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Climate Change Indicator Analysis[1]

Climate change is the single greatest threat to a sustainable future. But, at the same time, addressing the climate challenge presents a golden opportunity to promote prosperity, security, and a brighter future for all.

Ban Ki-Moon, Former Secretary-General of United Nations

Abstract: Climate change indicators are a measurable and acceptable method of collecting evidence of changes in the Earth's climate throughout time. Thus, climate change indicators capture the total impact of climate change on all economic activities and their participants. These indicators are used by policymakers, researchers, and scientists to better understand the effects of climate change, including trends and patterns. Adequate understanding and monitoring of these indicators are critical for developing successful climate change mitigation and adaptation strategies. Climate change indicators are examined by combining data collection, measurement, and analysis with scientific observations. These analyses need the use of complex statistical techniques and models, as well as the participation of scientists with varying specialties, such as ecologists, climatologists, and meteorologists. The purpose of collecting climate change indicators is to understand current and future climatic trends, as well as to provide policymakers with trustworthy information for developing climate change adaptation strategies.

Key words: climate change indicator, greenhouse gas (GHG) emission, low carbon economy; climate transition, climate finance

JEL Code: Q01, Q53, Q54.

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1. Introduction

Climate change has a greater impact today than ever before, affecting all economic activities and actors. As a result, long-term climate change strategies must be followed in order to adequately react to those changes. The majority of climate change can be ascribed to human factors and activities resulting in greenhouse gas emissions into the atmosphere. Given that climate change is a global issue, worldwide cooperation is required to implement strategies that ensure long-term economic growth and development. International agreements and conventions, such as the Paris Agreement, have been established with the goal of countries working together to minimize the effects of global warming and mitigate the repercussions of climate change. To effectively address the issues posed by climate change, effective collaboration at the local, national, and global levels is required.

To address the consequences of climate change, comprehensive and reliable data on climate change must be collected over time in order to develop appropriate and timely policies to lessen the impact of such changes. Climate change indicators are an important tool that scientists and researchers use to monitor climate change trends and patterns. The aforementioned indicators provide measurable evidence of changes in the planet's climate over time. These climate change indicators serve as the foundation for informing scientists and decision-makers since they facilitate the analysis of climate models, the testing of various stimulation scenarios, and the observation of satellite image data. A longer period of climatological data enables for the discovery of climatic trends and patterns that can clearly distinguish between human-caused changes and natural variability. In this paper, we analyse the climate change indicator. Following the introduction and literature review, we l give an analysis of the climate change general overview and climate change indicators, using the European Central Bank as a case study. In conclusion, we outline the key findings of this paper.

2. Literature review

The literature on climate change indicators is multidisciplinary, encompassing climatology, environmental science, meteorology, ecology, and other fields. Researchers and scientists utilize a wide range of indicators to assess and study changes in the Earth`s climate. Climate change indicators are a critical tool for assessing and understanding climate change on Earth over time. Thus, these indicators represent environmental changes such as global temperature rise, sea level change, changes in precipitation patterns, and variations in the intensity and frequency of extreme weather events. Each of the indicators contributes significantly to understanding the dynamics and interconnections of the climate system. Understanding climate change indicators is crucial not only for scientific research but also for raising awareness of the significance of taking collective action in the effort to fight against climate change. With this approach, the significance of climate change indicators grows, keeping in mind the imperative of implementing sustainable policies to alleviate the effects of climate change.

The Organization for Economic Cooperation and Development (OECD) was one of the first organizations to address the issue of climate change indicators. In 1993, the OECD identified thirteen indicators of environmental performance: climate change, stratospheric ozone depletion, eutrophication, acidification, toxic contamination, urban environmental quality, biological diversity and landscape, waste, water resources, forest resources, fish resources, and soil degradation, to reduce the number of parameters used until then and simplify the communication process (OECD, 1993). Climate change indicators are measurements or calculations that can be used to track climate conditions and changes. These indicators are a crucial tool for monitoring and communicating the causes and impacts of climate change. Thus, these indicators describe the condition or trend of a specific element in the climatological environment throughout a given period and geographic area. Climate change indicators are physical, ecological, or social changes that are used to assess climate risks and vulnerabilities, as well as to provide information on resilience and climate impact assessment (Balasubramanian, 2017). In addition to providing important information about climate conditions, indicators also serve as early warning indicators, allowing available data to be used to identify environmental problems that can be addressed before the situation worsens (Donnelly, Jones, & Sweeney, 2004).

The purpose of utilizing climate change indicators is to measure the environmental impact of various economic activities and then implement a sustainable transition accordingly. This allows for a differentiation between the application of indicators at different levels (macro versus micro indicators), as well as the ease with which indicators can be used. Some indicators are broad in nature, while others are narrowly focused on a specific part of the environment or features of a sustainable transition, such as the circular economy (Brusselaers, Can, & Sturm, 2022). According to Reyes-García et al. (2016), the term "local indicators of climate change" refers to local observations of climate change, whereas "local observations of climate change" refers to reporting on climate system changes like temperature and wind strength. Different scientists perform their research using various climate change indicators. For example, Bässler, Müller, and Dziock (2010) used geostatic models of local temperature in their analysis to investigate the effect of temperature changes on selected plant species and thereby assess the species' viability as a climate change indicator. Feldmeyer et al. (2019) created a climate change indicator to measure and monitor urban climate resilience, as well as monitoring the implementation of adaptation measures, whereas Bowler and Bohning-Gaese (2017) created a community temperature index (CTI) that represents a weighted average in temperature value movement and is used as an indicator for analysing temperature change. Clavero, Villero, and Brotons (2011) investigated the effect of various climate change indicators (such as environmental temperature and land use) on bird community data to include global changes in biodiversity trend indicators. The rising impact of humans on coasts, as well as the concerns posed by sea level rise, have impacted the development of several concepts and analytical methods to developing indicators of coastal vulnerability (Nguyen, Bonetti, Rogers, and Woodroffe, 2016). Karl, Knight, Easterling, and Quayle (1996) studied data from the United States and created two climate change indices: the Climate Extremes Index (CEI), which represents an aggregated set of conventional indicators for extreme weather conditions, and the U.S. Greenhouse Climate Response Index (GCRI), which consists of indicators that measure climate changes caused by increased greenhouse gas emissions. Guan et al. (2020) utilize the standard deviation (SD) index to assess the complex interaction between major climate zones.

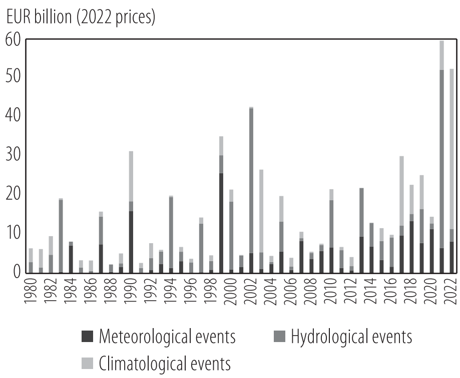
Human-caused climate change presents risks that must be addressed through adaptation (Engle, Bremond, Malone & Moss, 2014). As a result, it is vital to consider which sectors are most vulnerable, as climate change affects all aspects of human and natural ecosystems. Hatfield et al. (2020) carried out this study and discovered that climate change has the greatest influence on essential human necessities such as water and food preservation. As a result, it is critical to examine agricultural climate change indicators to ensure that agriculture can feed the world's future population in the face of significant climate change. Climate change will have a greater impact on natural and human systems as time goes on. In this regard, the most significant consideration is the speed with which adaptation actions are implemented to accommodate current and future changes. Adequate environmental indicators must be developed to measure progress in climate change adaptation (Pearce-Higgins et al., 2022). Climate change indicators provide a comprehensive approach to monitoring climate change. The collected data highlight the importance of taking immediate action to cut greenhouse gas emissions and implement policies that will ensure the construction of a more sustainable and resilient economy. To meet the challenges of climate change, international cooperation, political initiatives, and innovations in technology need to be established.

3. Climate change general overview

Combating climate change remains a major concern in the 21st century. Climate change, causing global warming, has become more obvious in our surroundings (Fabris, 2020). Climate change is a global danger that has raised damages and losses, endangered people's lives, and jeopardized the operation of natural systems. Climate change, as defined by the 1992 United Nations Framework Convention on Climate Change (UNFCCC), is "change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The UNFCCC went into effect in 1994 and does not legally bind parties to reduce greenhouse gas emissions or specify a timetable for reaching the goals. As of 2019, 197 countries have ratified this document, including the United States of America. The UNFCCC signatories' first conference, known as the Conference of the Parties, or COP1, took place in Berlin in 1995. This meeting resulted in an agreement known as the Berlin Mandate, which served as the foundation for the development of the Kyoto Protocol. At the COP3 summit in Japan in 1997, the Kyoto Protocol was established, which is a legally binding agreement for industrialized countries to cut harmful gas emissions by an average of 5% compared to 1990 levels, with the construction of a framework for monitoring countries' progress. However, the agreement did not require India and China, which are major carbon polluters, to take real action. After the United States withdrew from the Kyoto Protocol in March 2001, its implementation was jeopardized. In October that year, the signatory countries reached an agreement to establish rules for meeting the Kyoto Protocol's goals, paving the way for its official adoption in February 2005, when it was ratified by a sufficient number of countries accounting for 55% of global harmful gas emissions. The Kyoto Protocol`s first term of applicability covers five years, from 2008 to 2012. In 2007, the UN Intergovernmental Panel on Climate Change (IPCC) released the AR4 Climate Change 2007: Synthesis Report, which indicated that human activities are the most likely cause of global warming. In Doha at COP18, the Doha Amendment to the Kyoto Protocol was adopted, which extended the validity for the period from 2013 to 2020. The Paris Agreement, which went into effect in October 2016, is considered by experts to be the most important global climate pact, having been signed by 196 countries so far. Unlike past agreements, the Paris Agreement mandates all countries, including developed countries, to cut their emissions of dangerous gases. The Paris Agreement aims to keep global warming below 2, preferably 1.5 degrees Celsius, relative to pre-industrial levels. In September 2019, United Nations Secretary-General Antonio Guterres convened the UN Climate Action Summit in New York, inviting authorities to submit plans to decrease greenhouse gas emissions by 45% by 2030 and achieve carbon neutrality by 2050. The continuation of negotiations was postponed due to the Coronavirus pandemic, and an agreement was made at COP27, held in Sharm el-Sheikh in November 2021, to establish a fund to assist impoverished countries and countries most vulnerable to climate change. At COP28, held in December 2023 in Dubai, United Arab Emirates, an agreement was achieved to gradually reduce the use of fossil fuels, with a tripling of renewable energy sources and a reduction in methane emissions by 2030 (UN Climate Talks).

The degree of damage and losses caused by the impact of climate change is enormous, demonstrating the importance of taking immediate action to prevent the extent of the damage from increasing further in the future. According to data from the European Environment Agency, member countries of the European Union face large economic losses that increase over time, ranging from EUR 2 billion in 1988 to EUR 59 billion in 2021 –(Graph 1). According to the United Nations Adaptation Gap Report 2022, the yearly cost of climate change mitigation will vary from US$160 to US$340 billion by 2030 and US$315 to US$565 billion by 2050. Based on the Adaptation Gap Report 2023, developing nations must pay US$387 billion per year for adaption plans until 2030, and international assistance is required to collect these funds. The data above show how much it costs to remediate the effects of climate change, as well as how these changes affect the economy, society, and the environment.

Graph 1: Annual economic losses caused by weather and climate-related extreme events in the EU Member States



Source: European Environment Agency (EEA), Economic losses from weather- and climate-related extremes in Europe, Retrieved from https://www.eea.europa.eu/en/analysis/indicators/economic-losses-from-climate-related

Sustainable development is directly linked to climate change mitigation and adaptation. To create an equitable and environmentally sustainable future, these two concepts must be integrated and coordinated across sectors. Today, establishing sustainable economic growth, which can be described as a steady increase in the production of goods and services, as well as the creation of new jobs, is critical to achieving economic and financial well-being (Isibor et al., 2023). The efficient use of environmental resources ensures long-term economic prosperity, which is especially vital in times of global uncertainty such as climate change (Vallet, 2021). In addition to sustainability, another essential feature of economic and social progress is inclusion, which is measured as growth that benefits the poor (Jakšić & Jakšić, 2018). To develop a climate change adaptation strategy, timely and adequate climatological data represented through the climate change indicator are required, which will be addressed in the following section of the paper.

4. Climate change indicator analysis

Since the industrial revolution, human activities have resulted in enormous emissions of greenhouse gases into the atmosphere, contributing to global warming. Climate change evidence has grown in prominence in recent decades, ranging from rising temperatures to extreme weather occurrences such as floods and droughts. Climate change indicators include tracking global temperature rise, glacier melting, and forest fires, all of which contribute to a better understanding of climate change on Earth (www.worldatlas.com). The Intergovernmental Panel on Climate Change (IPPC), which was published in 2014, concluded that human activities are the primary cause of global warming with 95% certainty. Furthermore, the aforementioned analysis concluded that the more human activities affect the climate, the greater the likelihood of impact on ecosystems, resulting in long-term changes in all parts of the climate system (IPPC, 2014). In the 2016 report Global Guidance for Life Cycle Impact Assessment Indicators, the United Nations Environment Programme (UNEP) distinguished between climate change impacts in the short term, which include the rate of climate change and the impact on adaptation capacities to ecosystem changes, and long-term changes, which include long-term temperature rise and related ecosystem impacts (UNEP, 2016).

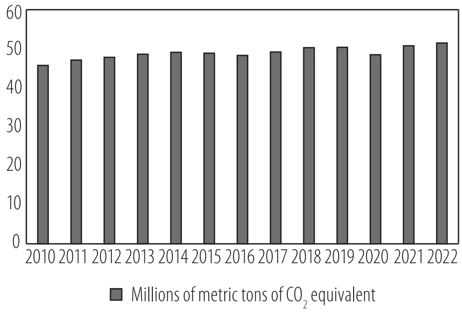
Since 2005, Germanwatch, the NewClimate Institute, and the Climate Action Network have released an annual Climate Change Performance Index (CCPI). The CCPI is an independent instrument for monitoring each country's performance in environmental conservation and preservation. As a result, national and international climate policies become more transparent, allowing for comparisons of particular countries' climate protection efforts and progress. The CCPI is calculated using fourteen metrics divided into four categories: greenhouse gas emissions (participation weight 40%), renewable energy (20%), energy use (20%), and climate policy (20%). According to the most recent data, the CCPI for 2024 measures climate performance in 63 countries and the European Union, which includes countries that account for more than 90% of global greenhouse gas (GHG) emissions. In November 2022, the International Monetary Fund, the Financial Stability Board (FSB), and the Inter-Agency Group on Economic and Financial Statistics (IAG) created a proposal for the new Data Gaps Initiative (DGI). The plan has 14 proposals that, in addition to climate change, address financial inclusion and fintech, population income distribution, and access to private data. All DGI participants agreed that governments needed to take more decisive action to promote equitable and environmentally friendly growth while also making progress toward climate goals (IMF, 2022).

The International Monetary Fund, in collaboration with other international organizations, has identified and created a set of climate change indicators to demonstrate the impact of economic activity on climate change. The International Monetary Fund classified these climate change indicators into six categories: (1) greenhouse gas (GHG) emissions; (2) mitigation; (3) adaptation; (4) transition to a low-carbon economy; (5) climate finance; and (6) climate and weather. The International Monetary Fund introduced the Climate Change Indicators Dashboard in April 2021, which was presented at CNN's A Critical Year for Climate Action conference. At the conference, Kristalina Georgieva, President of the International Monetary Fund, and John Kerry, Special Presidential Envoy for Climate, explored how to translate climate objectives into tangible actions while also generating chances for a transition to a new climate-sustainable economy. The Climate Change Indicators Dashboard was last updated on December 19, 2023. The time and spatial coverage of the data are determined by the climate change indicator used. For example, data on CO2 emission intensities and multipliers for indicator greenhouse gas (GHG) emissions are available for 66 countries from 1995 to 2008, whereas data on environmental taxes and indicator mitigation are available for 126 countries from 1995 to 2021 (IMF, Climate Change Indicators Dashboard).

4.1. Greenhouse gas (GHG) emissions

Climate change indicator greenhouse gas (GHG) emissions reflect seasonally adjusted annual and quarterly emissions produced by each regional economic activity. The System of Environmental-Economic Accounts (SEEA) is the source of annual data, while GHG emissions by country are provided by Climate Watch, an online platform designed to provide climate data to policymakers, researchers, and media representatives, and the Emissions Database for Global Atmospheric Research (EDGAR), an independent global database of GHG emissions and air pollution on the planet. The International Energy Agency (IEA) and other organizations collect sub-annual data on GHG emissions (Graph 2).

Graph 2: Annual Greenhouse Gas (GHG) Emissions



Source: International Monetary Fund, Greenhouse Gas Emissions, Retrieved from https://climatedata.imf.org/pages/greenhouse-gas-emissions#gg1

The International Monetary Fund has determined mitigation targets for each country based on its interpretation of Nationally Determined Contributions (NDCs). The NDCs indicate each country's obligation to reduce its GHG emissions as stipulated under the Paris Climate Agreement. Mitigation targets reflect the dynamic relationship between the annual level of GHG emissions and each NDC at a given date, and they are displayed for illustrative purposes because the International Monetary Fund is constantly improving its method of calculation. CO_2 emissions are specifically monitored within GHG emissions, as they indicate the amount of CO_2 emitted into the atmosphere as a result of direct and indirect fuel burning per one million USD of output. According to the most recent available data for 2018, Saudi Arabia is the largest CO_2 emitter (499 metric tons for one million USD of output), followed by Vietnam and the Russian Federation (477.7 and 454.2 metric tons per one million USD of output, respectively). Furthermore, within the framework of GHG emissions, carbon footprints from economic activity are monitored, which show the production of emissions related to each country's import, export, and domestic demand, as well as CO_2 emissions in output and cross-border trade by firm ownership, which represents CO_2 emissions resulting from production activity.

4.2. Mitigation

Under the category of mitigation, there are indicators that give information on how to lower the amount of greenhouse gas emissions. These indicators include measures like raising carbon taxes, cutting back on fuel subsidies, and improving regulations to assist nations in meeting their nationally determined contributions, which are specific to each nation. Several indicators are included in the mitigation of climate change, including (1) environmental taxes; (2) environmental protection expenditures; (3) fossil fuel subsidies; (4) renewable energy; (5) trade in low carbon technology, and (6) forest and carbon. *Environmental taxes* are a cost levied on each physical unit of an item that has been proven to harm the environment. A physical unit can be a ton of rubbish in a landfill or a gallon of petroleum. *Environmental protection* expenditures demonstrate how much money each government allocates for conservation and environmental protection initiatives, and they are typically stated as a proportion of each country's GDP. This indicator covers waste management, water management, environmental protection, environmental research and development, pollution reduction, and biodiversity conservation. The projected value of government subsidies for fossil fuels—oil, coal, gas, and electricity—is included in the category of *fossil fuel subsidies*. These subsidies are classified as either explicit or implicit. Explicit subsidies reflect the lower prices that consumers pay compared to the cost of production. Implicit subsidies, on the other hand, refer to the difference between supply costs and socially efficient prices and include the cost of the negative externalities associated with the use of fossil fuels as well as tax revenue from consumption that has not been charged. *Renewable energy* is an indicator used to track advancements in the usage of renewable energy sources, which are classified into hydropower, solar energy, wind energy, and geothermal energy based on the technology in place. When compared to conventional industrial methods, *trade in low-carbon technologies* guarantees a decrease in emissions. Systems based on biomass, wind turbines, and solar energy utilize less carbon dioxide. Considering that forests create the majority of the carbon on land, *forests, and carbon* are indicators that provide information about carbon stocks. A reduction in carbon emissions and a subsequent acceleration of global warming may result from changes in forests, regardless of their size or state.

4.3. Adaptation

The adaptation indicator's indicators refer to the necessity of establishing institutional and financial resilience to create a system that can withstand extreme weather, natural disasters, and other climate change-related occurrences. The climate-driven INFORM risk and the frequency of disasters linked to climate change are the two measures that make up the adaptation indicator. Leading international organizations like the United Nations Office for Disaster Risk Reduction (UNDRR), the Centre for Research on the Epidemiology of Disasters (CRED), the Intergovernmental Panel on Climate Change (IPCC), and the World Meteorological Organization (WMO) gather data on the relationship between climate change and natural disasters. This data is known as *climate-related disaster frequency*. Looking at the global data for 2022, the most common events were floods (176 times), followed by storms (105) and droughts (22). *Climate-driven INFORM risk* is a global crisis and disaster risk index that takes vulnerability, climate exposure, and climate risk into account.

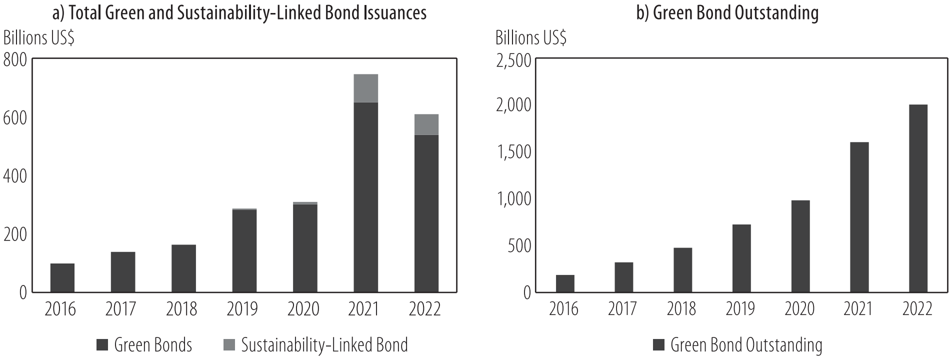
4.4. Transition to a low-carbon economy

The shift to a low-carbon economy is a climate change indicator that shows how efforts are being made to move toward a future with less carbon dioxide emissions while also examining the risks related to climate change that may affect financial stability and economic growth. The forward-looking risks and the trade in low-carbon technology are the two elements that make up this indicator. Analysing the carbon cost to assets/revenues indicator, which displays the ratio of carbon taxes to income/assets of companies required to report environmental impact data during the establishment of climate neutrality by 2050, and the assets/revenues at risk indicator, which displays the participation of companies reporting data for specific nations and sectors predicted to be impacted by the three distinct climate stress test scenarios (hot house world, orderly, and disorderly) created by the Network for Greening the Financial System (NGFS), are indicators of *forward-looking risks*. *Trade in low-carbon technology* items plays a significant part in the shift to a low-carbon economy by providing information on which products generate products with less pollution when compared to old energy production methods.

4.5. Climate finance

The ability to gather data on the distribution and utilization of financial resources supporting all efforts to combat climate change is made feasible by the climate finance. Green debt and the carbon footprint of bank loans are the two metrics that are tracked under this one. In order to fund environmental protection and climate change remediation projects, *green debt* is represented by the issue of sustainability-linked and green bonds (Graph 3). In addition, green debt is a crucial component of green finance, which aims to create sustainable funding for initiatives that take social and environmental factors into account when making investment decisions (Martin, 2023).

Graph 3 - Green Debt



Source: International Monetary Fund, Climate Finance,
Retrieved from https://climatedata.imf.org/pages/climate-finance

Based on a comparative analysis of the banking sector's vulnerability across nations, the *carbon footprint of bank loans (CFBL)* measures each bank's exposure to transition risk. Increased carbon dioxide levels in bank credit portfolios are indicated by higher levels of this indicator. Consequently, it is imperative to move toward a low-carbon economy, which will involve the financial sector as well. Banks are crucial in this regard because of the various industries in which they grant credit.

4.6. Climate and weather

Indicator climate and weather give data on weather patterns, climate, temperature fluctuations, and sea level changes. This indicator monitors four metrics: annual surface temperature change, atmospheric CO_2 concentrations, change in mean sea levels, and land cover. *The annual surface temperature change* comprises data on the average temperature change between 1961 and 2021, with the temperature from 1950 to 1980 serving as the basis for calculation. The Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) and the National Aeronautics and Space Administration Goddard Institute for Space Studies' publicly available database (NASA GISS) supply the aforementioned data. *Atmospheric CO_2 concentrations* are the concentrations of carbon dioxide in the atmosphere, and monthly and annual data have been available since 1958. *Changes in mean sea levels* provide an approximation of global sea-level increase. This shift is measured using satellite radar altimeters, which work by monitoring the time it takes for a radar pulse to return from the satellite to the sea surface and back again. *Land cover* has a critical association with climate regulation because the soil's ability to store/retain carbon directly influences the quantity of CO_2 that ends up in the atmosphere. This indicator examines the change in land cover over time and the impact that land cover can have on the climate, ranging from regulating the climate to having a neutral impact.

5. Case study of the European Central Bank

In July 2021, the European Central Bank (ECB) approved a new monetary strategy that incorporated climate change. This shift indicates that the analytical capacity for climate change in the fields of macroeconomic modeling, monetary policy, and statistics should be increased. The strategy was changed to include climate change challenges in monetary policy operations, specifically in the risk assessment, collateral framework, and corporate sector asset purchase programs. The definitive incorporation of climate change in the framework of monetary policy signaled the implementation of an action plan in line with the progress of European Union policies and initiatives in the field of reporting and getting information on environmental sustainability. By incorporating climate change into the new monetary policy framework, it was agreed that the Governing Council of the ECB would develop climate change indicators (ECB, 2021).

The ECB announced its first set of climate change indicators in January 2023, including sustainable finance, physical risks, and carbon emissions (ECB, 2023). The European System of Central Banks (ESCB) established these climate change indicators using data from international organizations such as the Analytical Credit Dataset (AnaCredit) and the Register of Institutions and Affiliates Data. The publication of climate change indicators was done to highlight the risks posed by climate change to the euro area's financial sector. Furthermore, the goal of providing the data is to encourage investors and governments to develop appropriate solutions to address the issues of climate change. Climate change has substantial consequences for central bank operations, given that they have to attain and maintain price and financial stability, as well as for bank supervision. The growing risk of climate change highlighted the need for a better understanding of financial institutions' exposure to climate change, as well as their role in providing funds to corporates and households, to better respond to such risks. The creation of the climate change indicator required a great deal of complexity because data at various granularities are interconnected, and the indicators had to maintain qualities like representativeness and dependability. Data that is only available at the national level was not used in the calculation of the indicators because they were computed utilizing a harmonized methodology amongst the euro zone's member states. As more and more information becomes accessible, the quality of the indicators related to climate change may increase even further. The European Union has enacted several initiatives aimed at gathering more information on sustainability and climate data from financial and non-financial organizations. Regarding those initiatives, we have the Sustainable Finance Disclosure Regulation (adopted in 2019) that aims to increase market transparency for sustainable instruments, and the Taxonomy Regulation (adopted in 2020) that mandates large financial and non-financial institutions publish data that is in line with the taxonomy (Statistics Committee of the European System of Central Banks, 2023).

The ECB's publishing of climate change indicators aims to assist in the analysis of climate change-related matters in the financial sector. Climate change indicators at the ECB are classified into three categories: *carbon footprint*, sustainable finance instruments, and physical risk indicators. One of the most significant indicators is the carbon footprint of financial institutions' portfolios. Insurance firms, pension funds, credit unions, and investment funds are all considered financial institutions. This indicator encompasses two dimensions: the total amount of emissions financed by the financial sector through loans, and the total exposure of the financial sector to contractual parties that have high emissions. By monitoring greenhouse gas emissions from various economic activities to which financial institutions lend directly or indirectly it is possible to assess the progress of financial institutions in reducing the carbon footprint in their portfolio, as well as their role in the transition to a low-carbon economy. With the ongoing development of the European Climate Agenda, large polluters face growing regulation and restrictions, potentially rendering particular sectors and assets outdated or losing value. Carbon emissions, which are the most significant contributors to climate change, are the releases of carbon dioxide and other greenhouse gases into the atmosphere, which are primarily caused by human activity. Bustamante and Zucchi's (2024) analysis revealed that the implementation of carbon regulations may come at a considerable cost to businesses that produce a significant amount of pollution or are positive net emitters. This may lower the company's overall worth and, as a result, discourage investment in green technologies.

The second significant indicator is *sustainable finance instruments*, which may be used to track data on issuers and buyers of various green financial products, such as green bonds. Sustainable finance data provide information on the issue and holding of sustainable financial instruments in the euro area. Sustainable debt securities can be split into four categories: social, green, sustainability, and sustainability-linked. The issue of these securities has increased, with green and socially sustainable debt securities accounting for the largest portion. The greatest issuers of sustainable financial securities are monetary financial institutions and governments, while investment funds are the largest purchasers, followed by eurozone national central banks. Securities Holdings Statistics (SHS) and the Central Securities Database (CSDB) are the sources of information on the issue and ownership of sustainable finance instruments.

Physical risk indicators assess the direct implications of climatic events such as rising sea levels, shifting temperature patterns, and extreme weather conditions. These indicators were designed to assess the vulnerability of several economic sectors to climate change caused by physical disasters such as devastating fires, floods, landslides, and storms. By studying these variables, the ECB aims to assess the vulnerability of economic activity to physical risks. In the first instance, physical risk indicators are used to measure the vulnerability of the financial sector's credit portfolio and the portfolio of securities. Normalized exposure at risk (NEAR), which links measures of financial success (revenue) or company size (total assets) to expected annual losses (EAL), is one of the indicators of physical risk. As a result, this indicator shows the total annual financial exposure at risk. The fact that between 1980 and 2020, hydrological and climatic events accounted for around 77% of all damages in 28 EU countries serves as the clearest example of how crucial it is to monitor this indicator.

6. Conclusion

A green transition needs to be implemented in order to adequately address climate change, and businesses, individuals, and governments have to collaborate together to achieve this goal. During this transition, efforts are to be made to lessen the negative impact that human activity has on the environment, particularly in the areas of industrial production, electricity generation, and consumption. Enabling the development of a robust and sustainable future is the goal of the green transition. As the financial sector is expected to identify and quantify the risks associated with the shift to a low-carbon economy, maintaining its stability is essential to implementing the green transition.

The analysis of climate change indicators, which are markers of long-term variations in temperature, sea level, and other atmospheric parameters, is the aim of this paper. Many of these indicators are used by scientists and decision-makers to study and track the trends and effects of climate change. Climate change indicators, in addition to providing information about climate conditions, can be utilized as early warning indicators, allowing environmental issues to be recognized before they get worse. The Organization for Economic Cooperation and

Development was one of the first organizations to develop a list of climate change indicators. In 1993, the organization defined thirteen indicators that evaluate environmental performance. The Climate Change Indicators Dashboard, which shows the monitoring of six climate change indicators to ascertain how climate change affects economic activity, was presented by the International Monetary Fund 2021 in collaboration with other international organizations. The European Central Bank released a set of climate change indicators in January 2023, which include carbon emissions, sustainable financing, and physical risks, following its presentation of a new monetary policy that took climate change into account in July 2021.

It is reasonable to anticipate more advancements in climate change indicators as an understanding of the climate change phenomenon and its effects on economic activity grows. Policymakers, communities, and scientists with differing degrees of competence must work together to attain this achievement. A strategy like this can guarantee that the problems caused by climate change, which have profound effects on human civilization, the economy, ecosystems, and the environment, are resolved. Sufficient funding for scientific research and technological advancements will be essential for humanity to adapt to climate change and enhance its capacity to observe and address it.

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