THE IMPACT OF CLIMATE CHANGE ON SELECTED AREAS OF THE WORLD ECONOMY

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Abstract

Background and Objective: Climate change and its impact on the environmental system poses significant risks on the global economy. Yet, most economic theories do not or insufficiently take these into account. Ecological economics is a new scientific field that looks into the risks of climate change impacts on the global economy as extreme weather events are believed to hold disruptive potential towards future economic developments.

Study Design/ Materials and Methods: This review article is based on a primary literature review of key authors within the respective field. As main criteria the articles publication year has been considered.

Results: Climate change risks negatively impact the world's economic system. Key sources of anthropogenic climate change are industrial CO_2 emissions. The logistic industry is one of the major contributors. Impact of climate change are evident through disruptive changes in various environmental systems materializing in e.g. biodiversity loss, change in land, shifts of natural resources and natural catastrophes posing significant threats of economic losses and rising global inequalities.

Conclusion and practical implications: This study adds to our understanding of the direct and intense connection between climate change effects and local and global economic developments.

Keywords: climate change, global warming, economy, ecological economics

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1. Introduction

The economic system plays a central role and can be seen as a dominating factor in modern societies. Trust into and a stable growth of the economy are seen to be essential to maintain individual human wellbeing as well as political stability. The economic system is usually described as the sum of the gross values added representing the GDP, inflation rates and cost of living (Burke et al., 2018; Diffenbaugh and Burke, 2019; Hoegh-Guldberg et al., 2019; Nyambuu and Semmler, 2020; Roche et al., 2020). Though ignored by classical economists, it has become evident that the economic system is not an isolated system within the framework of human activity but dependent from the environmental system represented by so called ecosystem services, estimated to add value as high as 124.8 trillion/year [normalized to USD 2007] in 2011 (Costanza et al., 2014).

In the light of recent evidence of man made global warming, it has become impossible to ignore the existence of an interdependency between the economy and climate change (Ravishankara et al., 2015; Hoegh-Guldberg et al., 2019; Lenton et al., 2019). However, until recently the only question economics and politics had, was how much an economy balanced between emissions and compensation would cost.

The first question will be answered by a desktop research of scientific studies. In addition for the second question this article looks into insurance reports as early and relatively exact indicator for climate change induced costs.

Based on the Swiss Re's sigma reports and the Worlds Bank's loss data from 1970 to 2019 there is evidence for a significant increase of natural catastrophes as presented in Table 1 (Swiss Re, 2021; World Bank, 2021). In this analysis natural catastrophes refer to events caused by natural forces. These include but are not limited to floods, storms, droughts or frost. Man made disasters are associated with human activities or technical disasters. These include but are not limited to fires, explosion excluding war, and war like events. The loss cost refers to direct loss cost like direct physical damage, indirect financial losses such as loss of sales, shortfalls in GDP and non-economic losses, such as loss of reputation are not accounted for. All values are normalized to USD 2010.

The Table 1 illustrates some of the main characteristics of the effects of climate change and the economic system. Since the 1970s both, the number of events and loss cost increased. Man made disasters almost doubled, considering both number of events and average loss cost per event. In the same period natural catastrophes quadrupled and with doubling average loss cost. Interestingly, the number of casualties per event remarkably decreased for natural catastrophes. What is striking about the figures in this table is the relationship of loss costs and the GDP. The economic impact of natural catastrophes is significantly increasing since the 1970s on a worldwide basis. In the same period average temperature increased compared to preindustrial times at a rate of approx. 0.15–0.20°C per decade ("IPCC – Intergovernmental Panel on Climate Change," 2021).

Table 1. Worlds loss data categorized in man made and natural catastrophes

5yr Average	Man Made		Natural Catastrophes	
	1970/75	2014/19	1970/75	2014/19
Number of Events	77.6	131.4	43.8	192.6
Average Loss cost per Event M USD (2010)	33.5	67.7	321.2	706.6
Average Number of Casualties per Event	47.5	30.7	2,098	55.0
GDP per Capita USD (2010)	5,497.6	10,651.5	5,497.6	10,651.5
% of GDP per Capita	0.12	0.11	0.59	1.65

Source: Own study based on (Swiss Re, 202.; World Bank, 2021).

This study set out to investigate and present the relationship of climate change on selected areas of the world economy highlighting interdependencies and limitations of classical economic models. The research seeks to obtain data from primary literature review which will help to improve the general understanding addressing research gaps.

This paper begins by providing an overview and historical trends relating economic development and climate change. Chapter two and three begin by analyzing and providing a definition and common sources of climate change stressing multiple perspectives and including agreed targets. The fourth sections highlights the economic impact of climate change by showing the transition from classic and neoclassical economic models to ecological economics concluding impacts on the macro- and micro-economy. This paper closes with the conclusion summarizing research goals and closing the gap to current research gaps.

2. Definition of climate change

Historically, the term "Climate Change" has been used to describe ecosystems and the change of global weather. The meaning of this term has evolved. Unfortunately, it remains a poorly defined term which is often used as a synonym for "Global Warming". In contrast, the latter term is used to describe the impact of Climate Change on the temperature of the earth's atmosphere. According to a definition provided by Oxford Dictionaries, Climate Change is the noun describing "a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels" ("Oxford dictionary," 2021). This definition has been broadened to include both natural and anthropogenic Climate Change.

Chemists and physicists follow a different approach when referring to climate change. Their definition includes the basic processes and physico-chemical interaction between the atmosphere, biosphere and anthroposphere (Ravishankara et al., 2015). This definition highlights the thermodynamic principles and generalizes the implications for the natural sciences. This descriptive approach generally requires high levels of common knowledge and is not considered to be intuitive. Since climate change is not considered to be a purely theoretical model to help human kind to better understand its origins, disruptive effects can be potentially ascribed to it by means of global warming. Therefore, the meaning of this term for the public shall be considered.

Socio-ecologists use this term to frame a guide for action (Blue, 2016). Companies, institutions and politics have the same deliberation and do not only inform the public but also transform the issue, hence the social interaction. This definition poses a problem as knowledge disparities and gaps can potentially be used to manipulate and therefore undermine informed decisions.

3. Source of climate change

The science of climate change, by means of the identification of effects of certain substances on the average surface temperature has its origins in the early works of Joseph Fourier in 1827. By that time these studies helped to develop the theory of "Ice Age" and how it ended.

Based on Fouriers work John Tyndall found evidence that certain gases, such as but not limited to methane and carbon dioxide, today referred as „Greenhouse Gases GHG" may be one cause of temperature changes (Fleming, 1999; Fourier, 1827). In 1896 Svante Arrhenius calculated the impact on the average temperature by varying carbon dioxide levels in the atmosphere (Fleming, 1999).

Almost 100 years later in the early 1950s first effects of industrial CO_2 emission where linked to potential harmful impact on humankind (Slocum, 1955). Simulations and calculation models have been refined ever since and by the 1970s strong evidence highlighting the impact of anthropogenic or manmade climate change was found (Holland, 1970; Jacobs et al., 1988; Rich, 2018). This was also confirmed by a study performed by Exxon in 1970 the then world's leading oil company linking the impact directly to the burning of fossil fuels (Holland, 1970).

The same was found by Shell in the 1988s (Jacobs et al., 1988). Both reports were kept under seal and Exxon as well as Shell started lobbying against stricter pro-climate legislation (Holland, 1970; Jacobs et al., 1988; Rich, 2018). Skepticism and lobbyism showed their effects and deferred the general understanding and public perception.

Today man made climate change can no longer be neglected and a common understanding throughout the scientific community is established.

3.1. Anthopogenic climate effects

Rockström et al. tried to give a more holistic approach towards climate change besides only focusing on the mean temperature increase. In his paper, Rockström et al. considered an enlarged environmental system approach. As part of this new approach Rockström et al. defined additional environmental systems playing a crucial role in the climate change (Rockström et al., 2009). Key concept is to maintain the planet's environment in a state similar to the preindustrial Holocene, or generally known as Anthropocene.

For this purpose, Rockström et al. identified ten global systems. They suggested individual levels for each and every system in order to maintain the Anthropocene. These ten systems with planetary boundaries are: (i) Climate change, (ii) Rate of biodiversity loss, (iii) Nitrogen cycle, (iv) Phosphorus cycle, (v) Stratospheric ozone depletion, (vi) Ocean acidification, (vii) Global freshwater use, (viii) Change in land use, (ix) Atmospheric aerosol loading, (x) Chemical pollution (Rockström et al., 2009).

Different to other authors, Rockström et al. followed a unique approach identifying the key parameter and maximum levels for each category (Rockström et al., 2009). An example is the system climate change. Unlike his peers, Rockström et al. considered changes in the radiative forcing a critical parameter besides atmospheric CO_2 concentration (Rockström et al., 2009). This incorporates changes in the earth's atmosphere on a more holistic level.

Critics have argued that Rockström et al. did not take other GHG into consideration, such as but not limited to methane. Furthermore it is questionable whether these ten systems are truly independent, do not influence each other and can be evaluated separately. As an example, the carbon dioxide concentration is closely related to the oceans acidification, while the nitrogen and phosphorous cycle are closely linked to chemical pollution.

3.2. Agreed targets

As climate change is already taking place, efforts should be made in order to minimize its impact on the world's economy and society. The Intergovernmental Panel on Climate Change [IPCC] suggests a moderate impact if the mean temperature increase is limited to 1.5°C, compared to preindustrial times. Further impact on the world's economy and society resulting from disruptive changes in each of the ten by Rockström et al. defined global systems must also be considered.

In their article Hoegh-Guldberg et al. described the potential effects on the planet with significant changes in the above mentioned global systems (Hoegh-Guldberg et al., 2019). Hoelgh-Guldberg et al. simulated various scenarios based on the latest IPCC reports and suggestions. Effects and impacts have been analyzed on a time scale period up to the year 2200 (Hoegh-Guldberg et al., 2019).

In contrast to other papers, Hoegh-Guldberg et al. concentrated on expected impacts on the system such as increased sea levels, natural catastrophes and implications thereof on human life and ethical aspects whilst ignoring the origins of said impacts. Interestingly they used a non-linear exposure model unveiling different tipping points of certain ecological systems. This is a common approach, putting greater emphasis on extreme events.

According to Hoegh-Guldberg et al. limiting the mean temperature increase to 1.5°C compared to preindustrial times and reduce net GHG emission to zero by 2050 requires a total investment of USD2010 71.4-150.3 trillion (Hoegh-Guldberg et al., 2019). This potentially results in the mitigation of direct loss costs of USD2010 496 trillion until 2200 (Hoegh-Guldberg et al., 2019). Indirect loss costs, based on decrease of GDP, migration of human communities or loss of biodiversity are not included. Indirect loss cost are expected to be considerably high.

4. Economic impact of climate change

4.1. The relationship between economy and climate change

Traditionally the economic system was described through classical and neoclassical economics. These have been the basis for the formulation of various models always evolving alongside with the market. The introduction of these economic theories improved the comparability of governments and businesses against each other. The key concept is that production, consumption and valuation of services and goods is driven by the markets supply and demand (Smith, 1776). Each individual has the goal to maximize his profits or obtained utility. The output in terms of services and goods is realized by defined production factors.

Classical economics differentiates three production factors as follows: Land, Labor and Capital. Land often refers to a natural resource such as but not limited to an area or crops (Grosse, 1991; Smith, 1776). Labor results from human capita and includes both, physical and mental work. Capital can be machinery or buildings as well as monetary resources.

Yet, with the development towards neoclassical economics slight changes led to a further refinement of these production factors. However, the key concept remains unchanged: Production factors are fully substitutional assets and efficiency can be increased without limit (Grosse, 1991). The above means, that economy can show unlimited growth and e.g. loss of Land can be compensated either from increased Labor, Capital and/ or an increased efficiency.

These claims have been strongly contested in the recent years by a number of writers. Especially considering growing economy and worlds population. Resources such as area, space, certain elements and products are becoming scarce. This transition from an unlimited to a restricted supply is known as the transition from an empty to a full world (Boulding, 1996; Costanza et al., 1997a; Daly and Farley, 2004).

Boulding's 1966 paper on the economics of spaceship earth gave general criticism that the economic system is an open subsystem of the closed biosphere and is subject to biophysical laws and constrains (Boulding, 1996). The concept of substitution is limited and economic maximization with unlimited growth is therefore not possible. This follows the thermodynamic principles. Costanza et. al, and Daly et al. further refined this framework in the 1990s and 2000s (Costanza, 1989; Costanza et al., 1997a, 1997b; Daly and Farley, 2004). The latter authors accounted all generated outputs in their analysis including environmental polluters such as but not limited to GHG. This is often referred as the start of Ecological Economics.

Having established the boundaries of the economic system a proper valuation of each resources becomes necessary. While the cost of Land, Labor and Capital as defined by classical economics are well understood, full value of the environment needs further recognition.

Kenter et al. relate the importance and significance of environmental resources towards their value to society differentiating between an ethical and social dimension (Kenter et al., 2015). Within this context values may be created individually with additional respect to ones individual fulfillment through the enjoyment of others. Kenter et al. distinguishes between the following four categories (Kenter et al., 2015):

- Shared value: Guiding principles and normative values. These values are for the greater good with no direct benefit to the individual e.g. natural reserves;
- Social values: None-use benefits that people derive from ecosystem. These values have a social meaning;
- Shared social values: Used to describe a combination of various the above concepts;
- Ecological value: Score based on the overall attributes to human benefit.

This is in contrast to neoclassical economics which does not account values of others as it might result in double counting in an aggregate perspective (Kenter et al., 2015). Classical and neoclassical economics do not recognize the full value of the environment. Market benefits resulting from the environment [e.g. wood for paper, land for crops] are held by individuals. This is in line by the common understanding of production factors in which full substitution and/ or an increased efficiency are identified as the key factors for stabilizing long term growth.

4.2. Macro-economic impacts

On a macro-economic level global warming does not only hold risks but also chances for certain countries, within certain limits. In his study, Burke et al. examined the relationship of global warming and development based on the GDP on a country level. Surprisingly, a correlation between the annual average temperature and the change in GDP per capita can be found. Based on a dataset of 165 countries over the years 1960-2010, 13.1°C [+/- 3.4°C; 95%] is the optimal annual average temperature for GDP per capital maximization (Burke et al., 2018).

Diffenbaugh et al. applied Burke's et al. research identifying countries with a higher likelihood of benefitting and loosing from global warming. Generally, countries with annual average temperatures below the identified optima of 13.1°C are more likely to profit from global warming, and vice versa (Burke et al., 2018; Diffenbaugh and Burke, 2019). Countries in the northern hemisphere are cooler and tend be positively impacted. These use to be "wealthy" countries in such as but not limited to Norway or Germany. Whereas countries in the southern hemisphere are expected to be negatively impacted. India and Brazil are some examples for such. This effect intensifies with increasing distance from the equator.

During the analyzed period relative changes in the GDP per capita among countries in the northern and southern hemisphere have been 25% (Diffenbaugh and Burke, 2019). In said years the average temperature increased by 1.0°C (Diffenbaugh and Burke, 2019). The growing gap promotes global inequality and can be a cause of conflicts.

Some criticism can be based on the simplification and limited consideration of other parameters besides GDP per capita. However, the GDP can be seen as a holistic indicator incorporating a vast number of variables such as but not limited to the level of industrialization, education as well as resources.

4.3. Micro-economic impacts

Climate change is expected to further shift the availability of natural resources in an unprecedented way potentially provoking national conflicts. The impact of climate change may cause microeconomic failures resulting from a fluctuating availability of natural resources due to severe weather events. Violent conflicts may be formed on this basis.

Following the study of Couttenier et al., high opportunity gains can be expected when starting violent conflicts [wars] during bad years [in terms of resource availability] as potential future returns outweigh the costs (Couttenier & Soubeyran, 2015). On the other hand, during high-yield years cost of opportunity exceed future gains.

As a result of global warming the frequency of extreme and disruptive weather events will potentially increase and therefore bad resource years. Thus the risk for violent conflicts amongst states. However, it is important to note, that with increasing disruptive weather events, possible opportunity gains are also diminished. The result of this research supports the idea, that global warming and climate change strongly influence income, based on the resource availability and opportunity cost, hence affect the GDP on a macroeconomic level.

As these impacts are driven by severe weather events, frequency changes of such events can be related to economic variations (Roche et al., 2020). The scope of the study was limited in terms of variables. Historical, political and other governmental social factors have not been included. Furthermore mitigation and regulatory strategies not limited to technological development, institutional support by insurance companies and economic regulations by governmental or market as well as the development of substitutes have not been accounted. The generalisability of the results is also subject to additional limitations. For instance, caution should be used as microeconomic models are being applied and conclusion on a macro economical are drawn.

4.4. The impact of climate change on the functioning of the logistics system

Central to the world economy is the logistics system. It connects businesses, manufacturers, productions and client products with their respective consumers. In 2020, the logistic industry is estimated to have contributed some USD 6,000bn to the worlds GDP (More, 2021; Penose, 2021). Germany is responsible for some 5%. Regardless of its economic benefits it is one of the largest GHG emitters. Logistics in the fossil fuel sector account for two-thirds of GHG emissions (Birol, 2016).

This high figure can be explained, as the logistics require an intense use of energy primarily obtained by fuels such as but not limited to coal, oil or gas (Vitharana & Kandegama, 2020). The most common energy transformer are internal combustion engines. Current legislation and political trends suggest a mid to long term exit of such system and a transition to alternative concepts such as electric or hybrid powered solutions (Campbell, 2019). A recently published article by Serrano et al. casts doubt on the effectiveness of these measures (Serrano et al., 2019).

Without neglecting the importance towards a zero-emission economy, a disruptive technological change in the transportation and logistics industry is not supported based on net emission potential. In support of this, Buchal et al. calculated the net CO_2 emissions over a lifetime for both electrical powered and modern diesel powered vehicles (Buchal et al., 2019). The results indicates that electric powered vehicles tend to show 11 to 28% higher emissions compared to the diesel vehicles (Buchal et al., 2019).

Besides this, the logistic industry is showing high sensibility towards disruptive climate events. This is empathized by modern logistic systems following cost efficient lean methods, such as just-in-time or zero-inventory (Kovács & Sigala, 2021). Continuous material flow is key to ensure uninterrupted production. While this principle leads to cost optimization, it becomes more vulnerable to disruptive events thus minimizes resilience. Such disruptive events can be based on climate change. Supply sources and supply routes can be impacted by storms, flooding, droughts, fires or more generally extreme disruptive weather events (Er-Kara et al., 2020). The 2018 drought in Germany is a good illustration of the impact of blocked supply routes. Low water levels at the River Rhein led to significant production impacts due to material shortage resulting in economic losses of some USD 2.8bn in Germany (Förster et al., 2020).

5. Conclusion

This paper has discussed the reasons for the necessity of a new scientific field by highlighting and associating economic risks to global climate change. The purpose of the current study was to present an overview of current literature.

One the one hand, the increasing impact of natural hazards as a result of anthropogenic global warming can no longer be neglected. First evidence was found in 1970s and 1980s, however with a rising economic pressure efforts were made keeping it classified for public.

On the other hand, with no actions taken and continuing global warming, the impact of such events [natural hazards] materialized on the world's economy and on individuals as measured in by means of GDP per capita. Numerous industries are already experiencing its impacts. Industries showing high dependency and sensitivity to the changes in the ecological systems, such as logistics are especially vulnerable.

Additional stress is expected with rising temperatures and severe weather events. This is further promoted as global inequalities are expected to increase.

Present classical/ neoclassical economic theories are based on a conventional production factors model, allowing full substitution of all inputs. Together with an assumed unlimited progress, allowing an infinite efficiency increase, all with climate change [and other] related challenges can be overcome.

However, these models fail to cope with changes in external superior systems such as the ecology. First limitations apply as only limited substitution can be realized for inputs, outputs and inputs show strong dependency and the environment has to be considered and valued by the economic system. Ecological economics respects this relationship and accounts thermodynamic principles on a holistic level. This study adds to this rapidly expanding field by presenting an overview of current literature and developments.

A practical challenge is the transition from the classical economic theories towards more holistic ecological economics stressing global practice and reevaluating established systems. Yet, this information can be used to further develop targeted transitions for future practice. Further research should focus on identifying critical carriers and fields driving economic behaviors. Financial providers such as the insurance sector is believed to be a key stakeholder showing impacts by both climate change and economic development.

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