolic relationship can be found between temperature and economic growth, as rising temperatures increase growth in high-latitude countries and decrease growth low latitude countries.

We must embark on a new path that maintains economic growth, but this time not at the cost of our own wellbeing. As temperatures warm beyond the Paris Agreement targets, the risks of triggering unprecedented climate damages grow.

[33] Capitalism is an economic system based on the private ownership of the means of production and their operation for profit.

Being that the self-organized biosphere is complex and non-linear, it may be inherently impossible for science to discover the limits of the systems resilience.

" It may be possible to burn all the fossil fuels, protect the coastlines from sea-level rise, convert the Amazon to a market garden, and cultivate wheat in Antarctica. But it may not. If it is impossible to know how far it is safe to perturb the system we live in without triggering a catastrophic collapse, then the only reasonable policy is not to perturb it more than it has been perturbed by natural phenomena in the past."

(Robert U. Ayres et al. 1995)[34]

[34] Robert Underwood Ayres is an American-born physicist and economist. His career has focused on the application of physical ideas, especially the laws of thermodynamics, to economics. His most recent work challenges the widely held economic theory of growth.

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