MASTERARBEIT | MASTER'S THESIS

Titel | Title

Toward a Broader Perspective on Global Welfare: A Critical Look at Existing Macroeconomic Indices and Their Capacity to Reflect Existential Risk

verfasst von | submitted by

Annika Martin BA

angestrebter akademischer Grad | in partial fulfilment of the requirements for the degree of

Master of Arts (MA)

Wien | Vienna, 2025

Studienkennzahl lt. Studienblatt | Degree programme code as it appears on the student record sheet:	UA 066 589
Studienrichtung lt. Studienblatt | Degree programme as it appears on the student record sheet:	Masterstudium Internationale Entwicklung
Betreut von | Supervisor:	Univ.-Prof. Alejandro Cunat PhD

Abstract

The disintegration of the Greenland Ice Sheet highlights the existential risks of climate change and challenges the adequacy of traditional macroeconomic indices in capturing global welfare. This thesis evaluates longterm macroeconomic indicators, including the Genuine Progress Indicator, Social Progress Indicator, Environmental Performance Index, Legatum Prosperity Index, World Happiness Report, and the Index of Economic Sustainability, against the backdrop of the Greenland ice disintegration. By employing a mixed-methods approach and analyzing key datasets related to the ice sheet, this research aims to identify limitations in current indices and propose improvements to better measure longterm global welfare. The findings emphasize the need for an interdisciplinary approach that integrates climate science and macroeconomics to redefine global welfare metrics, with potential implications for policymaking and future research endeavors.

Das Abschmelzen des grönländischen Eisschilds verdeutlicht die existenziellen Risiken des Klimawandels und stellt die Eignung traditioneller makroökonomischer Indizes zur Erfassung des globalen Wohlstands in Frage. Diese Arbeit untersucht langfristige makroökonomische Indikatoren wie den Genuine Progress Indicator, den Social Progress Indicator, den Environmental Performance Index, den Legatum Prosperity Index, den World Happiness Report und den Index of Economic Sustainability im Kontext des Zerfalls des Grönlandeises. Mithilfe eines Mixed-Methods-Ansatzes und der Analyse zentraler Datensätze im Zusammenhang mit dem Eisschild zielt die Untersuchung darauf ab, die Grenzen der aktuellen Indizes aufzuzeigen und Verbesserungen vorzuschlagen, um die langfristige globale Wohlfahrt besser zu erfassen. Die Ergebnisse unterstreichen die Notwendigkeit eines interdisziplinären Ansatzes, der Klimawissenschaft und Makroökonomie integriert, um globale Wohlfahrtsmetriken neu zu definieren, mit potenziellen Auswirkungen auf die Politikgestaltung und zukünftige Forschungsbemühungen.

Forword

The choice of topic for my Master’s thesis is deeply rooted in my personal background and convictions. Growing up in Europe, I have been fortunate to enjoy privileges that have shaped my life in countless ways. I was raised in a time of relative peace and stability, untouched by the horrors of war or large-scale existential crises. While events like the 2008 financial crisis or the 2019 pandemic affected me and many others, these experiences pale in comparison to the struggles faced in other parts of the world. This awareness of my privileged position has become a central driving force for me. Too often, I feel, we forget how fortunate we are, while others endure far greater hardships. Around 2013, I encountered the philosophy of Effective Altruism—a worldview that has since profoundly influenced me. It offers not just a perspective on the world but also a motivation to contribute, however small, to making it better. This philosophy reminds me to think beyond myself, to consider those who are disadvantaged, often as a result of the very systems and societies that have afforded me privilege.

The way humans interact—locally, regionally, nationally, and globally—frequently leaves me feeling sadness, hopelessness, and confusion. By the year 2025, I often wonder, shouldn’t we have moved past behaviors like greed, hubris, and the thirst for power? These instincts, while perhaps once useful for survival, seem to hold us back now, preventing progress and the realization of potentials that could benefit humanity as a whole.

In our pursuit of wealth, power, and greatness, we often fail to grasp just how insignificant we are in the vastness of the cosmos. Looking beyond Earth’s borders reveals how unique and invaluable our planet truly is—a serendipitous product of evolution that we still do not fully understand. Instead of nurturing this singular habitat, we are actively destroying it, potentially one of the few, if not the only, places of its kind within billions of light-years. This knowledge should inspire humility, reverence, and a profound sense of responsibility.

This thesis represents more than just the culmination of my academic journey. It is a personal testament to my commitment to engage with complex and pressing questions. It is a reminder to think beyond oneself, to act with gratitude for what we have, and to remain vigilant and critical—for the sake of others and for future generations.

At the same time, this thesis is an attempt to step beyond the boundaries of the prescribed curriculum. It aims to show that there is always more to explore than what is given or expected, and to encourage thinking outside the mainstream. Tackling topics that may seem unpopular, complex, or challenging is, I believe, essential for meaningful progress.

I hope this work inspires others to think on a broader scale and to have the courage to confront the uncomfortable truths of our time.

Acknowledgments

I would like to express my deepest gratitude to several individuals who have supported me throughout the process of writing this thesis.

First and foremost, I am sincerely thankful to **Prof. Alejandro Cunat**, my thesis supervisor, for taking the time to read and provide invaluable feedback on my work. Especially in times when university staff are overwhelmed with supervising numerous theses, I deeply appreciate his guidance and advice to remain pragmatic and open to whatever challenges arose during the writing process.

My heartfelt thanks also go to **Conor Spence** from the nonprofit organization *Effective Thesis*, who provided significant support during the early stages of topic development. His assistance in connecting me with experts in the research field was invaluable, particularly in the initial phase when the idea for this thesis was beginning to take shape. Conor's encouragement helped dispel my doubts and gave me the confidence to move forward.

I am profoundly grateful to **Philipp Trammell**, from the *Stanford Digital Economy Lab* and formerly the *Global Priorities Institute*, for his guidance during the initial stages of my research and his comprehensive, constructive, and critical feedback at the end of the writing process. His insights challenged me to look at my work with fresh, critical eyes and inspired me to refine key aspects, adding depth and precision to the final product.

Special thanks are also due to **Kevin Kuruc**, Senior Researcher at the *Population Wellbeing Initiative* of the *University of Texas at Austin* and Senior Research Affiliate at the *Global Priorities Institute*, for his valuable input during the early development of my case study. His expertise significantly enhanced this work, allowing me to approach the topic with greater clarity and rigor.

I also want to extend my gratitude to **Prof. Dr. Johannes Reitinger**, Rector of the *Private University of Education of the Diocese of Linz*. Perhaps unknowingly, you became a mentor to me, back in 2020. Your encouragement and faith in my abilities came at a time when I needed it most. Through our academic collaboration, you provided me with invaluable lessons and insights that have shaped my academic journey in ways I could never have imagined.

To **Prof. Dr. Fares Kayali** and his team, I am grateful for the opportunity to work as a student assistant under your guidance. The experience taught me so much about academic work and administration, and it strengthened my resolve to pursue an academic career. Your trust in me allowed me to grow both personally and professionally.

Lastly, but by no means least, I want to thank **Manuel**. You have been my anchor and my voice of reason when I pushed myself too hard. Thank you for your patience and understanding throughout the process of writing this thesis. Your unwavering support has meant the world to me.

To all of you, my heartfelt thanks.

Contents

List of figures & tables

1. Introduction

The disintegration of the Greenland Ice Sheet (GIS) serves as a striking warning of the existential risks posed by climate change, highlighting the profound and long-lasting threats to both environmental stability and global welfare. With its potential to accelerate sea-level rise, disrupt ecosystems, and undermine socio-economic security, this phenomenon underscores the inadequacy of traditional macroeconomic indices, such as Gross Domestic Product (GDP), in capturing the true complexities of our interconnected world. For this reason, the disintegration of the GIS serves as a case study in this paper to illustrate the shortcomings of existing indicators. While GDP remains the dominant measure of economic progress, its focus on short-term productivity neglects critical aspects like environmental sustainability, intergenerational equity, and resilience to existential risks. This disconnect raises a vital question: Which macroeconomic indices effectively reflect longterm global welfare, particularly in light of the existential risks associated with climate change?

This thesis aims to contribute to this question by assessing the longterm considerations of six alternative macroeconomic indicators such as the Genuine Progress Indicator (GPI), Social Progress Indicator (SPI) , Environmental Performance Index (EPI) , Legatum Prosperity Index (LPI) , World Happiness Report (WHR), and the Index of Economic Sustainability (ISEW). These indicators take a more comprehensive view than the Gross Domestic Product (GDP) by considering the dimensions of the social and natural environment, but they also face difficulties in representing climate change and the complex dynamics of the Greenland ice disintegration. The aim of this study is to outline the limitations and the improvements that can be made to the mentioned indices, with the intention of bringing them into more consistent accordance with the basic goals of discussion on gauging longterm prosperity.

To achieve these objectives, this research employs a mixed-methods approach. An extensive literature review lays the foundation by analyzing the theoretical underpinnings and current applications of the selected indices. This is complemented by empirical data analysis focusing on key datasets related to the Greenland Ice Sheet, including basal melt rates and discharge rates. By applying descriptive statistics, this study explores how climate risks intersect with welfare measurements and evaluates the potential for integrating environmental and existential risk factors into macroeconomic frameworks.

The findings of this research have aim to provide an initial contribution to decision-making processes for policymakers, scholars, and practitioners. They highlight the urgent need for an interdisciplinary approach that bridges climate science and macroeconomics to redefine global welfare metrics. By illustrating the gaps in current indices and proposing insights for their improvement and it may contribute to the development of tools that better align with the realities of a warming world.

The structure of this thesis is as follows: the first and second chapter provide a detailed review of the selected macroeconomic indices, focusing on their theoretical foundations and practical applications as well as key-concepts like global welfare, sustainability economics and the concept of Existential Risk. With the third chapter an extensive explanation will be provided to underline the need of new measurements and alternative indicators. In the fourth chapter the case of the Greenland Ice Sheet will be introduced and its classification as a possible existential risk for humanity explained. The fifth chapter outlines the methodology, detailing the integration of climate datasets and the analytical techniques employed. The results of the empirical analysis in chapter six are followed by a discussion in chapter seven and connect findings to the broader discourse on welfare measurement. Finally, the last chapter eight concludes by summarizing the key insights and offering recommendations for future research and policy.

2. Introduction to Macroeconomic Indices & Global Welfare: a theoretical framework

Macroeconomic indicators are statistical measures that provide insights into the overall economic performance of a country or region. These indicators encompass a wide range of data, including Gross Domestic Product (GDP), unemployment rates, inflation rates, and trade balances. Understanding macroeconomic indicators is vital for grasping the complexities of the global economy. They serve as critical tools for assessing economic stability, guiding fiscal and monetary policies, and predicting future economic conditions. They inform policymakers, investors, and businesses about the economic environment, enabling informed decision-making and strategic planning (Aliukov & Buleca, 2022; Malay, 2021; Pissourios, 2013).

In an increasingly interconnected world, where economic events in one country can have ripple effects across others, these indicators play a crucial role in fostering economic awareness and contribute to promoting sustainable growth on a global scale.

In the context of global welfare, "global" refers to the interdependence and connectivity of economies, societies, and nations in tackling welfare-related issues that cut across national borders. This definition reflects the knowledge that welfare is impacted by global factors, such as social policies, economic globalization, and environmental challenges, and is not just a national issue. Globalization has made nations more interdependent, so the welfare policies of one nation can have a big impact on others. Because of this interconnectedness, assessing welfare systems requires a global viewpoint because issues like poverty, inequality, and health crises frequently call for coordinated responses across national boundaries. The issues that cut across national boundaries, like pandemics, climate change, and economic instability, must also be taken into account. Global welfare systems can be significantly impacted by these threats. The COVID-19 pandemic, for instance, brought to light the weaknesses of international health systems and the necessity of teamwork in order to protect public health and safety. A comprehensive approach to welfare that incorporates social justice, economic resilience, and environmental sustainability is required in light of these global issues (Anderson, 2013). The term also highlights the significance of justice and equity in resolving inequalities both within and between societies. Policies that lessen inequality and encourage social inclusion, especially for vulnerable and marginalized groups, are supported by global welfare frameworks. In order to attain sustainable development and social advancement, this viewpoint recognizes that welfare is not evenly distributed and that global inequalities in wealth, health, and resource accessibility must be addressed (Conable et al., 2024).

Often, the focus of measurement, in case of traditional indicators, is primarily on economic aspects (such as GDP per capita) to determine the state of society. However, over the decades, newer approaches have emerged that take into account far more factors than just economic indicators (Greve, 2017; Pissourios, 2013; Thiry & Cassiers, 2010; Ziegler, 2007).

Macroeconomic indicators have significantly evolved since the early 20th century, with the systematic collection and analysis of economic data. Initially, the focus was on traditional economic measures like GDP and unemployment rates (Aliukov & Buleca, 2022; Fleurbaey, 2011; Gruen & Klasen, 2008; Singer, 2013). Over time, the scope of these indices expanded to include social and environmental factors. Today, indices may consider variables such as income inequality, environmental sustainability, and overall well-being, reflecting a more comprehensive understanding of economic health.

This shift recognizes that economic growth is closely linked to social equity and environmental impact, enhancing the relevance of macroeconomic indices in our increasingly interconnected and complex world (Aliukov & Buleca, 2022; Kreinin & Aigner, 2022; Tsara et al., 2024).

One aspect regarding economic growth frequently addressed in studies and reports is global welfare (Backhouse et al., 2021; Berlian, 2023; Deeming & Hayes, 2012; Fellner & Giehmann, 2019; Fleurbaey & Zuber, 2021; Gowdy, 2005; Heys & et al., 2019; Gruen & Klasen, 2008; Kwarciński & Turek, 2021; Sabetan, 1997; Wang et al., 2022). In economic terms, welfare refers to the quality of lif of individuals and society as a whole, often measured by the distribution of resources and opportunities to ensure a decent and socially desirable level of equity, efficiency, and quality of life (Arifin et al., 2020; Gruen & Klasen, 2008; Heys & et al., 2019; Van der Slycken & Bleys, 2020). A broad range of indicators has been developed to measure this, moving beyond purely economic factors (Brennan, 2008; Kubiszewski et al., 2013; Monadiyan & Haris, 2022; Pais & et al., 2019; Tsara et al., 2024). However, no consensus has emerged on what the "one right approach" might be.

The use of macroeconomic indices to measure welfare is rooted in several key economic theories. These theories provide a framework for understanding how different aspects of the economy—such as income, consumption, investment, and quality of life—contribute to overall welfare. However, it is crucial to view welfare as a multidimensional concept, with theories evolving to include broader indicators beyond traditional economic metrics like GDP.

2.1. Definition of macroeconomic indices

'Macroeconomic indicator' is a general term indicating measures that reflect the macroeconomic position of a country or region and used to evaluate and monitor various aspects of the economy and serve as important information to policy makers, economists, and researchers (Embrett et al., 2021; Suresh & Banerjee, 2016; Tsara et al., 2024). Common known and used indicators include the areas of

- Economic Growth: these include measures like GDP, which is a primary indicator of economic activity and growth. GDP per capita is often used to assess the economic performance relative to the population size, as seen in studies linking GDP per capita with health outcomes during the COVID-19 pandemic (Brennan, 2008; Pardhan & Drydakis, 2021; Pais & et al., 2019; Tsara et al., 2024).

- Inflation and Price Stability: Inflation rates and consumer price indices are critical for understanding the purchasing power and cost of living within an economy. These indices help in assessing the stability of prices over time (Brennan, 2008; Pais & et al., 2019; Tsara et al., 2024; van de Ven, 2018).
- Employment and Labor Market: Employment rates, unemployment rates, and labor force participation are key indicators of economic health. Changes in these indices can reflect economic recessions or expansions, as demonstrated in studies analyzing employment situations and their impact on mental health (Brennan, 2008; Pais & et al., 2019; Tsara et al., 2024).
- Monetary and Fiscal Policy Measures: Indices related to fiscal and monetary policies, such as interest rates and government spending, are used to evaluate the effectiveness of economic policies in stabilizing or stimulating the economy (Brennan, 2008; Embrett et al., 2021; Tsara et al., 2024; van de Ven, 2018).

It becomes evident, that the main focus of evaluation regarding a states performance is based around economic factors and less social and environmental aspects. They also not fully capture the informal economy, the distribution of wealth between individuals, or comparatively new concepts such as Existential Risks (x-risk). The reliance on these indicators can lead to an oversimplification of complex economic phenomena. Hence, a comprehensive assessment that considers qualitative evaluations and wider socio-economic factors is needed in order to give a clear idea of the economic health and resilience of a country.

2.2. Importance of measuring global welfare

Measuring global welfare is essential for understanding and improving the overall welfare of societies (and in large: all sentient beings) around the world. Unlike traditional economic measures, global welfare indices aim to capture a broader view of human progress by including factors such as health (life expectancy, disease prevalence), education (attainment rates), income equality, environmental sustainability, social stability, quality of life, social inclusion, and environmental sustainability. This framework aims to offer a more comprehensive view of progress than GDP alone and may help to identify areas where societies may be struggling beyond economic performance (Monadiyan & Haris, 2022; Ferryono et al., 2022; Pais et al., 2019; Rizki, 2024; Tsara, 2024).

In this study, welfare is understood as the comprehensive well-being of individuals and societies, encompassing not only economic stability but also social equity, environmental sustainability, health, education, and psychological well-being[1].

The knowledge and insights obtained thereby give critical information to governments and international organizations for setting policies in the right perspective and hence allocation of resources. It helps policymakers, by tracing indicators to establish interventions that enable sustainable and inclusive growth since given numbers show specific needs of different regions and demographic groups for targeted funding and initiatives (Monadiyan & Haris, 2022; Pais et al., 2019; Tsara, 2024). This helps track progress toward sustainable development goals (SDGs) and provides insights into areas where, regarding the focus of this work, resilience to climate change or resource scarcity needs improvement. This type of assessment serves as a normative basis for policymaking as well, which applies pressure, regarding effective distribution of resources and formulation of interventions aimed at improving living standards globally.. Such an all-inclusive approach is important for reflecting the real state of welfare in different societies. The sections below address the significance of measuring global welfare, pointing out different approaches and implications involved (Altmann, 2013; Brennan, 2008; Kar, 2022; Monadiyan & Haris, 2022; Pais et al., 2019; Tsara, 2024; Ravallion & Chen, 2017).

While the focus on comprehensive welfare measurement is crucial, it is also important to consider the broader implications of these efforts. The process of measuring welfare itself can be seen as a form of social action, influencing how societies perceive and address issues of welfare (Brennan, 2008; Monadiyan & Haris, 2022; Pais et al., 2019). This perspective emphasizes the transformative potential of welfare measurement, not just as a tool for analysis, but as a catalyst for positive change in the world. To date, the development of new indicators and measurement methods is ongoing, with efforts to create more consistent and comparable data across countries and over time (Gruen & Klasen, 2007; Pais et al., 2019; Tsara, 2024, 2024; van de Ven, 2018).

2.3. The role of climate change in longterm global welfare

Climate change significantly impacts longterm global welfare, influencing multiple d

[1] The concept of global welfare[1] is influenced by both political and economic factors, as power dynamics and resource distribution are crucial in shaping social welfare policies and outcomes These complexities make it difficult to arrive at a universal definition of welfare. According to Oxford Dictionaries: “the general health, happiness and safety of a person, an animal or a group”; synonym: well-being; November 9th 2024; https://www.oxfordlearnersdictionaries.com/definition/english/welfare?q=welfare

mensions of human existence, economic structures, and environmental sustainability. It is generally regarded as an existential threat, which may also amplify international conflict and promote risky technological interventions (Shulman & Thornley, 2024). The effects of climate change are multifaceted, influencing biodiversity, agricultural productivity, social policies, and economic growth. These impacts are not uniform across the globe, with poorer and more vulnerable regions facing more severe consequences. Extreme climate change could damage resilience and increase vulnerability to other risks, although it poses a saller direct risk of causing human extinction or civilization collapse (Chang et al., 2022; Kiley, 2023; Shulman & Thornley, 2024).

Climate change results in the rise of temperature globally and in the intensification of extreme weather events, both of which jeopardize biodiversity and human well-being. Natural disasters, decreased crop productivity and the rise in sea levels are direct consequences of this change (Hicks & Janus, 2023; Magnan et al., 2023; Shivanna, 2022).Given these circumstances, the loss of biodiversity and changes in ecosystems can disrupt food chains and natural resources, which are vital for human survival and economic growth, This can also lead to a widening economic disparities between regions and groups. Overall, this implies a challenge regarding the sustainability of life on earth (Shivanna, 2022). It implies the need for a new international pact based on the green economy's promotion (Büchs, 2021; Gowdy, 2005; Nakamura & Hulten, 2022). It is also obvious that a global outlook and joint efforts are required to prevent these possibly disastrous events since certain climate interventions can be too costly for one nation alone, but feasible for multi-country alliances. A shift from traditional welfare paradigms to more sustainable and equitable ones is necessary since the dominant exploitative model of capitalism and welfare pays little attention to the climate crisis hence, there is an apparent need for a new international effort focused on promoting a green economy (Shulman & Thornley, 2024).

These changes.

For example, negative impacts on agrigulture could often lead to a net negative impact on global agricultural welfare because the losses in consumer surplus usually outweigh the gains in producer surplus (Chang et al., 2022; Kiley, 2023 Stevanovic et al., 2016). When agricultural markets experience changes—whether due to policies like subsidies or tariffs or external factors like climate change—economic benefits are redistributed between producers and consumers. Consumer surplus is the benefit consumers receive when they pay less for a good than the maximum amount, they are willing to pay. Producer surplus, on the other hand, is the benefit producers gain when they sell a good for more than their minimum acceptable price. As agricultural prices rise, producers may benefit from higher revenues, increasing their surplus. However, consumers face higher costs, reducing their surplus. Since consumer surplus affects a much larger population—everyone who buys agricultural products—the overall loss to consumers often outweighs the producers' gains. This results in a net reduction in global economic welfare as the losses in consumer surplus outweigh the gains in producer surplus. The rising prices are mainly driven by reduced agricultural yields caused by climate change. Extreme weather events such as droughts or floods decrease food supply, making food scarcer and pushing prices up. Additionally, higher production costs—such as expenses for irrigation, fertilizers, or pest control—further increase prices.

This imbalance creates economic instability and disproportionately affects lower-income regions and households, highlighting the need for policies that consider broader social impacts to avoid harming overall welfare. This results in risks to economic growth and social stability, particularly in poorer and more vulnerable regions. The interaction between climate change and, economic growth highlights the need for early actions to mitigate global warming and its associated social costs (Bansal et al., 2016; Battiston et al., 2021; Kiley, 2023).

Given the phenomena resulting from negatively changing climate conditions, the necessity arises to focus also on human needs, which are essential for avoiding serious harm and ensuring sustainable welfare. Human needs are universal and provide a foundation for moral obligations across global and intergenerational contexts. The concept of human needs is more fundamental than other welfare theories, as it encompasses both material and non-material aspects of well-being (Büchs, 2021; Chang et al., 2022; Kiley, 2023; Sabetan, 1997).

To understand how climate change contributes to x-risks, it is crucial to identify pathways such as crossing tipping points like the collapse of the Greenland Ice Sheet, triggering cascading system failures, or intensifying risks like conflict and resource scarcity. Measurable proxy indicators can provide valuable insights, including physical factors like sea-level rise, temperature anomalies, glacial melt rates, and CO_2 concentrations; systemic factors such as shifts in global food production, water availability, and biodiversity loss; and social factors like population displacement, economic disruptions, and geopolitical tensions.

While climate change presents significant challenges to global welfare, it also offers opportunities for transformation towards more sustainable and equitable systems. This transition and the focus on human needs can provide pathways to mitigate the adverse effects of climate change. However, achieving these goals requires coordinated international efforts and policy interventions that prioritize longterm sustainability and equity.

2.4. Relevant key concepts

With the intensification of climate change, understanding the interplay between x-risks, global welfare, sustainability economics and welfare economics become increasingly vital. This chapter covers these key concepts and highlights their significance in the context of climate change.

As explained in chapter 2.1, global welfare extend beyond traditional economic measurements. Changing climate poses signigicant threat to the various dimensions covered. The urgent need to adopt more holistic approaches, which fully capture the impacts on human life becomes more visible.

Our generations have a moral obligation to ensure that today's economic activities do not compromise the needs of future generations. The use of sustainability economics (SE) provides a framework for assessing the longterm viability of economic systems. This by emphasizing practices that safeguard resources and ecological systems, which could in consequence, lead to a transition of models to support human prosperity and environmental health.

This can be accomplished by effective and efficient resource allocation. Welfare economics applies this approach and focuses on the maximization of societal well-being. By integrating environmental costs into economic decision-making, it is ensured that policies aim towards mitigation of climate change and enhancing human welfare. This shows the need to evaluate the trade-offs and synergies between economic growth and environmental sustainability.

The introduction to key concepts of this research opens with the concept of x-risks, a critical element in understanding the challenges posed by climate change. This concept highlights the potential for significant disruptions to human civilization, emphasizing the need for comprehensive strategies that address these threats while enhancing societal resilience and continuity. This focus provides important insights for an analysis regarding the intersection of economy and environment.

2.4.1. Existential Risks (X-Risk)

Existential risks are severe global threats that could lead to (premature) human extinction, drastically reduce humanity's potential for future development or the irreversible collapse of civilization, profoundly impairing humanity's longterm future. These include nuclear war, pandemics, and ill-aligned artificial intelligence, but most importantly climate change. Characterized by their global scale, irreversibility, and potential for lasting harmful consequences, existential risks are the object of a multi-disciplinary approach, implying consequences not only for human life but also for the sustainability of ecosystems and socio-economic structures critical to humans (Bostrom, 2013; Cotton-Barratt & Ord, 2015; Hicks & Janus, 2023; Huggel et al., 2022; McLaughlin, 2024; Ord, 2020; Shoqeir, 2022; Turchin & Denkenberger, 2018).

Longterm welfare depends on dealing with such risks, though the current welfare indicators are generally not capable of demonstrating these risks and their implications for future generations, also leading to some skepticism regarding the possibility of making longterm predictions (Gruen & Klasen, 2007; Kreinin & Aigner, 2021; Millner, 2013; Muehlhauser, 2019). This section examines existential risks, with an emphasis on climate change to explore the implications for global welfare and potential integration into welfare measurement frameworks.

Llongtermism is a philosophical stance that argues the most significant factor in determining the social value of our actions and policies today is their expected impact on the far-off future. This viewpoint stresses that the consequences of our decisions should be evaluated not just for their immediate effects but also for their lasting influence on future generations. A crucial element of llongtermism is it’s zero rate of pure time preference, which implies that it does not diminish the importance of future welfare or assign less value to individuals based on when or where they exist in time and space (Beckstead et al., 2019). Considering longterm impacts is essential, as it encourages a comprehensive evaluation of interventions by urging policymakers to account for both immediate and delayed effects, including those that unfold in the distant future. This perspective aligns with the moral responsibility to enhance the welfare of future generations, recognizing that today's actions will shape the lives and well-being of countless individuals yet to be born. It suggests that achieving significant welfare improvements may require prioritizing measures with longterm benefits, such as addressing existential risks, even if they seem less urgent today. By challenging the conventional focus of policy and economics on short-term gains, this approach calls for a reevaluation of resource allocation strategies to ensure they maximize social value over extended time horizons. To achieve beneficial outcomes for humanity, it is essential to anticipate decision-making processes that could lead to more effective strategies aimed at the larger goal of global welfare (*ibid*.).

The number of people who will be born in the future is uncertain, but the immense scale of the universe and the potential longevity of humanity suggest a vast future ahead. The exact number depends on factors like population size, life expectancy, and, most critically, how long humanity can survive. If humanity were to persist for one million years—the average lifespan of a mammalian species—and the population stabilized at 11 billion people with an average life expectancy of 88 years, approximately 100 trillion people could be born over the next 800,000 years. If we consider Earth's habitability, estimated at around 1 billion years, this number could rise to 125 quadrillion people. If humanity endures for the remaining lifespan of the sun, approximately 5 billion years, the number could reach an extraordinary 625 quadrillion. Max Roser (2022) from *Our World in Data* provides a visual emphasis the immense potential of humanity's future and our ethical duty to safeguard and enhance it. It points out that our choices today will influence the lives of future generations, either negatively—through environmental harm and hazardous technologies—or positively, by advancing science and nurturing vibrant cultures. The history of humanity, shaped by the contributions of 109 billion individuals, has established the groundwork for our current civilization, yet those living today account for only 6.8% of all humans who have ever existed. Looking forward, the future could be vast, extending over millions or even billions of years. If humanity endures as long as Earth remains livable, trillions or even quadrillions of individuals could come into existence, far surpassing the population of the past. This underscores the urgency of addressing existential threats which pose risks to humanity's potential.

Figure 1. Visualization by Max Roser (2022). "The future is vast – what does this mean for our own life?"

What distinguishes humanity from other species is its dual capacity to both destroy itself and the ability to protect itself against x-risks. Modern technologies, like nuclear weapons, pose immediate risks, while emerging challenges such as artificial intelligence and engineered pandemics add to the complexity. However, humanity has the unique ability to mitigate these threats—monitoring asteroids, for example, or potentially colonizing beyond Earth, allowing for survival beyond planetary limits.

This vast potential also brings significant responsibility. The concept of Llongtermism highlights the importance of preventing x-risks. A catastrophe today, such as nuclear war or uncontrolled AI, would not only devastate those currently alive but also annihilate the potential lives of trillions in the future. While efforts to combat risks like climate change are gaining traction, broader existential threats remain neglected.

According to Nick Bostrom (2013), existential risks are distinct from other types of risks because they pose an unmatched threat to not only the present generation but also humanity's entire future. Existential risks present a far more serious threat than more well-known ones like pandemics or world wars, which, despite their devastation, do not essentially reduce humanity's capacity for longterm success. Bostrom emphasizes the vital significance of giving initiatives to reduce existential risks top priority by expressing the size of anticipated loss in terms of humanity's longterm prospects. According to his illustrations, the stakes span the entire range of human potential in the future rather than being limited to the present. The main worry is that humanity's future could be destroyed, which Bostrom contends, would be far worse than any historical disaster. Such an event would result in astronomical loss, not just large-scale loss. This is due to the fact that an existential disaster would wipe out the enormous potential of intelligent life that originated on earth, including innumerable generations and accomplishments that might have been made.

Addressing these risks requires not just bravery, to look into the abyss of our own action, but proactive measures, including increased research, cultural awareness, and political action. Investing in the reduction of existential risks today not only secures the future for generations to come but also protects those living now, many of whom may witness the next few centuries. Waiting for a disaster to strike is not a feasible option; by taking action today, humanity can unlock its vast potential and create a thriving future for countless generations (Roser, 2024).

Bostrom develops a classification scheme for existential risks and discusses their relation to axiology, the area of philosophy that studies the nature of value and appraisal. emphasizing the importance of normative evaluation in determining risk seriousness:

> "Since a risk is a prospect that is negatively evaluated, the seriousness of a risk—indeed, what is to be regarded as risky at all—depends on an evaluation. Before we can determine the seriousness of a risk, we must specify a standard of evaluation by which the negative value of a particular possible loss scenario is measured. There are several types of such evaluation standard. For example, one could use a utility function that represents some particular agent's preferences over various outcomes. This might be appropriate when one's duty is to give decision support to a particular decision maker. But here we will consider a normative evaluation, an ethically war- ranted assignment of value to various possible out- comes. This type of evaluation is more relevant when we are inquiring into what our society's (or our own individ- ual) risk-mitigation priorities ought to be" (Bostrom, 2013, p. 16).

He contends that our assessment of a risk's potential negative impact determines its seriousness rather than its inherent characteristics. An established framework or criterion is necessary for this evaluation in order to compare the potential loss scenarios. The assessment of risk seriousness, according to Bostrom, transcends individual preferences or the utility functions of particular people or decision-makers. Rather, a normative assessment—a value judgment based on ethical reasoning—is what he supports. This method establishes the moral or societal worth of different outcomes and forms the foundation for prioritizing which risks should be addressed first in terms of mitigation. Normative evaluation is especially important as it helps society to make well-informed decisions about risk management by methodically evaluating the possible outcomes of various scenarios. This strategy makes sure that risk mitigation priorities are determined by longterm societal values rather than just personal or transient preferences by taking ethical considerations into account. The importance of axiology is as a necessary step in deciding what should be considered risky and how seriously such risks should be treated. This viewpoint is essential for directing resource allocation and policy in the face of existential and catastrophic global threats.

X-Risk-theory prioritizes minimizing risks that threaten human survival and longterm[2] development. This theory emphasizes the critical importance of addressing and mitigating risks that pose existential threats to humanity's survival and longterm progress by recognizing that certain risks, if realized, could have catastrophic consequences for the entire human species, potentially leading to extinction or irreversible setbacks in our development. Existential risks are defined as

- "[o]ne where an adverse outcome would either annihilate Earth-originating intelligent life or permanently and drastically curtail its potential (Bostrom, 2002, p. 2)" or
- "[…] one that threatens the premature extinction of Earth-originating intelligent life or the permanent and drastic destruction of its potential for desirable future development (Bostrom, 2013, p. 15)".

or, as distinguished by Toby Ord (2020), as an catastrophe which means the destruction of humanity's longterm potential. These definitions include both natural and anthropogenic threats, emphasizing the need to address even low-probability events due to their potentially catastrophic consequences.

[2] In the context of existential risk (X-Risk) and longtermism, "longterm" typically refers to timescales that extend far beyond the current century, often encompassing thousands to millions of years, considering humanity's potential impact on future generations and the survival of sentient life.

Natural risks may include asteroid impacts, super volcano eruptions, or extreme solar flares. However, many experts in the field argue that human-caused risks are becoming increasingly prominent and concerning (Boyd & Wilson, 2021a; Cotton-Barrat et al., 2020). These anthropogenic risks include, but are not limited to, artificial intelligence (AI) gone awry, global pandemics (both natural and engineered), unforeseen consequences of emerging technologies such as nanotechnology or synthetic biology and environmental collapse due to climate change. By prioritizing the reduction of these existential risks, proponents of this theory aim to safeguard humanity's future and ensure our continued ability to thrive and evolve.

According to Bostrom (2013) in figure 2, there are four classes of X-Risks, namely risks, that (1) extinct humanity prematurely, (2) prevent humanity from reaching technological maturity, (3) reaching that maturity but insufficient and/or defective and (4) humanity achieves advanced technology that promises a bright future, but later developments permanently destroy that potential. In the context of climate change, classes 2-4 could occur, which could mean that if climate change leads to global catastrophes such as uncontrollable warming, extreme resource scarcity, or a total collapse of civilization, it could prevent humanity from ever reaching a technologically mature stage; if technological advancements are made but are insufficient to address the consequences of climate change or if these technologies cause further harm, humanity could remain in a permanently unstable state; if humanity manages to initially cope with the climate crisis and advances technologically, longterm climate damage, such as irreversible glacier loss and sea level rise, could ultimately threaten the foundations of civilization and destroy promising prospects.

Table 1. Classes of existential risk

Human extinction	Humanity goes extinct prematurely, i.e., before reaching technological maturity. [12]
Permanent stagnation	Humanity survives but never reaches technological maturity. Subclasses: *unrecovered collapse, plateauing, recurrent collapse*
Flawed realisation	Humanity reaches technological maturity but in a way that is dismally and irremediably flawed. Subclasses: *unconsummated realisation, ephemeral realisation*
Subsequent ruination	Humanity reaches technological maturity in a way that gives good future prospects, yet subsequent developments cause the permanent ruination of those prospects.

Source: Author.

Figure 2. Classes of X-Risk, Bostrom (2013, p. 19)

Research argues that addressing and mitigating these risks should be a top priority for governments, organizations, and individuals worldwide. It is stated that the potential consequences of these risks are so severe and far-reaching that even a small probability of occurrence warrants significant attention and resources (Beckstead, 2013; Bostrom, 2013; Boyd & Wilson, 2021b; Ord, 2020).

It is important to highlight that the relationship between welfare and existential risk is deeply interdependent. Threats posed by climate change have the potential to severely undermine welfare by damaging essential systems that support human well-being, such as food security, health, and infrastructure. The impacts of climate-related disasters, resource scarcity, and displacement can result in economic instability, social unrest, and a decline in the quality of life, threatening both short-term and longterm welfare. On the other hand, robust welfare systems, which include healthcare, social safety nets, education, and strong governance, can enhance resilience against these existential risks. Such systems help societies adapt to and recover from climate-induced shocks by ensuring that vulnerable populations receive necessary support. Additionally, a focus on sustainability within welfare policies can drive innovations and practices that mitigate climate change, thus contributing to the reduction of existential risks over time. In this way, welfare systems not only help alleviate the immediate effects of existential threats but also build longterm capacity to withstand them. Addressing such risks requires a longterm perspective that includes considerations for future generations and ecosystem sustainability, reshaping how welfare is assessed over extended time horizons.

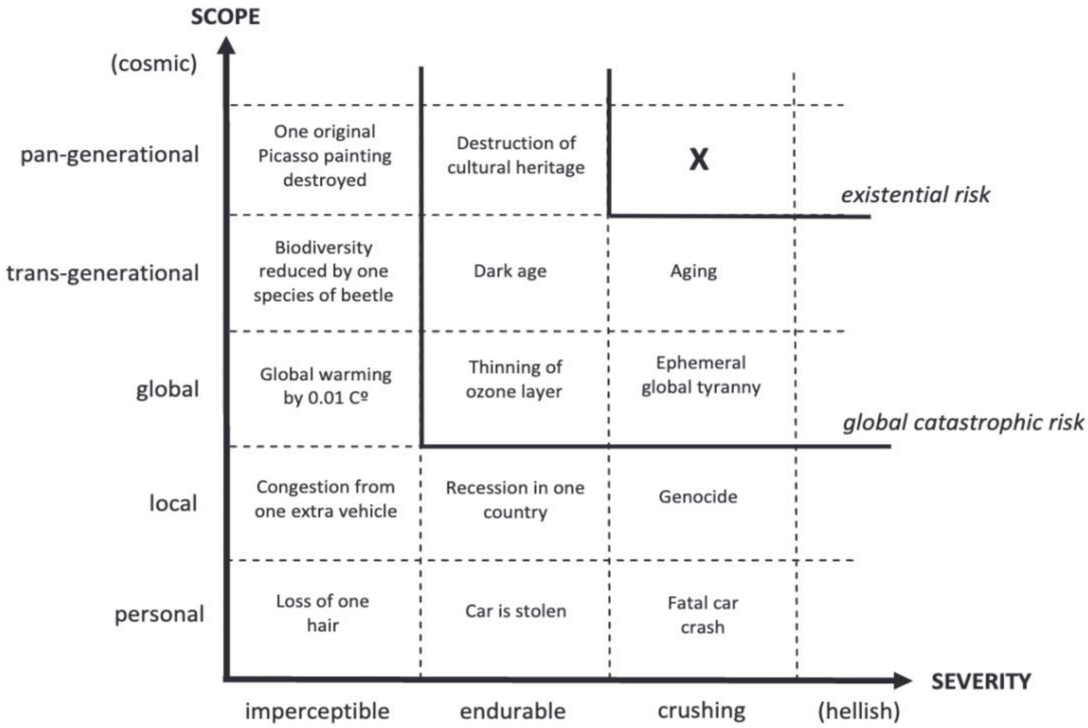

Figure 3 Qualitative risk categories, Bostrom (2013, p. 17

Nick Bostrom's (2013) framework for understanding risks offers a structured approach to evaluating threats by considering their scope, severity, and evaluation standards. The scope of a risk refers to the extent of its impact, ranging from risks that affect only one individual to those that influence entire populations or even humanity's longterm future. For example, personal risks are confined to a single person, while local risks affect specific regions or communities. Global risks, by contrast, have far-reaching consequences for the entire human population or a substantial part of it. Extending beyond immediate impacts, Bostrom also considers trans-generational risks, which influence multiple future generations, and pan-generational risks, which affect humanity over nearly all future generations.

Severity further categorizes risks based on the degree of harm they cause. Imperceptible risks have minimal or barely noticeable effects, while endurable risks result in significant damage without entirely destroying quality of life. Crushing risks, however, are catastrophic, leading to death or a severe, irreversible reduction in living standards. Assessing the seriousness of these risks requires an evaluation standard, which may involve a utility function representing preferences over different outcomes. This approach allows for a systematic comparison of risks, emphasizing the importance of addressing those with the greatest potential to disrupt human well-being or survival across temporal and spatial scales.

While the X-Risk-theory emphasizes the importance of addressing existential threats to humanity's survival and progress, critics argue that it may divert attention and resources from more immediate and tangible global challenges (Hicks & Janus, 2023; McLaughlin, 2024; Turchin & Denkenberger, 2018). However, supporters counter that longterm thinking and preparation for low-probability, high-impact events are crucial for ensuring humanity's continued existence and prosperity (Boyd & Wilson, 2021a; Cotton-Barrat et al., 2020; Hicks & Janus, 2023; Ord, 2023).

The theory of X-Risk has gained traction in academic circles, particularly in fields such as philosophy, futurology, and emerging technology studies. Researchers and institutions dedicated to studying existential risks have emerged, including *The Future of Humanity Institute* at Oxford University and the *Centre for the Study of Existential Risk* at Cambridge University. These organizations work to identify, analyze, and propose solutions to potential existential threats. The X-Risk-theory has implications for policy-making, scientific research priorities, and ethical considerations in several fields. It encourages a more holistic and longterm approach to risk assessment and management, emphasizing the need for global cooperation and foresight in addressing potential threats to human existence as it serves as a framework for considering the unintended consequences of human progress and the responsibility we bear in shaping the future of our species and potentially the entire universe (Bostrom, 2013; McLaughlin, 2024; Turchin & Denkenberger, 2018).

Recognizing existential risks demands strategies that enhance current welfare while safeguarding future sustainability and welfare, ensuring that short-term benefits do not compromise longterm goals. However, the multifaceted nature of welfare and existential risks creates significant challenges in measurement, as traditional metrics often overlook relevant factors. Therefore, is essential to create more inclusive indicators that reflect both immediate well-being and longterm survival.

Ethical considerations also play a critical role in coordinating efforts toward welfare and the alleviation of existential risk. Policies need to consider issues of justice and fairness; measures that ensure longterm welfare should not exacerbate current disparities or prove harmful to vulnerable groups. Building on this holistic view that weaves together these principles, the research promotes more effective welfare metrics and creates resilient policies capable of facing both present and future challenges.

This context aligns with Martin Weitzman's **Dismal Theorem** (2009, 2011, 2014) which highlights the inadequacies of traditional economic models that often overlook the extreme impacts associated with low-probability events, particularly in the face of fat-tailed[3] uncertainties (Nordhaus, 2006). Just as the risks posed by emerging climate change necessitate a reevaluation of how we quantify and prioritize potential losses, the Dismal Theorem stresses the importance of integrating considerations of high-risk aversion[4] and unbounded expected losses into our decision-making frameworks. The focus on existential risks highlights the pressing need for a fundamental change in policy and economic analysis. We must tackle not just natural threats but also the increasing number of human-made challenges that jeopardize our shared future. The theorem suggests that, given specific circumstances of fat-tailed uncertainty and significant risk aversion, the anticipated loss from low-probability, high-impact events (such as those linked to climate change) can reach unbounded or infinite levels. This poses a challenge to conventional economic modeling and cost-benefit analyses, which frequently do not sufficiently account for these extreme risks (Nordhaus, 2006; Weitzmann, 2009, 2011, 2014).

Given that the possible catastrophic effects of climate change may surpass the costs of preventive interventions, the theorem advises policymakers to reevaluate conventional approaches that downplay future risks and rewards. Therefore, a deeper comprehension of probability distributions and the structural uncertainties included in climate scenarios must be incorporated into decision-making under uncertainty. This calls for more thorough and reliable studies that support efficient climate policy (*ibid*.). This perspective is often framed in terms of expected value calculations, where the immense potential loss (i.e., the extinction of humanity or the permanent derailment of human progress) outweighs the perceived low probability of occurrence. The Dismal Theorem and X-Risk theory are related as they both emphasize longterm catastrophic risks and how they might affect human survival and prosperity. Existential dangers that potentially endanger humanity's future, such nuclear war or climate change, are

[3] Refers to probability distributions in which the likelihood of extreme events (far from the mean) declines more slowly than in normal distributions. In typical distributions, the probabilities of rare events diminish rapidly, which leads to a misrepresentation of actual risks. In contrast, fat-tailed distributions suggest that, while low-probability events are rare, their potential impacts are significant and cannot be ignored. This characteristic is especially relevant in the context of climate change, where rare but catastrophic outcomes—such as major ice sheet disintegration or widespread ecological collapse—may have considerable consequences.

[4] Describes a preference for certainty over uncertainty. Individuals or decision-makers with high risk aversion are particularly sensitive to the potential for severe losses, even if those losses are of low probability. In the realm of climate policy, this means that decision-makers may assign disproportionate weight to the risks of low-probability, high-impact climate events, leading them to pursue aggressive mitigation strategies to avoid catastrophic outcomes.

addressed by X-Risk theory. However, according to the Dismal Theorem, even catastrophic occurrences with a low probability[5] of occurring could wreak so much damage that they exceed any future advantages or prosperity. Both theories stress that in order to protect longterm wellbeing, these risks must be taken seriously and efforts should be made to reduce their likelihood.

In contrast, or expanding, to the X-Risk theory, Bostrom (2013) introduced the **Maxipok Rule** as a decision-making principle. It suggests that we should "[…] maximize the probability of an okay outcome, where an okay outcome is any outcome that avoids existential catastrophe (p. 19)." This is used to evaluate welfare measurements to determine how effectively they reflect dangers to longterm wellbeing because it provides a foundation for the proposal, which prioritizes reducing existential risks to ensure humanity's future[6]. Therefore, reducing risks that could keep mankind from achieving a sustainable, prosperous future should be the top priority when making decisions. In actuality, this entails allocating funds to avert major disasters that pose a serious threat. Instead of controlling smaller, more temporary risks, the focus is on preventing outcomes that would make longterm thriving difficult. Maxipok is also an application of decision theory and moral philosophy, suggesting that given the immense potential value of the future. For instance, because the future could hold vast welfare if catastrophic risks are avoided, reducing these risks yields high expected value, making existential risk mitigation a priority. This this could involve nuclear arms control, responsible AI research, advancing preparing for pandemics or climate resilience (Beckstead, 2013; Bostrom, 2013; Cotton-Barratt et al., 2020). However, some criticize the Maxipok Rule's ambiguity — the concept of an "okay" outcome can be interpreted differently, leading to varied priorities (Bostrom, 2013). Others argue that exclusive focus on existential risks may overlook pressing issues like poverty or inequality, questioning whether the resources for risk prevention justify the uncertain benefits (Hicks & Janus, 2023; Ord, 2020). Nonetheless, it remains central to llongtermism, as it guides resource allocation to actions that maximize humanity's survival prospects over time. By following this rule, decision-makers could, if

[5] Is a key concept in Weitzman's theorem. It implies that when calculating potential risks and benefits of certain actions (like investments in climate mitigation), traditional economic models often fail to account for the unbounded nature of these expected losses when they arise from events that could have devastating impacts. If the consequences of a catastrophic event are high enough, even a low probability of occurrence can result in an infinite expected loss. This makes standard cost-benefit analyses inadequate, as these analyses generally rely on finite estimates of risks and returns.

necessary, secure the possibility of a flourishing future, recognizing the moral significance of even small increases in the likelihood of humanity's survival and success.

Building upon this foundation, the Maxipok Rule provides a practical framework for implementing the principles of X-Risk-Theory. This rule suggests that the most effective way to maximize positive outcomes for humanity is to focus on reducing existential risks. By applying this rule to various welfare measures, it is possible to evaluate how well these measures account for and address longterm risks to human welfare.

In short, main differences between the two approaches can be summarized as follows:

	X-Risk	Maxipok
Scope	Broad with focus on identifying and understanding various existential risks	Specific decision-making guideline derived from existential risk considerations
Approach	Analytical and descriptive	Prescriptive, offering a concrete decision-making framework
Flexibility	Allows for nuanced analysis of different risks and their potential impacts	Simplifies decision-making by focusing solely on avoiding existential catastrophe
Risk tolerance	Considers varying degrees of risk	Adopts a more conservative stance, prioritizing the avoidance of worst-case scenarios
Application	Informs research, policy, and public discourse	Used in ethical decision-making and prioritization of actions

Table 1 Comparison of characteristics between X-Risk-Theory and Maxipok-Rule

Both concepts are related and often used in conjunction within the field of existential risk studies and longterm future planning (Bostrom, 2013).

Climate Change as an Existential Risk

The scientific foundations of climate change are built on a solid framework of physical theories, mathematical models, and empirical observations, which together enable a comprehensive understanding of climate dynamics and the role of human activities in influencing them. Central to this foundation is the physics of the greenhouse effect, where gases like carbon dioxide trap heat in Earth's atmosphere, causing global temperatures to rise—a concept initially identified by scientists like Fourier (1999) and Arrhenius (1997). Empirical observations, such as longterm temperature records and ice melting data, reveal historical trends and reinforcing the urgency of human-induced impacts.

Climate change poses a unique existential threat due to its potential to destabilize ecological and socio-economic systems on a global scale, leading to impacts that may exceed humanity's adaptive capacity (Danil, 2020; Hicks & Janus, 2023; McLaughlin, 2024). Associated events, such as extreme weather, ecosystem disruptions, and biodiversity loss, could trigger irreversible tipping points, permanently affecting global food security, economic stability, and, in consequence, overall global welfare (Dietz et al., 2021; Kemp et al., 2021; Menegaki, 2018; Shoqeir, 2022). Longtermist scholars, including Toby Ord (2020), contend that while climate change alone may not cause human extinction, it significantly heightens the probability of broader existential crises, estimating a 1 in 1000 chance of it leading to catastrophe (Hicks & Janus, 2023; McLaughlin, 2024). This assessment is consistent with the the classes of X-Risk according to Bostrom (2013, this section p. 18).

A worsening of climate impacts, such as desertification and altered precipitation patterns, may result in severe shortages of food and water, especially in vulnerable regions; the increasing frequency and intensity of hurricanes, droughts, and heatwaves carry longterm implications for agriculture, water resources, and human health; and climate change increases risks through extreme weather events, rising sea levels, and disruptions to food and water supplies, all of which could destabilize social, economic, and political structures (Boyd & Wilson, 2021b; Butler, 2018; Magnan et al., 2023; Sears, 2020). This situation not only escalates human suffering but also increases the likelihood of conflict over scarce resources (McNamara & Jackson, 2022). Compounding these problems, climate systems have feedback mechanisms—polar ice melt and permafrost thawing—that could spur runaway warming. Once triggered, these feedbacks may lead to unstoppable warming that will make much of the globe uninhabitable, potentially destabilizing the foundations of societies (Beard, 2024; Dietz et al., 2021; Huggel et al., 2022; Kumar et al., 2021; Stollberg & Jonas, 2021). For instance, they reveal darker regions of land and sea that absorb more heat when the ice melts at the pole, hastening the warming process. Similarly, methane, a highly greenhouse-causing substance, is released into the atmosphere when permafrost melts, adding even more heat to the system. Specifically, there would be a runaway warming, in which the temperature rises faster than any control, if these mechanisms had a chance to function and come to a junction. The destruction of the major water supplies and natural gas would undermine the natural foundations of civilization and make many parts of the planet nearly uninhabitable (Lenton, 2023; Schuur et al., 2015; Sommerkorn & Hassol, 2009). It is undeniable that these dangerous thresholds should not be crossed, so the world needs to move much more quickly to combat climate change and protect against the dangerous thresholds that lie ahead.

A significant contribution to this risks arise from human activities, including technological advancements and unsustainable economic practices. Climate change exemplifies an endogenous risk, resulting from industrialization, deforestation, and greenhouse gas emissions (Beard, 2024; Cotton-Barrat et al., 2020; Hicks & Janus, 2023; Huggel et al., 2022; McLaughlin, 2024). The concept of “loss and damage” in climate policy, as introduced by McNamara and Jackson (2018), underscores the irreversible impacts of climate change that are beyond adaptation efforts. For instance, large-scale ecosystem collapse, such as the Sixth Mass Extinction[7] driven by warming and habitat loss, endangers agriculture, water purification, and other critical ecosystem services, heightening humanity’s vulnerability to climate-related adversities (Cotton-Barratt et al., 2020).

The interconnected nature of climate change with other existential risks may lead to compounding crises, where multiple disasters occur simultaneously, overwhelming societal capacities. These occurrences could, for example be

- Pandemics: Climate change can intensify zoonotic disease outbreaks as changing habitats bring humans and wildlife closer together (Cotton-Barratt et al., 2020; Hicks & Janus, 2023; McLaughlin, 2024).
- Technological Risks: Climate-induced economic instability and social unrest could weaken global governance, complicating efforts to regulate emerging technologies like artificial intelligence or biotechnology (Baum, 2024).
- Compound Disasters: Climate change heightens the probability of simultaneous crises, such as wildfires, floods, and heatwaves, which could accelerate societal breakdown (Boyd & Wilson, 2021a).

[7] A mass extinction refers to a relatively brief interval in geological time during which a significant portion of biodiversity, including various species of bacteria, fungi, plants, mammals, birds, reptiles, amphibians, fish, and invertebrates, rapidly disappears. In geological terms, a "short" period may encompass thousands or even millions of years. Earth has already gone through five mass extinction events, the most recent of which took place around 65.5 million years ago and led to the extinction of the dinosaurs. Many experts now suggest that we are currently experiencing a sixth mass extinction.

Homework is done … but forgotten?

Investigations into the likelihood of climatic catastrophes resulting from melting glaciers underline the increasing dangers of faster glacial melting with precise quantitative information on such potential catastrophes.

Swarnkar and Mujumdar (2023) discussed the rising flood risks of the West-Central Himalayas, stating that floods in the future may rise above the threshold of 7,000 to 10,000 m^3/s in regions such as Alaknanda and Devprayag. Li (2023) refers to the fact that in the Eastern Himalayas, the melting of glaciers creates a greater likelihood of high-speed, long-runout events that can put the downstream communities at risk because melting glaciers are unstable.

He et al. (2023) show that the glaciers on the southeastern part of the Tibetan Plateau are losing mass at a rate three times higher than the average over this region, hence likely bringing more frequent flooding and water shortages. According to Khadka (2024), even a rise in temperature by 1°C can remarkably reduce the mass of glaciers within ten years, thus high-risk events of glacial lake outburst floods—GLOFs. Yang (2023) demonstrates that the frequency of debris flow in the Palong Zangbu catchment has reached 21 times a year, which shows an increase in hazards related to glacier melting.

Vincent et al. (2023) also projected that by the mid-21st century, glaciers in some basins will disappear, hence increasing water scarcity and flood events. Gao et al. (2023) further indicate that this cryospheric melting tends to enhance atmospheric methane emissions from inland waters over the Tibetan Plateau, adding up all the environmental risks.

The consequences of glacial melting and related climatic disasters can be huge and far-reaching in the economic situation and social welfare. Due to the recession of the glaciers, there is an increase in the frequency and magnitude of floods, which may damage critical infrastructure, disrupt transport networks, and destroy commercial businesses—especially in those economies heavily dependent on agriculture and tourism. This can substantially decrease the generation of hydropower, which many areas rely on for their energy needs and may cause energy shortages and further economic stress in areas where other energy sources are scarce.

The recession of glaciers further intensifies the issue of water scarcity. Glaciers serve as essential freshwater reservoirs for millions, especially in areas such as the Himalayas and the Tibetan Plateau. As these ice masses diminish, the accessibility of water is likely to decline, jeopardizing agricultural output, food security, and everyday life. The consequent water shortages may trigger economic instability, particularly in regions where agriculture plays a significant role in the economy.

This would lead to the failure of irrigation systems that are dependent on glacial meltwater, thus resulting in crop failures and reduced agricultural productivity. Prices of food would rise; hence, increasing poverty levels among the poor, particularly for the vulnerable groups. Also, this could trigger mass migration flows either internally or internationally in search of stable livelihoods. These movements will most probably put pressure on metropolitan areas and increase competition for resources, which may possibly lead to social unrest and political instability.

The vanishing of the glaciers will also add to the degradation of ecosystems that rely on them, thus leading to a decrease in biodiversity and a reduction in access to natural resources, such as fisheries and timber. These impacts might have negative effects on the communities that depend on those resources for their livelihoods and further undermine social welfare. The health systems will also be burdened by direct and indirect impacts due to climate change, such as heat stress, air pollution, and the spread of diseases, which will impact public health services and result in the reallocation of resources away from other priorities.

Eventually, glacier retreat and climate change are projected to intensify inequality because weaker communities often show a stronger vulnerability to these changes. Those latter groups may lack the appropriate resources to respond adequately and thus will face an aggravation of disparity in access to wealth and basic services. The additional financial stress that climate change can create can be quite burdensome for low-income countries in investing in basic infrastructure and social welfare, and it perpetuates inequality.

In sum, the impacts of glacial melting can yield significant economic losses, welfare decreases, and increases in inequality, particularly in vulnerable regions. These problems show how urgently needed comprehensive policies aimed at climate change mitigation and adaptation are, to ensure both economic stability and social welfare. This exemplary studies collectively show that the likelihood of climate catastrophes linked to glacier melting is increasing and, therefore, there is an immediate call for monitoring and risk mitigation strategies to address possible flooding, water scarcity, and environmental degradation.

It becomes evident that creating a resilient and sustainable future necessitates integrating longterm factors into economic governance in addition to addressing current threats. A stable and prosperous future depends on policymakers taking existential risks into account, but doing so necessitates a more comprehensive view of global welfare. The significant effects that existential risks—from climate change to technological advancements—can have on human survival and prosperity are frequently overlooked by conventional measures of societal well-being. Therefore, we need to broaden our focus to include not only existential threats but also the more expansive idea of social global welfare in order to promote genuinely sustainable and equitable outcomes. The following chapter will examine how our conception of global well-being can be altered by incorporating existential risks into welfare evaluations. We can develop a framework that more effectively tackles the problems that humanity faces on a global basis by taking a more thorough approach that incorporates both the longterm effects of risk and the goal of sustainable development. In the end, this change will lead us to make better decisions and create a more resilient and just future.

2.4.2. (Social) Global Welfare (SGW)

The concept of global welfare is difficult to define due to the various underlying complexities (see chapter 2.2). Furthermore, it is essential to clarify that in the context of international research, welfare often extends beyond humans to include animal welfare. However, for the purposes of this thesis, the focus is solely on human welfare and societal well-being (Bacon et al., 2021; Cockburn et al., 2012; Sabetan, 1997; Valente & Stilwell, 2022). It is important to note, that well-being and welfare are related but distinct concepts. Wellbeing focuses on subjective experiences and satisfaction, while welfare often includes economic and material conditions. Welfare is broader, encompassing economic stability, health, and education, whereas wellbeing emphasizes personal perceptions and happiness.

Historical Context of Social Welfare

Traditionally focused on resource distribution and poverty alleviation, the concept of social welfare has undergone substantial change over time. Based on utilitarianism, early work on welfare economics sought to maximize societal utility by influencing welfare measurement with ideas such as poverty indices and stochastic dominance (Gruen & Klasen, 2007; Kot & Paradowski, 2024). The origins of social welfare can also be traced to utilitarian philosophers such as Jeremy Bentham “[t]he greatest happiness of the greatest number is the foundation of morals and legislation" (Bentham, 1843, 1999) and John Stuart Mill, who proposed that the goal of policy should be based on the moral principle of the greatest number, the greatest happiness, is the foundation of morality and legislation (Mill, 2009). This laid the foundation for utility-based measures of welfare[8].

Early classical economists like Adam Smith and David Ricardo emphasized individual self-interest and market efficiency as key drivers of social welfare but paid less attention to the distribution of wealth (Fogel, 1985; Ricardo, 2012; Smith, 2018; Valente & Stilwell, 2022). As economies advanced, the understanding of welfare expanded to incorporate factors beyond income, such as health, education, and employment (Heys et al., 2019; Jacobs & Šlaus, 2010; Pais et al., 2019; Schuller, 2014). This reflected a growing acknowledgment that welfare is influenced by social determinants as much as economic ones. The welfare state emerged in response to these complexities, using government intervention to address inequalities and promote social rights (Bonoli, 2005; Gruen & Klasen, 2008; Hasanaj, 2023).

Welfare economics (chapter 2.4.4.) evolved in the late 19th and early 20th centuries after Italian economist Vilfredo Pareto popularized the idea of Pareto optimality. Despite becoming a pillar of welfare economics, Pareto optimality—the idea that no one can be made better off without making someone else worse off—failed to address issues of equity (Luc, 2008; Stiglitz, 1981). Later, Arthur Pigou (2017) developed welfare economics by emphasizing the part externalities and market failures play and arguing that taxes or subsidies should be used by the government to address these problems.

Post-War Development and Beyond

Economists like Kenneth Arrow and Amartya Sen (1979, 2000,2009) expanded the concept of welfare measurement in the middle of the 20th century. Sen highlighted fairness and rights as essential components of welfare assessments, while Arrow's impossibility theorem illustrated the difficulties in combining individual preferences into a social welfare function. Despite worries about distributional equity and environmental

---

[8] The phrase "personal experiences and broader economic conditions" refers to how individuals' own life circumstances—such as job security, income level, or personal encounters with social safety nets—influence their attitudes toward welfare policies. These personal experiences combine with the broader economic environment, including factors like unemployment rates, inflation, and general economic stability, to shape people's views on welfare. When people feel financially secure, they may support different policies than they would during times of economic hardship or uncertainty, reflecting how both individual and societal economic realities impact public opinion on welfare measures.

degradation, GDP emerged as the primary indicator of economic performance and social welfare following World War II. This was based on the idea that economic growth would inevitably improve welfare (Bacon et al., 2021; Dalton & Ghosal, 2017; Fleurbaey, 2011; Valente & Stilwell, 2022; Van der Slycken & Bleys, 2020). In recent decades, the limitations of GDP as a welfare measure have become more apparent, leading to the development of several alternative indicators like the Human Development Index (HDI), the inequality adjusted Human Development Index (I-HDI), the Genuine Progress Indicator (GPI), the Gross National Happiness Index (GNH), the Environmental Performance Index (EPI), the Index of Sustainable Economic Welfare (ISEW), the Social Progress index (SPI), the Multidimensional Poverty Index (MPI), the Inclusive Wealth Index (IWI), the Better Life Index (BLI), the Gender Inequality Index (GII), Quality of Life (QOL), the New Social Economic Welfare Index (N-SEWI), the World Happiness Report (WHR), the Misery Index (MI), the Welfare Index (WI), the Legatum Prosperity Index (LPI), the Human Capital Index (HCI), the Ecological Footprint (EF), the Macroeconomic Performance Index (MPI) and the Happy Planet Index (HPI). These metrics account for social and environmental factors alongside income (Fleurbaey, 2011; Jones & Klenow, 2016; Kalimeris et al., 2020). Amartya Sen's (2020; 2000, 1979) capability approach has also gained prominence, focusing on individuals' abilities to achieve valuable outcomes—such as access to education, healthcare, and social opportunities—rather than material wealth alone (Chacon-Hurtado, 2023; Clerc et al., 2011; Collste et al., 2021; Fleurbaey, 2011; Offer, 2000).

The concept of global welfare evolved, to date, to the earlier mentioned multifaceted idea with various viewpoints, consideration of a larger number of variables and therefore it's inherent difficulties to measure. Moreover, the ethical component, emphasizing that societal gains should ideally enable compensation for losses among different groups, adds further complexity. Translating this ethical and holistic framework into a single index risks oversimplification, potentially losing the richness of the individual factors that contribute to welfare. In light of globalization and environmental challenges, the need to balance these diverse welfare dimensions underscores the limitations of a one-dimensional measurement, encouraging instead a composite or multidimensional index that can more faithfully represent global welfare's intricate fabric.

Frameworks such as Jones and Klenow's (2016) welfare metric, which integrates consumption, leisure, inequality, and mortality, offer a nuanced understanding of welfare that traditional economic metrics like GDP often overlook. Their index highlights significant deviations from GDP, showing that countries may have high economic output yet perform poorly on income equality or life expectancy—factors critical to overall quality of life and social justice. Weisbrod and Hansen's (1968) approach similarly broadens welfare measurement by emphasizing both income and net worth, capturing wealth inequalities that affect longterm social mobility and quality of life.

The concept of social welfare not just incorporates social well-being (physical, mental, and health outcomes like life expectancx and disease prevalence; educational attainment) but also special attention regarding marginalized groups, inequalities in the distribution of economic well-being as well as feminist perspectives (Deeming & Hayes, 2012; Greve, 2017; Gruen & Klasen, 2008; Heys et al., 2019; Phillips, 2023).

Globalization has affected welfare in two ways. On the one hand, it has helped to improve employment, education, and health, especially in developing nations. However, in some areas, it has made social risks and inequality worse. Positively, it has made it possible for significant advancements in employment, education, and health, especially in developing nations. Globalization boosted economic growth, improved living standards, and decreased poverty in many areas by expanding access to global markets, resources, and knowledge exchanges. For example, international cooperation has increased access to infrastructure, educational materials, and medical technologies, while international trade and foreign investment have promoted innovation and the creation of jobs. Globalization has, nevertheless, also increased social risks and disparities in some areas. Income disparities within and between nations have widened as a result of the unequal distribution of the advantages of economic growth and development. Some regions have seen job losses, environmental damage, and social displacement as a result of local industries being undermined by the entry of multinational corporations and competitive pressures. Furthermore, the increased cross-border movement of labor and capital has led to economic vulnerabilities like exploitation of workers and reliance on unstable international markets. This twofold effect demonstrates how globalization can both promote welfare advancement and present fresh obstacles to social justice and stability (Gong et al., 2022; Jacobs & Šlaus, 2010; Powell & Chen, 2012).

As environmental concerns grow, the balance between human well-being and planetary sustainability has become critical. The work of Kreinin & Aigner (2021) emphasizes the need for welfare metrics that account for environmental sustainability, and indices such as the Ecological Footprint and Sustainable Development Goals (SDGs) have emerged to address these concerns.

In order to maximize social welfare and address X-Risks—which inevitably impact all of humanity rather than just specific countries—global welfare must now take into account global public goods like biodiversity and climate stability (Nordhaus, 200). Weitzmann (2009) highlights how decision-makers prioritize preventing catastrophic losses over pursuing incremental gains, highlighting the need for a lack of reflected risk aversion. This is necessary because threats like climate change, pandemics, and ecosystem collapse have global implications, necessitating collective and shared responsibility for mitigating these risks. This viewpoint is crucial in the discussion of social global welfare as it contends that policies should be created to guard against the potentially disastrous effects of low-probability events as well as to improve welfare under normal circumstances. Therefore, concerted efforts are necessary to ensure the welfare of current and future generations globally as well as for the effective distribution of resources (Chacon-Hurtado et al., 2023; Cotton-Barrat et al., 2020; van den Bergh & Bozen, 2017; Sandmo, 2007).

The relationship between environmental sustainability and social welfare is further highlighted by climate change. Social welfare is at risk due to its effects on livelihoods, food security, and health, especially for vulnerable groups (del Carmen Pérez-Peña, 2021; Kraay et al., 2023; Zheng et al., 2022). Calls for more all-encompassing welfare strategies that incorporate sustainability issues have resulted from this (Büchs, 2021; Hasanaj, 2023; Stevenson & Wolfers, 2008).

Economic systems that put social justice and longterm stability first are necessary, as evidenced by the move towards a more thorough understanding of societal well-being. The difficulty arises from the need to successfully incorporate wider dimensions into policy frameworks as we move beyond conventional measures like GDP. This leads to the study of sustainability economics, which provides a way to balance the need for social and environmental responsibility with economic growth. The following chapter examines how sustainability economics offers the instruments and approaches required to develop economic systems that are not only effective but also robust, just, and able to support future generations.

2.4.3. Sustainability economics (SE)

Sustainability economics connects environmental responsibility with economic development by integrating environmental and economic considerations. It aims to balance economic growth with the preservation of ecosystems and natural resources for future generations. This field addresses the challenges of balancing social justice, environmental preservation, and economic growth. It provides a framework for decision-making that considers longterm impacts on both natural systems and human well-being, combining ideas from environmental science, resource management, and economic theory. (Gowdy, 2005; Kubiszewski et al., 2013; Liu et al., 2017; Pais et al., 2019; Tsara et al., 2024)

Sustainability economics differs from welfare economics in its emphasis on longterm environmental and resource considerations rather than immediate social welfare alone. While welfare economics economics (chapter 2.4.4.) focuses on optimizing current well-being, sustainability economics prioritizes the preservation of resources and environmental health to ensure that future generations can achieve a similar or improved quality of life (Fleurbaey, 2011; Gowdy, 2005; Zhu et al., 2021). This approach involves addressing ecological limits and intergenerational equity, aiming for development that is both economically viable and ecologically responsible.

Definition of sustainability

Sustainability is a multifaceted concept that encompasses ecological, social, and economic dimensions, each playing a crucial role in ensuring the well-being of current and future generations. The definition of sustainability often refers to the ability to meet present needs without compromising the ability of future generations to meet their own needs, as highlighted by the Brundtland Report (Gehringer & Kowalski, 2023). This concept has evolved to include a holistic approach that integrates environmental, social, and economic considerations, emphasizing their interconnectedness (Liu et al., 2017). The dimensions of sustainability contain:

- Ecological Sustainability: focuses on the responsible use of natural resources to prevent depletion and ensure longterm environmental health. This includes practices like sustainable forestry, agriculture, and fisheries. Second, managing pollution and reducing emissions are critical to maintaining ecological balance. This involves implementing technologies and policies that minimize environmental impact. Third, protecting ecosystems and biodiversity is essential for ecological sustainability, as it ensures the resilience of natural systems against environmental changes (Kaimovs & Skarupins, 2024).

- Social Sustainability: addresses, first, issues of equality, social justice, and the well-being of communities; it, second, involves ensuring fair access to resources and opportunities for all individuals (Arora-Jonsson et al., 2023; Kaimovs & Skarupins, 2024). Third, recognizing cultural dimensions as part of social sustainability, this aspect emphasizes the importance of preserving cultural heritage and promoting social resilience and adaptive capacity in the face of global challenges (Järvelä, 2023) and, fourth, active participation and engagement of communities in sustainability initiatives are vital for fostering social cohesion and resilience (Järvelä, 2023).
- Economic Sustainability: emphasizes, as a first step, developing systems that sustain longterm economic growth without destroying social structures or depleting natural resources (Kaimovs & Skarupins, 2024). By combining social inclusion, environmental resilience, and economic performance, this strategy encourages sustainable patterns of production and consumption (Al-Habash et al., 2023; Alshehry & Belloumi, 2024; Hysa et al., 2020; Kaimovs & Skarupins, 2024). Third, economic sustainability is in line with international programs such as the Sustainable Development Goals (SDGs), which seek to strike a balance between social justice, environmental preservation, and economic growth (Arora-Jonsson et al., 2023; Kreinin & Aigner, 2022).

While the traditional view of sustainability focuses on these three dimensions, there is an increasing recognition of the need to integrate cultural aspects as a fourth pillar:

- Cultural sustainability emphasizes the role of cultural identity and heritage in shaping sustainable development practices (Järvelä, 2023).

Additionally, the interconnectedness of these dimensions suggests that sustainability cannot be achieved by addressing each aspect in isolation; rather, a holistic approach that considers their interdependencies is necessary (Arora-Jonsson et al., 2023; Gehringer & Kowalski, 2023).

While sustainability is often presented as a comprehensive and beneficial approach to development, there are valid arguments against its current implementation and conceptualization:

- Economic trade-offs: Pursuing sustainability goals can lead to significant economic costs and reduced competitiveness for businesses and nations. Implementing sustainable practices often requires substantial investments, which may not yield immediate returns, potentially hindering economic growth and job creation (Al-Habash et al., 2023; Alshehry & Belloumi, 2024; Pais et al., 2019; Tsara et al., 2024).
- Technological limitations: The current state of technology may not be sufficient to achieve sustainability goals without compromising living standards or economic progress. Overreliance on unproven or inefficient technologies could lead to unintended consequences and wasted resources (Alimohammadlou & Khoshsepehr, 2022; Beckstead, 2013; Kalimeris et al., 2020).
- Unequal burden: Developing countries argue that sustainability initiatives disproportionately affect their ability to industrialize and improve living standards, as they are expected to adopt costly green technologies while still struggling with basic infrastructure and poverty issues (Pérez-Peña et al., 2021; Spierre et al., 2013).
- Vague and subjective definition: The concept of sustainability lacks a universally agreed-upon definition, leading to inconsistent implementation and potential misuse of the term for greenwashing or political purposes (Arora-Jonsson et al., 2023; Liu et al., 2017; McPherson Frantz, 2024).
- Short-term focus: The emphasis on meeting present needs may inadvertently prioritize short-term solutions over longterm, more effective strategies for environmental and social well-being (Greve, 2017; Nyberg, 2018; Turchin & Denkenberger, 2018).
- Oversimplification of complex issues: The three-pillar approach (ecological, social, and economic) may oversimplify the intricate relationships between these factors, leading to inadequate solutions that fail to address root causes of unsustainability (Kaimovs & Skarupins, 2024; Tsara et al., 2024).
- Potential for unintended consequences: Well-intentioned sustainability initiatives may have unforeseen negative impacts on ecosystems,

economies, or social structures, particularly when implemented without thorough consideration of local contexts (Hämäläinen et al., 2020; Gowdy, 2005; Tsara et al., 2024).

- Conflict with individual freedoms: Some sustainability measures may infringe upon personal liberties or cultural practices, leading to resistance and potential social conflicts (Hämäläinen et al., 2020; Järvelä, 2023).

These counterarguments emphasize the need for a more critical and nuanced examination before any implementations genuinely benefit present and future generations.

Insertion: The idea of resilience in relation to climate change

In the context of climate change, resilience is a complex idea that is essential to a society's ability to endure, adjust to, and recover from the effects of climate-related disasters. In order to ensure sustainable development and lessen vulnerability, it entails strengthening the ability of communities, systems, and individuals to manage and mitigate the effects of climate change. Resilience's capacity to convert adversity into chances for societal adaptation and advancement highlights its significance (Schleussner et al., 2021; Zhai & Lee, 2024).

Resilience is often misrepresented as merely adapting to climate change without addressing the root causes, such as fossil fuel dependency. True resilience requires a systemic transformation that incorporates climate justice and anti-racism to achieve meaningful change. The concept can be co-opted by fossil fuel interests to maintain the status quo, highlighting the need for a cross-class and multi-racial approach to climate politics (Schleussner[9] et al., 2021).

In order to handle the effects of climate-induced natural disasters on human security, traditional policing must change. As demonstrated by the reactions to Hurricane Katrina and Hurricane Harvey, resilience policing entails building the capacity to foresee and address non-traditional security threats. Given the rise in

[9] For example and by taking into account the generations currently growing up, integrating resilience into educational curricula, such as English Language Teaching (ELT), can empower learners to become informed advocates for environmental sustainability. This approach promotes critical thinking, global citizenship, and empathy, which are essential for fostering a resilient future. Despite challenges like diverse learner needs, educators are encouraged to creatively incorporate climate change topics into language learning to enhance resilience awareness (Uma, 2024). Local minority languages and dialects are vital for climate change resilience as they carry local knowledge and expertise crucial for developing locally-adapted strategies. This highlights the global challenge of preserving linguistic and cultural diversity to enhance environmental awareness and protection. Supporting the survival and development of minority languages can contribute significantly to resilience by leveraging their unique insights into local environmental dynamics (Järvelä; 2023).

natural disasters, a resilience policing framework can improve security and governance (Mutongwizo et al., 2024; Sears, 2020; Zhai & Lee, 2024). In order to improve anticipatory, absorptive, adaptive, and transformative capacities, interdisciplinary approaches are necessary, and resilience must be viewed as a boundary concept that is applied across multiple disciplines. While desired changes are normatively valued by various stakeholders, building resilience entails enhancing systems' or communities' ability to adapt to change and produce favorable results (Howarth et al., 2020; Järvelä, 2023; Zhai & Lee, 2024). Understanding the interrelationships between vulnerability, adaptation, and resilience is crucial for effective climate change adaptation strategies. This involves incorporating social, institutional, economic, and environmental factors into planning to develop a societies capacity to withstand, recover from and adapt to shocks and disruptions. This might involve economic resilience, energy grid stability, food security or healthcare robustness. Innovative approaches are needed to boost adaptive capacity and resilience, ensuring societies can withstand future climate-related disasters are needed to set frameworks in place for managing X-Risks. (Zhai & Lee, 2024). This could be approached by strong regulations and ethical guidelines or the availability of rapid response systems for environmental disasters.

Although resilience plays a vital role in combating climate change, it is crucial to understand that it is not a cure-all. Sometimes the idea is applied superficially, failing to address more fundamental systemic problems or the necessity of radical change. In order to ensure that underserved communities are not left behind in the pursuit of climate adaptation and mitigation strategies, resilience initiatives must also be inclusive and equitable. This emphasizes how crucial it is to have a thorough and sophisticated understanding of resilience in relation to climate change.

– End insertion

The ideas of strong and weak sustainability are fundamental to sustainability economics. According to strong sustainability, maintaining the integrity of natural systems is crucial to longterm well-being because natural resources, or "natural capital," are irreplaceable and shouldn't be replaced by other types of capital. On the other hand, weak sustainability implies that, provided investments and technological advancements can counteract environmental degradation, natural capital can be substituted with manufactured or human capital (Giannetti et al., 2015; Gowdy, 2005; Jacobs & Šlaus, 2010; Kreinin & Aigner, 2022; Kubiszewski et al., 2013; Zhang & Zhu, 2022). These perspectives lay the groundwork for alternative economic indices—such as the Index of Sustainable Economic Welfare (ISEW) and the Environmental Performance Index (EPI)—which aim to capture dimensions of well-being beyond economic output alone (Lovrinčević et al., 2013). These indices consider ecological degradation, resource depletion, and social inequities, areas GDP metrics tend to overlook. The drawbacks of GDP-centered models have been emphasized by Amartya Sen and Joseph Stiglitz, especially their indifference to environmental costs and the depletion of natural resources. As a result of this criticism, frameworks and indices that better reflect sustainable welfare have been developed. Examples of these include the GPI and the ISEW, which take social equity and ecological health into account (Stiglitz, Sen, & Fitoussi, 2009, 2020; Lovrinčević et al., 2013). This approach is especially relevant given existential risks like climate change, which threaten the viability of current economic practices (Al-Habash et al., 2023; Bagstad & Shammin, 2012; Beça & Santos, 2009; Jones, 2022; Kandrács & Ritter, 2024; Nordhaus, 2006; Van der Slycken & Bleys, 2020).

Despite the growing recognition of sustainability economics, consensus on effectively integrating its principles into macroeconomic indices remains elusive (Assa, 2021; Pissourios, 2013). While indices like the ISEW and the Environmental Performance Indicator (EPI) provide valuable insights, they lack universal acceptance as comprehensive welfare measures, with ongoing debates regarding the best ways to measure strong sustainability and account for the social and ecological costs of economic activity (Arifin et al., 2020; Pais et al., 2019; Tsara et al., 2024).

This research seeks to address this gap by comparing a selection of macroeconomic indicators and their ability to reflect longterm global welfare, focusing on climate change risks.

This chapter explained that sustainability economics requires balancing longterm stability, ecological responsibility, and intergenerational justice. To ensure a resilient future, we must integrate these initiatives into the broader context of societal well-being. Sustainability should not be viewed in isolation but as part of a comprehensive concept of human well-being that includes resource conservation and individual and community welfare. This leads to welfare economics, which provides the framework to assess how well societies achieve these broader goals. In the next chapter, we will explore how welfare ecology can guide policies that balance sustainability, social justice, economic growth, and longterm human well-being. This approach helps us learn how to design economic systems that enhance individual and community welfare while ensuring future generations inherit a world that supports their prosperity.

2.4.4. Welfare Economics (WE)

Welfare economics focuses on optimizing social welfare through efficient resource distribution. It evaluates individual satisfaction and well-being, providing a theoretical basis for assessing how macroeconomic indices reflect wealth and welfare. Using tools like the social welfare function, it aggregates individual utility to enhance overall social welfare by determining optimal resource and policy allocation. In a global context, this approach considers externalities – the unintended costs or benefits of economic activities that affect third parties not directly involved in the transaction– and international impacts from global interactions. Beyond income distribution, welfare is measured using subjective indicators like health, education, environmental sustainability, and quality of life. This broader approach addresses market failures, such as common goods and externalities, which are crucial for understanding global welfare.

These market failures frequently call for international cooperation and group efforts, particularly when dealing with cross-border problems like resource management and climate change. To ensure that the costs and benefits are shared fairly among countries, policy interventions that address these externalities are necessary due to the global nature of climate change (Fleurbaey, 2011; Menegaki, 2018; Nakamura & Hulten., 2022; Pryimak et al., 2021; van der Slycken & Bleys, 2020). While WE aims to maximize efficiency and individual wealth, it also addresses moral issues of resource distribution and equity, especially in a global context where wealth disparities, resource access, and vulnerability to issues like climate change must be considered for fair outcomes. A key challenge is the interpersonal comparability of utility, essential for crafting strategies to enhance global well-being despite differing views on measuring individual well-being across cultures. By considering diverse preferences and needs worldwide, policymakers can create strategies that better tackle global welfare challenges while respecting cultural and individual differences.

Two core assumptions underpin WE:
(I) pareto efficiency, which is achieved when no one can be made better off without making someone else worse off. However, this framework tends to focus on short-term efficiency without accounting for longterm sustainability or equity;

(II) social welfare functions are used to aggregate individual preferences and outcomes into a single measure of social well-being.

Critics draw attention at the fact that traditional welfare economics frequently overlooks non-market goods like social capital and environmental quality, which are essential for longterm welfare, in favor of market outcomes and material well-being.

New perspectives focusing on social justice and environmental sustainability are essential for tackling globalization and climate change issues, complementing traditional economic theories like welfare economics. Economists advocate for welfare policies that prioritize longterm risks and resource depletion over short-term gains, reflecting growing concerns about sustainability. Recently, sustainable development goals emphasizing longterm well-being and resource stewardship for future generations have been integrated into the concept of social welfare (Büchs, 2021; Nakamura & Hulten, 2022; Weisbrod & Hansen, 1968; Zhu et al., 2021).

Research indicates that individual perceptions of risk and economic insecurity frequently determine public support for social welfare policies, indicating that welfare preferences are influenced by both individual experiences and general economic conditions[10] (Andriantiatsaholiniaina et al., 2004; Fleurbaey, 2011;; Sabetan, 1997; Stevenson & Wolfers, 2008). The growth of welfare economics is already covered in a body of research, such as a more comprehensive definition of personal well-being that takes into account both economic and non-economic factors (Castellacci, 2023; Deeming & Hayes, 2012; Fleurbaey, 2011; Gruen & Klasen, 2007; Heys et al., 2019); an integrated policy framework that aligns labor rights with environmental sustainability (Galgóczi, 2022; Hayden & Wilson, 2016; Kreinin & Aigner, 2022); demand for a holistic approach that recognizes the interconnectedness of environmental health and community resilience (Gunathilaka et al., 2018; Kanmani et al., 2020; Schleussner et al., 2021); significant welfare impacts on both producers and consumers in a sector yielding to potential longterm reductions (Hudson et al., 2019; Kiley, 2023; Nguyen, 2022).

The concept of WE has volved from focusing solely on utility and economic performance to encompassing multidimensional measures like human capabilities,

[10] The phrase "personal experiences and broader economic conditions" refers to how individuals' own life circumstances—such as job security, income level, or personal encounters with social safety nets—influence their attitudes toward welfare policies. These personal experiences combine with the broader economic environment, including factors like unemployment rates, inflation, and general economic stability, to shape people's views on welfare. When people feel financially secure, they may support different policies than they would during times of economic hardship or uncertainty, reflecting how both individual and societal economic realities impact public opinion on welfare measures.

inequality, and sustainability. This shift acknowledges that longterm social well-being requires not just economic growth, but also equity, health, education, and environmental stability. Modern views incorporate environmental sustainability, resilience to shocks, and existential risks like climate change, recognizing that global well-being is intertwined with planetary health and societal adaptability. Consequently, the framework for well-being now emphasizes holistic, multidimensional measures that consider future generations, ecosystem sustainability, and community resilience against climate risks.

Modern welfare-economics and X-Risks - a new measurement?

Modern welfare economics must address existential risks—unprecedented threats to humanity's future. Traditional macroeconomic models often overlook rare, high-impact "black swan"[11] events, necessitating a shift to resilient approaches that consider unpredictability and potential catastrophic consequences across the economy and environment.

The limitations of traditional welfare metrics are evident in the face of existential threats. Modern welfare economics advocates for integrative metrics like the HDI and the GPI, which encompass health, education, and environmental quality for a comprehensive welfare view (Stiglitz, Sen, & Fitoussi, 2009). Environmental economics supports this by accounting for externalities like pollution and resource depletion, emphasizing the true costs of economic activities. Tools like the social cost of carbon (SCC) make climate costs visible in welfare calculations, assessing longterm economic damage from emissions (Beça & Santos, 2010). This framework calls for policies prioritizing ecological health and resilience in response to climate change and other existential threats (Büchs, 2021). Alternative indicators like the ISEW and the GPI adjust GDP to better reflect true prosperity and intergenerational equity (Menegaki, 2018). These measures promote resilience-oriented growth models by highlighting the limits of substitution between natural and industrial capital, crucial for

[11] "Black swan" events are defined as rare, unpredictable occurrences that have significant and widespread consequences. The term was popularized by Nassim Nicholas Taleb in his book "The Black Swan," where he identifies three main characteristics of such events: they are outliers, they have extreme impacts, and they are often rationalized in hindsight as if they were expected (Mustafa & Barabadi, 2021). Black swan events can manifest across various domains, including finance, ecology, and public health, illustrating their broad relevance and impact. Those events are known in the context of finance and the case of market disruptions (Velappan et al., 2022; Antipova, 2020; Phadnis et al., 2021). In ecological studies, black swan events can refer to sudden shifts in ecosystems or population collapses that are difficult to foresee. For example, the extinction of species or drastic changes in biodiversity can be classified as black swan events, as they often result from a combination of unforeseen environmental factors and human activities (Núñez & Logares, 2012; Rundle et al., 2012). These events highlight the importance of adaptive management strategies in ecology, as they can significantly alter ecosystem dynamics and resilience.

sustainability economics (Kubiszewski et al., 2013). They advocate for valuing ecosystem services and natural resources more highly and emphasize business practices that conserve the environment.

Macroeconomic models must evolve to incorporate sustainability and disaster risks, as growth theories have historically focused on capital accumulation without considering existential threats. Nordhaus' DICE model links greenhouse gas emissions to economic performance, highlighting the consequences of unsustainable practices and the urgent need to address climate risks (Dietz et al., 2021). It combines economic and climate systems to identify optimal climate change measures, assessing trade-offs between current consumption and future investment, based on the Ramsey model (Bressler, 2021; Nordhaus, 2017). Estimating the SCC, which measures longterm economic damage from carbon emissions, is a key task of DICE (Rezai, 2010; Khabarov et al., 2022). The model supports early climate action by simulating policies like carbon taxes and providing insights into optimal climate investments (Botzen et al., 2018; Nordhaus, 2018). Degrowth models further emphasize limiting environmentally harmful activities, advocating reduced economic growth for sustainability and resilience (Panton, 2020).

Addressing existential risks also requires revisiting discount rates, as high rates devalue future welfare and ignore intergenerational equity. Lowering or eliminating discount rates allows economic evaluations to better reflect the severe, lasting consequences of potential catastrophic events (Fleurbaey, 2011). Nordhaus's work (2006) exemplifies this approach, advocating for nearly equal valuation of future generations to effectively combat climate change.

Modern welfare economics, informed by environmental and sustainability principles, provides a critical framework for addressing existential risks. By integrating comprehensive welfare & sustainability indicators, these approaches offer essential insights for policies that protect longterm human and environmental well-being. Embracing this paradigm shift is necessary for fostering resilient, risk-aware growth that supports equitable welfare for current and future generations. However, a major issue in the literature is the lack of consensus on how well these indices represent longterm global welfare (Fleurbaey, 2011; Gruen & Klasen, 2007).

2.5. Synthesis and working definitions

The selection of aspects for a welfare index scorecard are significantly informed by the principles of welfare economics, sustainability economics, and the concept of existential risk. Each of these frameworks contributes unique insights that shape a coherent and comprehensive approach to measuring global welfare in the context of environmental and socio-economic challenges.

The concerpt of WE teaches how to prioritize the optimal allocation of resources to maximize individual and collective utility. Aspects selected for the scorecard may include economic factors (e.g., income levels, employment rates) and social factors (e.g., education access, healthcare quality) that directly affect well-being. Conceptions of equity and social justice guide the inclusion of measures of inequality and distribution of resources. Weighting is often assigned to aspects like income distribution and access to opportunities, reflecting their importance in promoting fair societies. Welfare economics accounts for market failures (e.g., negative externalities, public goods under provision) when selecting aspects related to environmental quality and social safeguards, which may require higher weighting to ensure that these critical dimensions are adequately reflected and addressed.

SE emphasizes the need to balance economic development with environmental sustainability and social equity. Aspects related to ecological health (e.g., biodiversity, resource consumption rates) are essential and typically weighted heavily, reflecting their importance for ensuring longterm prosperity. Sustainability economics recognizes the interdependence of economic, social, and environmental factors, prompting the selection of aspects such as community resilience and ecological footprint. This interconnectedness influences the weighting assigned to various dimensions, favoring those that reinforce the relationships between social well-being and environmental quality. Aspects that measure the impacts of production and consumption patterns on resource sustainability (e.g., carbon emissions, waste management) should be weighted significantly. This assessment ensures that metrics account for the longterm ecological footprint of economic activities.

The concept of x-risks highlights the importance of measuring risks that can lead to human extinction or irreversible societal collapse. This perspective necessitates selecting aspects such as climate change impacts, nuclear threat assessments, and technological risks. These aspects would be assigned substantial weight to reflect their potential catastrophic consequences on human welfare. The need to evaluate resilience against existential threats informs the selection of aspects related to risk mitigation and adaptive capacity (e.g., disaster preparedness, climate adaptation strategies). These aspects might receive considerable weight as they help gauge a society's ability to prevent or respond to future risks. Existential risk considerations also demand a focus on longterm implications for future generations. Aspects that reflect sustainability across generations (e.g., resource conservation, educational opportunities) may be weighted more heavily to encourage policies that prioritize longterm survival and well-being.

Grounded in welfare economics the concept of Social Global Welfare contains societal well-being and quality of life from a comprehensive perspective. Over recent decades, the approach has expanded to include not only material dimensions but also social, health, and environmental factors. Traditionally, welfare economics has focused on maximizing utility and aggregating individual preferences. Today,those studying social global welfare increasingly emphasizs sustainability, social equity, and the longterm resilience of societal systems.

Derived from these definitions, the applied criteria for assessment of welfare and x-risk considertions are shown in table 2 (chapter 5.2).

The research question aims to identify macroeconomic indices that accurately reflect longterm global welfare in the context of climate change threats. Frameworks from existential risk, sustainability economics, and welfare economics provide essential insights into the interplay between environmental factors, socioeconomic systems, and human survival. Together, these perspectives offer a comprehensive understanding of global welfare, balancing short-term human needs with longterm ecological sustainability. This integrated approach highlights the need for macroeconomic indices that capture the complexities of climate change and related risks to guide effective global welfare policies. By incorporating insights from these fields, a welfare index scorecard can offer a nuanced depiction of well-being, prioritizing resilience against existential threats and addressing the critical links between environmental sustainability and socioeconomic conditions. This multifaceted approach ensures the scorecard is a valuable tool for decision-makers aiming to enhance longterm welfare amid global challenges.

This chapter has examined key macroeconomic indicators, their significance for global welfare, and the impact of climate change on longterm economic stability. Traditional metrics often fail to capture the complexity of existential threats posed by climate change, highlighting the need for more comprehensive welfare measures that consider resilience and longterm sustainability. Integrating existential risks into welfare frameworks allows for a more accurate assessment of global well-being, aligned with the goal of preserving humanity's future. Addressing these complex risks requires overcoming institutional, philosophical, and scientific challenges, demanding new approaches to identify, quantify, and manage them effectively for improved global governance. The next chapter will explore alternative welfare indices, focusing on how new frameworks can better incorporate existential risks to enhance our understanding of global welfare in the face of climate change and other emerging threats.

3. Alternative indices for welfare-measurements and X-Risks

The need for alternative indicators extends beyond previously discussed factors, as climate change demonstrates the critical link between environmental health and global stability. Extreme weather events, melting ice caps, rising sea levels, and biodiversity loss are not only ecological challenges but also geopolitical risks, driving resource conflicts, mass displacement, and economic instability. Metrics that fail to account for social and environmental resilience are increasingly seen as inadequate or even irresponsible. The interconnected nature of existential risks—such as climate tipping points, artificial intelligence, and nuclear proliferation—further underscores the necessity for metrics that reflect the complexities of a rapidly changing global landscape.

The shift to alternative welfare metrics is not without controversy, nevertheless. Critics contend that adding social and environmental factors to welfare metrics could make policy decisions more difficult by reducing the economic precision offered by indices like GDP. Additionally, some economists argue that emphasizing existential and climate risks could result in restrictive policies that impede innovation and economic growth. Proponents of "ecomodernism" and economists like Bjorn Lomborg contend that technological development, not a change in metrics, is the best way to address global issues. They also believe that economic expansion will eventually supply the funds required to innovate solutions to climate risks (Begum, 2023; Stojkoski et al., 2023; Yan, 2024; Zhang, 2024). The possibility of policy misalignment adds to the controversy surrounding the suitability of these metrics. Critics caution that placing too much focus on social and environmental indicators may result in laws that unintentionally limit economic activity, which would lower welfare levels overall (Yan, 2024). This issue is especially important in the light of climate change, as the need for innovation and economic growth may conflict with the need to address environmental concerns (Yan, 2024; Stojkoski et al., 2023). The challenge at this point is to find a balance between economic growth and to ensure that this occurs equitable and sustainable.

Alternative indicators also face methodological and conceptual challenges. Selecting indicators that accurately reflect existential risks is complex and laden with subjective judgments about what constitutes "risk" or "well-being." Another issue is the weighting and aggregation of diverse indicators, which can skew results depending on the priorities embedded within the index design.

The demand for alternative welfare indices prompts fundamental questions about the purpose and philosophy of measuring societal progress. Transitioning from traditional metrics like GDP to sustainability-focused measures requires embracing a paradigm that prioritizes resilience over growth and longterm stability over short-term economic gains. This shift reflects a broader societal acknowledgment of the limitations of purely economic frameworks and the need to address the complex, systemic nature of existential threats.

These methodological hurdles underscore the need for clarity and transparency in alternative metric construction and highlight the underlying paradigm shift required for meaningful global welfare measurement: a move from short-term economic gains to longterm resilience and sustainability.

3.1. Criterias for Effective Welfare Measurement

Effectively measuring human welfare and x-risks requires a comprehensive framework that prioritizes relevance, accuracy, comprehensiveness, and actionability (see chapter 2.4.1, 2.4.2, 2.4.3). To develop meaningful indices that inform policy and improve societal well-being, welfare metrics must integrate subjective well-being, objective indicators, equity, resilience to x-risks, and a longterm perspective.

Subjective well-being, based on individuals' self-reported happiness and life satisfaction, is essential for welfare measurement as it reflects personal perceptions and experiences besides the required aspects covered in previous chapters 2.1 and 2.2 (Colander, 2007). Research consistently demonstrates a strong link between life satisfaction and socioeconomic factors (Sun et al., 2022; Atkinson, 2011). Incorporating qualitative research into welfare metrics further enriches understanding by capturing the nuanced experiences of people across different welfare systems

(Laenen et al., 2019). By combining subjective and objective measures, welfare assessments can provide a more holistic understanding of well-being that considers both individual perceptions and broader societal conditions.

An aspect that has not yet been considered is that of psychological well-being. This can evolve to one of the main standards to gauge welfare in the face of existential threats, which could have an impact that people and communities feel more anxious, depressed and hopeless (Kinslow, 2023; Collins, 2024). For instance, research has shown, that existential isolation, especially in those who have experienced a loss, can intensify psychological distress and feelings of gied (Zhou et al., 2023). In order to measure the mental health of populations facing x-risks, psychological tests need to be included in welfare metrics. This criteria could include the frequency of existential anxiety, efficiency of coping strategies or resilience building programs (Gawda, 2024).

Social stability could be considered as another crucial metric for assessing welfate in x-risk context. Social systems occur as interdependent, therefore threats can trigger significant unrest, inequality and a breakdown of community cohesion ((Arnscheidt, 2024; Jones, 2023). The COVID-19 pandemic brought those effects to light and made obvious how x-risks can shift political and social values, increasing support for welfare programs that protect vulnerable populations (Foa & Welzel, 2023). Future metrics should therefore account for social trust, community engagement and collective action capacity when evaluating welfare (Mäntyneva, 2023).

Another concept to be considered is the concept of existential security. It refers to the confidence that individuals and communities are able to live without a constant fear regarding existential threats that could endager their existance (Schubertová, 2023). This concept of safety entails physical as well as social and economic stability. Schubertová (2023) reported, when focusing on the improvement of this type of stability, mental health outcomes as well as societal resilience could be increased (Ferryono et al., 2022).

Equity considerations are another crucial dimension in welfare measurement. The distribution of resources and opportunities within a society significantly impacts overall welfare. Measures that account for equity, such as the Gini coefficient and other inequality indices, are necessary for understanding how well-being is distributed across different segments of society (Sun et al., 2022; Atkinson, 2011). In the context of existential risks, it is especially important to consider how marginalized groups may be disproportionately affected by crises, necessitating targeted interventions to safeguard their welfare (Colander, 2007; Sun et al., 2022).

To guarantee that these multifaceted and various metrics and variables are based on trustworthy, easily accessible data, measurability and data accessibility are crucial. This poses particular difficulties for existential risks since precise modeling is challenging due to the unpredictability and uniqueness of some threats. But improving the quantification of these risks will require developments in data science and modeling, which will improve our capacity to track and address possible emergencies (Cotton-Barratt et al., 2020; Turchin & Denkenberger, 2018). A broad scope is essential for understanding the wider societal and ecological implications of these risks and guiding policy toward longterm resilience. When creating welfare and x-risk metrics, transparency and objectivity are also essential. Clear comprehension of the presumptions, restrictions, and possible biases in the measurement process is made possible by transparent methodologies (Giannetti et al., 2015; Kreinin & Aigner, 2022).

There are important ethical issues when approaching to measure this complex system. Equity and justice must be reflected in welfare metrics, guaranteeing that well-being is evaluated both overall and in relation to how it is distributed among various social groups (Gruen & Klasen, 2007). Recognizing our moral duty to future generations is one ethical consideration in the context of existential risks, particularly when dealing with technological hazards or irreversible environmental damage. Developing metrics that support inclusive and longterm welfare requires this ethical sensitivity (Kreinin & Aigner, 2022; Méjean et al., 2020).

Implementing these criteria is challenging due to the complexities of measuring existential risks and multidimensional welfare, which may not align with traditional metrics. Forecasting low-probability, high-impact events, such as existential risks, is difficult due to their unpredictable nature. Disagreements on issues like inequality, ecological impacts, and the ethical significance of future generations further complicate consensus on these metrics.

A comprehensive, multifaceted approach is needed for effective welfare and X-Risk measurement, incorporating subjective well-being, objective indicators, equity, resilience, longterm focus, and ethical considerations. By meeting these requirements, societies can better anticipate and address emerging challenges, ensuring that welfare and X-Risk metrics are scientifically grounded, ethically sound, and relevant to decision-making for the well-being of current and future generations.

In a later chapter (chapter four), a concrete example of existential risk will be introduced: the disintegration of the Greenland Ice Sheet. This case illustrates the limitations of traditional welfare metrics and underscores the need for alternative indicators that can adequately capture the far-reaching impacts of longterm, climate-driven risks.

3.2. Conceptual Challenges in Defining Welfare & X-Risks

Given their complexities, defining existential and welfare is conceptually difficult. Both require balancing individual and collective experiences, subjective interpretation, and measurement challenges.

Since welfare encompasses a variety of factors, including psychological well-being, health, education, and economic stability, it is challenging to create a single indicator (Kobus et al., 2018; Schuller, 2014). Subjective well-being measures, like life satisfaction surveys, differ across cultures and individual experiences, while objective indicators, like income or health, frequently ignore elements like loneliness or meaning (Boston & Mount, 2006; Dodd et al., 2018; Nakamura & Hulten, 2022). The interaction of individual and collective experiences presents another difficulty. Individual well-being is the primary focus of welfare perceptions, but collective welfare—such as social equity and community resilience—needs equal consideration (Garzón et al., 2018). In a similar vein, existential threats are social in character and call for cooperation. Policymaking and resource allocation become more complex when individual needs and group strategies are balanced (Schulz et al., 2017). Moreover, existential and welfare risks have different time horizons. Existential risks necessitate a longterm perspective, taking into account threats that might not fully materialize for decades or even centuries, whereas welfare assessments usually concentrate on short- to medium-term living conditions. This makes it difficult to strike a balance between short-term welfare requirements and longterm resilience objectives because future investments might necessitate current sacrifices (Gruen & McLaughlin, 2024. Existential risks face challenges in definition due to their ambiguity and inherent uncertainties (Bostrom, 2013). It is positive to note that climate change is at least widely recognized and accepted but tot date maybe not as existential risks (Huggel et al., 2022),

Furthermore, ethical considerations complicate the needed definitions. Although they are difficult to quantify, topics like justice, equity and distribution are crucial to cover welfare. Regarding x-risk, there are conundrums regarding the relative importance of people or environment as well as how to strike a balance between disaster prevention efforts and enhancing today’s lifes of vulnerable populations (Bostrom, 2013; Hicks & Janus, 2023; McLaughlin, 2024).

The interdisciplinary nature of welfare and existential risks adds complexity, as these concepts span fields like economics, environmental science, sociology, psychology, and philosophy. Each discipline brings different methodologies and biases, leading to conflicting approaches in defining and measuring welfare and X-Risks (Gruen & Klasen, 2008; Hasanaj, 2023; Kreinin & Aigner, 2022; Schuller, 2014; Ziegler, 2007). Bridging these divides requires a collaborative, integrated approach.

Public and political perceptions also complicate matters. Existential risks are often seen as distant or abstract, reducing political urgency, while welfare is narrowly focused on economic prosperity. Shifting public perceptions to view X-Risks and welfare as interconnected and urgent is essential for building societal resilience.

In conclusion, because of their multifaceted nature, ethical dilemmas, and interdisciplinary conflicts, defining welfare and existential risks is difficult. It takes constant improvement, teamwork, and a balanced approach to present and future requirements to create metrics that work. Prioritizing and allocating resources for reducing these risks requires a strategy that incorporates both subjective and objective measurements while taking cultural differences into account.

3.3. Role of Existential Risk in Welfare Assessment

The need for a more comprehensive understanding of welfare, which goes beyond conventional indicators is highlighted by the growing awareness of x-risks (###ref). Conventional approached frequently overlook longterm, high-impact risks, like climate change, which pose a threat to human existence (Bostrom, 2013; McLaughlin, 2024).

The challenge for integration of x-risk is mentioned in chapter 3.2. Additionally their irreversible nature reaches beyond the scope of traditional metrics – which clearly highlights the need for new welfare analysis that takes both, present welfare, future survival and welfare as well as resilience and adaptive capacity into account (Bostrom, 2013; Büchs, 2021; Hasanaj, 2023). Policy decisions are also influenced by the inclusion of X-Risk in welfare metrics, which promotes funding for longterm initiatives that benefit the present and the future (Powell, 2015). This also requires a new generation of politicians who can finally overcome their greed and irrationality in order to truly act in the interest of humanity and our planet. It requires the actual use of our cognitive capacities, pushing them to their limits—and ideally beyond—to shed outdated, primitive behaviors and truly act as what some people believe our society is: the "crown of creation." This in alignment with global responsibility supports sustainable policies that reduce the probability of catastrophic events (Tonn & Stiefel, 2013).

Ultimately, incorporating X-Risks into welfare assessments bridges the gap between short-term prosperity and longterm survival, offering a comprehensive approach that safeguards humanity's future while improving present well-being. This shift is exemplified in the case study of the Greenland Ice Sheet, where the disintegration of this critical ice mass serves as a concrete example of how environmental risks should factor into welfare considerations. This holistic framework must prioritize flexibility and foresight, ensuring that welfare policies are adaptable to both current and future challenges.

Chapter four examines the continuous melting of the Greenland Ice Sheet as a case study of existential risk, highlighting the need for a revised approach to welfare calculation. This destabilization illustrates how climate change directly threatens ecosystems and societies. We will analyze how traditional metrics, like GDP, fail to capture longterm welfare aspects such as social equity, sustainability, and resilience to existential risks. The chapter aims to explore these indices' strengths, limitations, and relevance in assessing longterm global welfare.

4. Greenland Ice Sheet Disintegration: An Example for Existential Risk

4.1. Climate change-related X-Risks

The literature on climate change-related risks is extensive, highlighting the significant threats climate change poses to human survival and well-being (Butler, 2018; Magnan et al., 2023; McLaughlin, 2024). These risks are characterized by their potential to cause widespread societal collapse, disrupt ecosystems, and threaten humanity's very existence and can therefore be classified as x-risks[12]. However, a gap exists in the systematic framing and analysis of these risks, with existential threats often being poorly defined, which limits the ability to effectively engage with and mitigate them (Huggel et al., 2022). Estimating the probability of catastrophic climate change events,

[12] see chapter 2.4,1 and 3.3

such as a runaway greenhouse effect, is challenging, with some estimates suggesting a 1 in 1000 probability for such an event (Ord, 2020; Posner, 2004). However, for slow-onset processes like extreme sea-level rise, the probability of occurrence is high, shifting the focus to the speed and magnitude of these events (Farnsworth, 2023; Ren, 2024). Huggel et al. (2022) argue that while precise estimations are elusive, it is crucial to specify the natural and social processes involved, considering exposure and vulnerability even when only qualitative estimates can be made.

Climate change-induced risks can threaten basic human needs, potentially leading to societal collapse through interconnected pathways like food insecurity, economic shocks, and socio-political instability. These pathways require a structured empirical evidence base to understand their dynamics (Butler, 2018; Kiley, 2023; Kemp et al., 2022; Magnan et al., 2023). Richards et al. (2021) explored this through a causal loop diagram, which examines the impacts of climate change on agricultural systems, showing how these disruptions could cascade into broader societal collapse (figure 4). The diagram shows three pillars which are connected to each other in two ways. First, the state of existence, characterized by human-influences environment, technology and institutional frameworks. This comes together with the natural environment, matter and processes. Together, secondly, those two systems create social complexity, vulnerability but also resilience and adaptability. Both, humanity and environment, interact with one another in several ways, which in consequence create and lead to mechanisms of societal collapse and this with probable one of two outcomes: either collapse or recovery of the collapse. Whatever outcome will occur, there is an impact which leads (a) to reduced population and/or (b) to decreased institutional complexity – setting back humanity several years, decades or even hundreds of years which leads, in the end, again to a new state of existence.

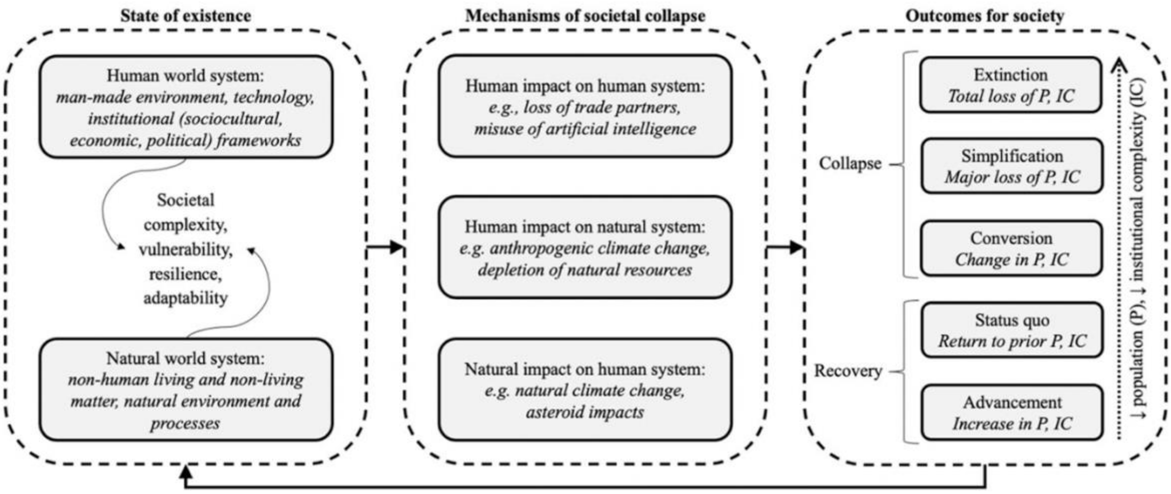

Figure 4 Conceptual model of the overarching process of societal collaps acc. to Richards et al. (2021; p. 48)

For example, in case of the melting GIS a scenario could emerge like follows: the state of existence starts with human-induced climate change, driven by greenhouse gas emissions caused by industrial activity, energy production, deforestation and transportation. Those actions have an impact on the environment with consequences like the rising of global temperatures which can accelerate the melting of the GIS.

As the ice melts, natural processes can be triggered. Processes like rising sea. Levels and the disruption of oceanic currents like the Atlantic Meridional Overturning Circulation (AMOC)[13]. In this case, far reaching consequences will probably take place, including more frequent and severe weather events, coastal flooding and shifts in regional climates. Such disruptions can affect ecosystems as well as human-made systems, including agriculture, infrastructure and habitation. The latter especially in vulnerable coastal areas.

These dynamics can, in consequence, trigger mechanisms of societal collapse. Environmental degradation and institutional failure may then exacerbate existing vulnerabilities. A possible outcome could be overwhelmed governments which then lose the capacity to coordinate effective responses, which leads to reduced institutional complexity. In very extreme cases, societal fragmentation, with declining populations due to compounded effects of displacements, resource scarcity and conflict become probable. If society collapses, populations may be significantly reduced, and society might revert to simpler organizational structures. In case of a more resilient community,

[13] An essential part of the Earth's climate system, the Atlantic Meridional Overturning Circulation (AMOC) greatly influences the patterns of the world's climate. The Atlantic Ocean's system of ocean currents, which carries warm, salty water from the tropics to the northern latitudes where it cools and sinks before heading back south at deeper ocean levels, is what defines it. This circulation affects weather patterns, sea levels, and marine ecosystems and is essential to the global distribution of heat and nutrients (McCarthy & Caesar, 2023; Mitusi & Boers, 2023; Pita et al., 2023).

there is the possibility of adaptation and to develop innovative mechanisms, strategies, technologies and governance systems to address the challenges faced. Whatever the outcome, society finds itself in a new state of existence, characterized by diminished complexity and population or a transformed, more sustainable interaction between humanity and the environment. For Greenland, this might mean a stabilization of the ice sheer in a drastically altered climate with significant shifts in global economic and social systems.

When looking at the possible economic consequences of the disintegration of the GIS, they could be categorized as direct economic damages, indirect impacts on the global system or longterm risks to society.

Direct economic damages could arise from the rising sea levels, flooding coastal cities and critical infrastructure. Highly relevant economic spots like ports, industrial facilities and urban areas could face significant destruction. This means not just high costs for reconstruction but also, at least temporary, a destruction of infrastructure of any kind. Agricultural productivity could decline due to changing regional climates, leaving certain areas unsuitable for farming. This in consequence could lead to crop failures and rising food prices. Poorer nations, heavily reliant on imports, would be especially vulnerable. Furthermore, insurance industry would face escalating risks from more frequent and severe natural disasters, potentially destabilizing financial markets.

Indirect impacts on global systems could worsen the change. Disruptions to supply chains from extreme weather or damage transport routes could destabilize trade, raise costs and slow economies. Coastal floodings could force people to relocate, straining labor markets and creating tensions in the new hyper-populated locations. Defaults by governments and companies might trigger financial instability, market volatility or even global recession.

In the longterm these effects could destabilize resource-scarce or politically fragile states, leading to civil unrest, failed states, regional instability or maybe even war. Competition for shrinking resources like land and fresh water might spark those types of conflict, particularly in the Arctic, where melting ice opens access to new, until then deeply hidden or covered resources.

As economies and societies are extremely strong interconnected, these crises could overwhelm multiple economies. This means further risks regarding systemic collapse and undermining capacity to address other global threats. Economic fallout from the GIS could create a destabilizing feedback loop, amplifying scarcity, conflict and systemic weakness.

The interconnectedness of ecological disruptions, human welfare and societal systems underscore the need for proactive risk management. According to Rising et al. (2022) the integration of unquantified risks into decision-making could improve mitigation and policy responses. This aligns with Magnan et al. (2023) who stresses the need for frameworks that consider magnitude, likelihood, timing and response capacity, especially for critical thresholds. Despite advanced models, estimation of these risks remains difficult, underscoring the need for comprehensive analyses and frameworks to enhance resilience and inform effective strategies.

4.2. State of Research – Climate Risks

The emerging field of research on climate change has gained significant attention in recent years, reflecting a growing recognition of the potential catastrophic impacts of climate change (figure five). Obvious is the, compared, low interest in related existential risks or even existential threats. The consideration of climate change rises gradually from around 1980 to 2022 with a steeper increase since around 2005. Existential risks and existential threats remain nearly flat throughout the same timeline which indicates that these terms have not been widely adopted in the mainstream discourse. This highlights a disparity in public and academic attention. While climate change has become a central concern, there is nearly to no framing as an X-Risk and therefore no equivalent traction.

However, there is some debate and one of the primary concerns articulated in the literature is the existential threat posed by climate change to global security and human prosperity (Hicks & Janus, 2023; McLaughlin, 2024; Sears, 2020). Comiskey et al. (2021) emphasize that climate change will significantly heighten threats to

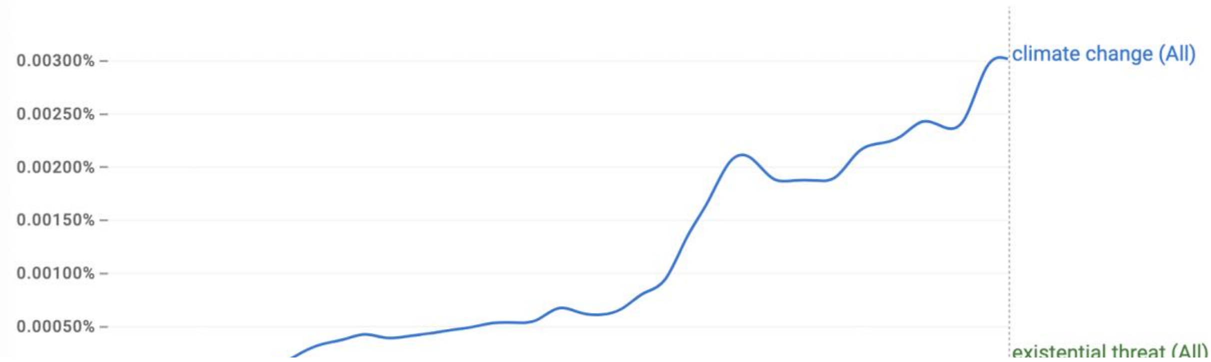

Figure 5 NGram representation of inclining significance of climate research from ~1980-2022

humanity, particularly if substantial and timely reductions in greenhouse gas emissions are not achieved.

Economically, the literature identifies climate change as a major risk that could disrupt global financial systems (Battiston et al., 2021; Cevik & Jalles, 2020). The latter argue that economic forecasting and planning are significantly more uncertain due to the complex, nonlinear dynamics of climate change. In vulnerable countries, where effects of climate change can worsen already present shortcomings and impede development opportunities (Jakob & Steckel, 2013). Financial instability can result in unrest, conflict and even war, endangering human survival. This highlights that the economic effects of climate change are connected to existential aspects.

The melting of glaciers significantly alters hydrological regimes, particularly in those regions which are dependent on this type of meltwater for their water supply. With the retreat of glaciers, the initial increase in meltwater could lead to a higher streamflow, which is beneficial for water supply only in the short term. This is followed by a decrease in streamflow, as glaciers diminish in size and volume (Singh et al., 2023). The variability in meltwater volume can lead to extreme hydrological events like floods during peak melt seasons and drought in the subsequent years (Anderson, et al., 2023; Dar et al, 2024).

Sea-level rise is highlighted as one of the most alarming consequences of glacier melting. The GIS and the Antarctic glaciers are significant contributors. The GIS alone has contributed approximately 17.3% of observed sea-level rise (Millan et al., 2023). With the continuous melting at an accelerated pace, projections suggest that sea levels could rise significantly and be a threat for coastal communities and ecosystems (Li, 2023). This also alters oceanic circulation patterns, which in itself have far-reaching effects on global climate systems (Haigh et al., 2023). According to Salehie (2024) glaciers worldwide are experiencing unprecedented rates of retreat. Another study, by Robinson (2024) states, that 61% of mean annual discharge, measured in the Kaskawulsh River, are caused by glacier melt. The glaciers in the Himalayas are projected to shrink by approx. 71.9% under high greenhouse gas emission scenarios by 2100. Further impacts are mentioned on freshwater and marine environments (Meire et al., 2023; Liu, 2024), foodwebs and aquatic ecosystems (Liu, 2024; Yang, 2023) and landslides (Walden, 2024). Those risks serve further socio-economic risks regarding tourism (Li, 2023) and damage of infrastructure for living & economy (Walden, 2024).

For example, flooding due to increased precipitation may intensify approximately by 7% for each 1°C warming, which could cause widespread damages in infrastructure and displacement. Also correlated to melting of glaciers is the intensification of water cycle, as the planet warms. This can lead to extreme monsoon rainfall and increasing droughts (IPCC, 2021). Among other aspects of global warming, sea level rise is predicted to threaten coastal assets worth up to 20% of the global GDP by 2100. This could further lead to destabilizing economies and displacing of populations (Kirezci et al., 2020; Marcos & Amores, 2014).

Disruption to supply chains, infrastructure and agricultural production, for example, to exacerbate existing disparities and increase the likelihood of major social collapse. The Intergovernmental Panel on Climate Change (IPCC, 2001) published a special report that highlights the financial cost of climate change (Fox & Erickson, 2020; Kiley, 2023; van den Bergh & Bozen, 2018). Moreover, wild capture fisheries, producing approximately 79.3 million metric tons of fish annually, represent a significant portion of global seafood production valued at $130 billion. Mariculture, producing over 38.6 million metric tons of seafood worth $67.4 billion annually, further highlights the immense economic stakes tied to climate change (Pinar, 2022).

Political responses to climate change also play a crucial role in shaping the discourse on existential risks. Iacobucci and Trebilcock (2022) highlight the need for effective institutional frameworks to address the multifaceted challenges posed by climate change and other existential threats, such as pandemics. They argue that without constructive roles for science and politics, the prospects for meaningful progress in mitigating these risks are bleak. This sentiment is echoed by Boyd and Wilson (2018), who categorize climate change as one of several large-scale existential risks that could threaten organized human civilization. A lack of coherent political responses, coupled with inadequate global cooperation, could exacerbate the existential threats posed by climate change, further destabilizing societies and economies.

Furthermore, the literature emphasizes the importance of interdisciplinary approaches to understanding and addressing climate change-related existential risks. Huggel et al. (2022) note that the scientific community must bridge the gap between scientific understanding and public discourse regarding existential risks associated with climate change. This is essential for informed public engagement and policy action– both are critical for mitigating the impacts of climate change. Inadequate risk communication and the failure to translate scientific insights into actionable policies can hinder the development of effective responses to these existential threats.

What becomes obvious, when looking for specific probabilities is, that (a) the effects of glacier melting on the ecosystem seem almost impossible to identify, which underlines the fact that they are difficult to calculate. However, (b) there is some literature on glacier melting and the impact on the ecosystem, which can be used to derive possible longterm consequences with regard to x-risk.

Research on climate change-related existential risks remains limited and complex. Addressing these risks requires combining quantitative methods with qualitative insights, yet precise forecasting is challenging due to uncertainties and the multifaceted nature of climate impacts. Multidisciplinary collaboration is essential to enhance models and develop effective solutions. Bostrom (2014) emphasizes the need for clear goals and evaluation methods to assess decision outcomes, likening this to strategies in chess. While human extinction from climate change is unlikely, risks such as the moist greenhouse effect, extreme biodiversity loss, and unknown mechanisms warrant serious attention. A comprehensive approach that integrates psychological, economic, and political factors with robust risk assessment tools is crucial for guiding mitigation and adaptation efforts.

4.3. Disintegration of the Greenland Ice Sheet (GIS)

There are significant implications for climate change from the breakdown of the Greenland Ice Sheet (GIS). Its melting affects oceanic and atmospheric circulation patterns, raises sea levels globally, and has complex effects on climate systems around the world. Understanding and reducing these effects is crucial because of the possibility of irreversible changes and tipping points (Armstrong et al., 2022).

The cryosphere, biosphere, and ocean-atmosphere systems are among the critical earth systems where climate tipping elements are distributed.

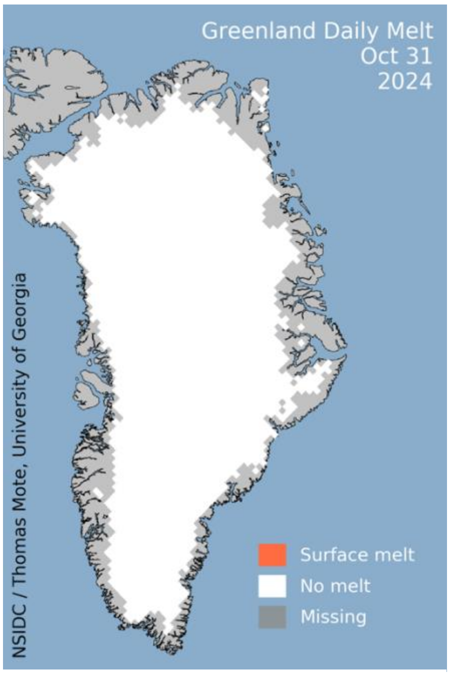

Figure 6. Greenland melt maps Oct 31 2024 (National Snow and Ice Data Center, 2024)

The Amazon rainforest, the Atlantic Meridional Overturning Circulation, and the West Antarctic and Greenland ice sheets are important areas that have these tipping elements.

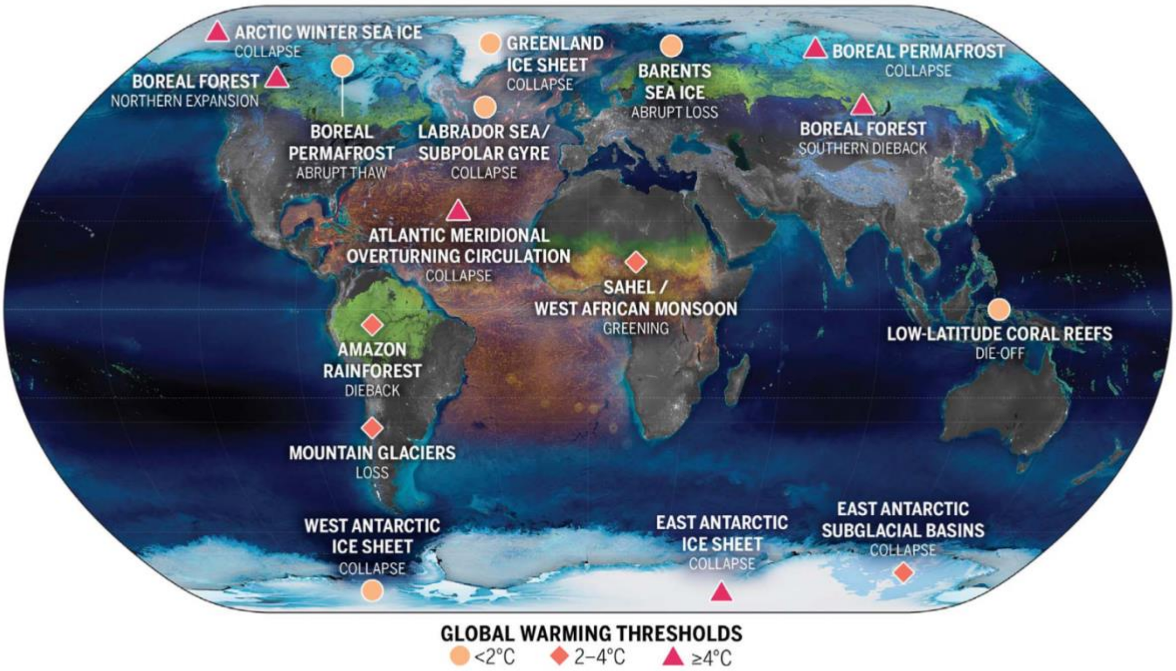

Figure 7. Locations of climate tipping elements (Armstrong et al. 2022)

These regions are particularly exposed to temperature swings, which have the potential to alter the climate irrevocably if certain thresholds are crossed. In figure seven the tipping points are highlighted for the ocean/atmosphere (orange), biosphere (green), and cryosphere (blue), as well as the levels of global warming at which these elements are most likely to tip. Understanding the temperature thresholds at which these tipping points occur is essential. If these thresholds are crossed, the earth system could undergo significant change as a result of self-replicating changes. These changes include increased carbon emissions, biodiversity loss, and significant sea level rise. Apart from exacerbating climate change, these advancements present significant risks to human well-being and affect ecosystems, economies, and societies across the globe. Thus, determining and keeping an eye on these thresholds is crucial for risk management and climate policy to be effective. With global temperatures having already increased by 1.1°C above pre-industrial levels, the world is nearing the lower end of the uncertainty range for some tipping points (Armstrong et al., 2022).

The melting of the GIS is one of the most critical contributors to contemporary sea-level rise, accounting for approximately 43% of the observed increase in recent decades (figure eight). According to estimates, the ice sheet lost roughly 3.800 gigatons of ice between 1992 and 2018. This indicates a significant increase in mass loss from the GIS over the previous few decades (Dar et al., 2024; Noël et al., 2017; Singh et al., 2023). The underlying processes, surface melting and calving of ice bergs, are predicted to speed up as global temperatures continue to rise (Anderson et al., 2023). If fully melted, the GIS could cause a global sea-level rise of approximately 7.4 meters, a catastrophic scenario for coastal regions worldwide (Keisling et al., 2022; Singh et al., 2023). Current future predictions indicate that the GIS could contribute about 30 to 60 centimeters to the global sea level by the end of the century. Assuming, this is the case, cities like New York, Miami or New Orleans or Jakarta, cities very vulnerable to sea level rises, would face probably trillions of dollars in damages (Gillet-Chaulet, 2012; Kulp & Strauss, 2019; Nicholls & Cazenave, 2010).

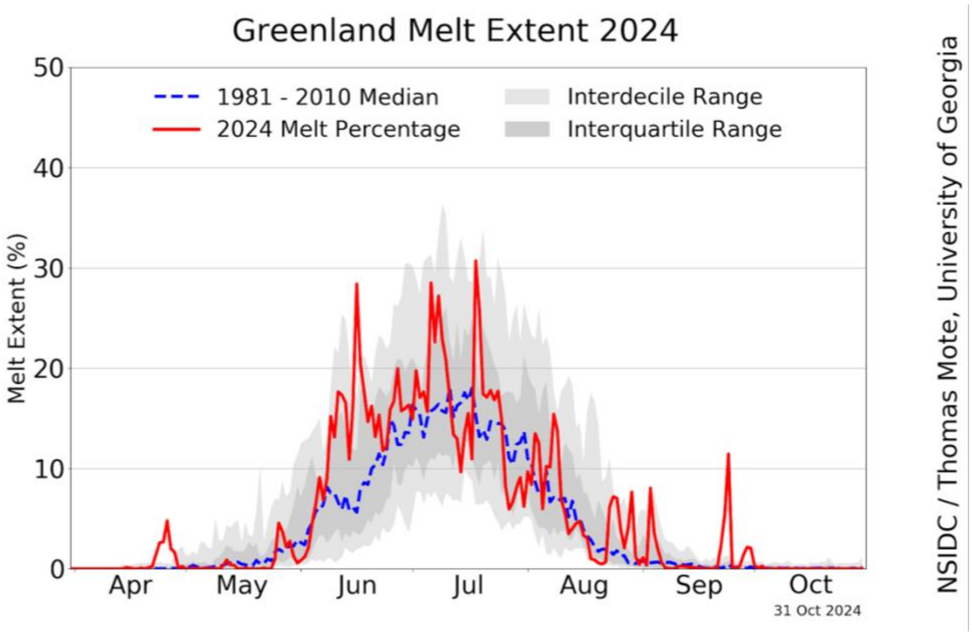

Figure 8. Greenland Melt Extent 2024 (National Snow and Ice Data Center, 2024

A very slow response time to changes is indicated by ice sheets. As a result, their melting will continue even if emissions are significantly reduced (Millan et al., 2023). In West Greenland, where precipitation lapse rates and spatial climatology increase sensitivity to warming, the ice sheet's vulnerability is particularly noticeable. The GIS has a low temperature threshold for collapse, according to historical data, with notable deglaciation taking place during previous warm periods when temperatures were only marginally warmer than they are now (Dar et al., 2024; Irvali et al., 2020).

These forecasts emphasize how urgent it is to take proactive measures to mitigate this risk.

The GIS also plays a critical role in regulating global climate systems, with its disintegration triggering far-reaching feedback mechanisms. The removal of the ice sheet alters atmospheric blocking patterns, leading to increased air temperatures and changing wind stress on oceans. This impacts ocean-mass transport through the Arctic gateways (Andernach et al., 2024; Singh et al., 2024). In particular, changes in the GIS affect deep-water formation in the Nordic and Labrador Seas, which are essential components of the global thermohaline circulation. Disruptions to this circulation could lead to cascading impacts, including altered weather patterns, regional cooling in Europe, and intensified warming in other regions. Furthermore, the supraglacial hydrological system—comprising meltwater runoff and supraglacial lakes—accelerates ice flow and increases iceberg discharge into the ocean, amplifying mass loss (Dar et al., 2024; Mostue et al., 2023; Gantayat et al., 2023).

There are significant ecological and socioeconomic implications to these physical changes. According to current assumptions, the economic impact of GIS disintegration is substantial, but it accounts for less than 5% of the social cost of carbon (Nordhaus, 2018; 2019). However, because it does not account for the longterm costs of infrastructure loss, displacement, and the economic consequences of disturbed ecosystems, this number understates the wider ramifications. Biodiversity loss in Greenland, driven by ice sheet thawing, compounds the global biodiversity crisis, with cascading effects on ecosystems that sustain human livelihoods (Dar et al., 2024; Singh et al., 2024; Ureta et al., 2022). Such destabilization poses risks to food security and heightens the potential for resource conflicts, making it's disintegration not just an environmental issue, but a civilizational threat.

This phenomenon represents a tipping point, with the potential longterm sea-level rise of up to 6.9 meters. This can occur as soon as the GIS critical points at temperature anomalies of 0.6K and 1.6K above pre-industrial levels levels (Höning, 2023; Singh et al., 2023). The likelihood of crossing these critical points is further increased by projections of enhanced surface melting and ice mass loss under high-emission scenarios (Mostue et al., 2023). This vulnerability to greenhouse gas emissions underscores the urgency of mitigation measures.

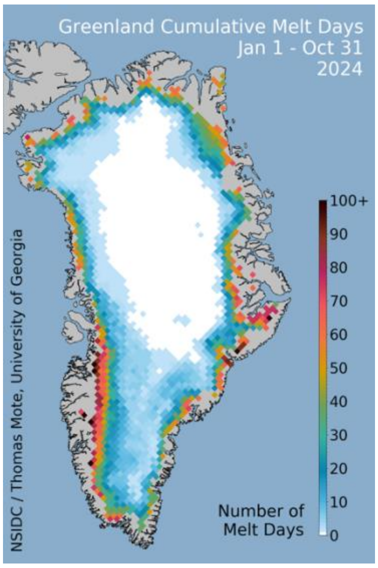

Figure 9. Greenland Cumulative Melt Days Jan 01- Oct 31 2024

The disappearing GIS serves therefore as a fitting example of the complex circumstances and incidents caused by climateand is just one of several tipping scenarios which pose threats on humanity.

This chapter showed the interconnectedness of several threats and their consequences. The necessity of swift and comprehensive climate action is highlighted by the possibility of irreversible tipping points and feedback mechanisms.

5. Method

This thesis examines which macroeconomic indicators, particular those related to existential threats like the introduced disintegration of GIS, best reflects longterm global welfare.

By examining the relationship between glacier melt and macroeconomic indicators, the aim of this research is to investigate the suitability of existing indicators to reflect those risks. As a quantifiable case for climate impacts, the melting of the GIS provides a useful perspective on the stated research question. This approach combines quantitative analysis with theoretical insights. This work is an attempt to contribute to find alternatives for measurement of longterm global welfare.

5.1. Research Design

In order to provide a possible answer to the underlying question, a mixed-methods approach is applied. Empirical data on the GIS has been combined with theoretical analysis of official reports regarding a specific selection of indicators.

The process entails three stages:

(1) Literature review: examination of welfare indicators and to what extend x-risks, sustainability and resilience are covered despite the given necessity of welfare-considerations. This also serves as a starting point for the selection of indicators to be compared.

(2) Empirical analysis: measures of basal melt rates of the GIS over time to provide information about the melting progress to derive any risks from and to show the connection to x-risks..
(3) Comparative analysis: analysis of selected indicators according to a set framework of specifics which cover global welfare and x-risks as well as correlational analysis.

5.1.1. Data Sources, Collection & Harmonization

Empirical data of GIS provided by Millan et al. (2023) focuses on basal melt and discharge rates, whereas such the former have been processed to keep the exemplary analysis as simple as possible. The data comes from regional climate models and remote sensing covers glaciers of the segments of the GIS Petermann, Ryder and Zachariae. The longterm effects of climate change, in simplified form, are to be represented by this data. With this metrics, an assessment has been conducted on how well existing welfare metrics can take the physical effects of climate change into account.

Data from several sources were used in quantitative analysis: data for the Environmental Performance Index (EPI) was provided by Wolf et al. (2022); Legatum Prosperity Index (LPI) by the Legatum Institute (2007-2023); World Happiness Report by Helliwell et al. (2024); the Gross National Happiness Index by Ura et al. (2023); Index of Sustainable Economic Welfare (ISEW) by Soupart & Bleys (2024) and the Social Progress Indicator (SPI) by the Social Progress Imperative (2024).

In preparation of the quantitative analysis, a thorough process of data preparation and harmonization has been performed to guarantee consistency and comparability. Incomplete or missing years have been excluded to close gaps in welfare indicators and linear interpolation was applied to fill in missing GIS data. Z-score normalization was performed to standardize units, allowing for trend and correlational analysis, by transforming different scales of welfare indicators and GIS melting rates into a common scale. To match the resolution of welfare indicators, initially monthly/seasonal recorded intervals of the GIS data has been transformed into annual averages to achieve temporal alignment. A single format comprising annual average melt rates and welfare scores for the years 2007-2023 was created by combining harmonized datasets.

The goal of this preparation process was the possibility to investigate possible connections between GIS disintegration and welfare indicators. To secure this, Spearman's Rank Correlation has been applied.

5.1.2. Conducted Analysis

A literature review of official reports and documents about the chosen indicators serves for a comprehensive understanding of how climate impacts could affect welfare. Those insights are gained by the combination of the literature review's results and the GIS analysis.

Based on the literature regarding global welfare, sustainability and x-risks, the following dimensions and elements, forming the standard for assessment for the indicators:

Dimensions Global Welfare	
Dimension	**Specifics/core elements**
Income	Income Distribution (Equity in wealth distribution and accessibility to economic opportunities)
Health	Health (Availability of healthcare, life expectancy, and overall health outcomes)
Education	Education (Literacy levels, quality of education, and accessibility to learning resources.)
QOL	Quality of Life (Living standards, housing conditions, and overall community well-being)
Society	Social Integration (Inclusiveness, societal cohesion, and cultural acceptance)
Economy	Economic Stability (Resilience to economic shocks, steady growth, and financial security)
Politics	Political stability and governance (Institutional strength, policy effectiveness, and trust in governance)
Well-being perception	Subjective well-being (Levels of happiness, public satisfaction, and mental health)
Environment	Environmental Indicators (Conservation of natural resources, pollution control, and ecological sustainability)
	Sustainability (Resource management, longterm planning, and environmental resilience)

Table 2 Overview of the dimensions assessed to evaluate the representation of global welfare by indicators

Dimensions for Existential Risk	
Dimension	**Specifics/core elements**
Physical and Environmental Risks	Extreme weather events (frequency, intensity and damage caused by events such as hurricanes, floods and forest fires)
	Sea-Level Rise: Impacts on coastal populations, land loss, and ecosystem disruption.

	Ecological Health: Biodiversity loss, changes in land use, and water resource depletion.
Social and Governance Factors	Governance Challenges: Adaptive capacity of institutions, effectiveness in managing resources, and societal responses.
	Public Awareness and Education: Levels of climate literacy and preparedness for climate adaptation.
	Security Perspective: The extent to which climate change is framed as a security issue influencing governance responses.
	Implementation of Climate Protection Measures
	Implementations to generate renewable energy
	Measurement of CO2-Emission
Impact Horizon	Immediate, Delayed, and Longterm Effects: Assessments over time (short, medium, longterm).
	Vulnerability Assessment: Population, economic sectors, and ecological systems' susceptibility to climate impacts.
Economic and Financial Impacts	Climate Adaptation and Mitigation Investments: Support for renewable energy, sustainable infrastructure, and climate protections.
	Economic Vulnerabilities: Measurement of economic damage, resource costs, and climate impacts
Severity and Likelihood of Climate Impacts	Scale of Impact: Metrics capturing the number of people affected (e.g., climate displacement risks).
	Likelihood: Probability of various climate events and their anticipated effects.
Interconnectedness and Feedback Loops	Feedback Loops: Potential cascading effects from changes in CO2 emissions, land use, biodiversity, etc.
Uncertainty and Knowledge Gaps	Uncertainty Factors: Consideration of unpredictability in climate projections and associated risk assessments.
Ethics and Intergenerational Equity	Longterm Considerations: Focus on future generations and sustainability of resources.
	Intergenerational Fairness: Commitment to equitable resource distribution and risk management.
Psychological, Cultural, and Ideological Dimensions	Public Beliefs and Climate Knowledge: Reflects psychological awareness and belief in climate science.
	Cultural Adaptability: Sensitivity to cultural influences in climate adaptation and mitigation strategies.

Table 3 Overview of the dimensions assessed to evaluate the representation of X-Risk by indicators.

These criteria serve as an evaluation framework, to choose suitable indicators for analysis and uses a 1-10 scoring system to assess each welfare index's performance across these dimensions. An initial number of 22 indicators[14] has been narrowed down to the selected indicators: Genuine Progress Indicator (GPI), Environmental Performance Index (EPI), Social Progress Index (SPI), Legatum Prosperity Index (LPI), Index of Sustainable Economic Welfare (ISEW), Gross National Happiness (GNH), and the World Happiness Report (WHR). These indicators capture economic,

[14] Available in the appendix

social, and environmental factors essential for understanding longterm resilience and sustainability, particularly in the context of climate-induced existential risks.

This research's correlation analysis employs Pearson and Spearman analysis to provide insights on the relationship between melting rates, EPI, LPI, SPI and WHR/GNH by using R version 4.4.1. The Shapiro-Wilk test has been performed to confirm normality of the data and the scatterplots' linear associations. This tested, the application of the Pearson correlation could be justified as the main technique. Spearman correlation has been conducted to assess robustness.

Additionally, a data validation procedure has been carried out. This included aligning variables, looking for inconsistencies and addressing outliers and errors in order to guarantee dataset accuracy and reliability. Therefore, extreme values, improper units or formats would skew the analysis.

The analysis addresses gaps that traditional measures of global welfare miss and in direct line with the thesis' focus on welfare metrics and climate risks. A multifaceted understanding of global welfare with regard to climate change and X-Risk is provided by the research.

5.1.3. Limitations

Temporal and spatial gaps, measurement uncertainties and incomplete historical records are some of the limitations of the datasets used. Time series, for instance, range in duration from 2000 to 2023 and few datasets for the glacier have few observations. Error margins vary across measurements and data quality problems, such as negative melt values of the glacier need to be handled carefully.

Despite the potential significance of x-risks, those are still hypothetical and have not been fully validated by empirical research. These risks are examined using the GIS disintegration as a case study, however, the data at hand does not allow for their complete quantification or verification.

The conducted research focused on a selection of macroeconomic indicators but important information about other indicators like the Better Life Index (BLI) or the Genuine Progress Indicator (GPI) was either inconsistent or not available. Data for the SPI was available indirectly by already processed data and in form of graphs and needed to be analyzed manually.

The research design and methods applied contribute to a general understanding of the correlation between macroeconomic indicators and glacier melt. However, causal statements are omitted. Even though dataset heterogeneity and incompatibility restrict conclusive findings, correlation analysis are utilized for illustration. The speculative nature of climate-related risks and the lack of official statistical validation are significant limitations.

There are additional complications when comparing methods used by the chosen indices. Direct comparisons have been challenging because official reports or documents for these indicators frequently employ disparate methodologies, definitions and weighing schemes. Numerous indices limit their global applicability by concentration on particular regions or time periods and outdated or inconsistent reports lessen their relevance to current developments.

Subjective weighing combined with opaque calculation procedures could lead to biases. Furthermore, some indicators objectivity may be impacted by political or economic factors, making it more difficult to incorporate them into a comprehensive framework. Results need to be interpreted cautiously, especially in lager global contexts, due to limitations relating data availability, methodological variations and lack of empirical validation.

Correlation analysis may not be effective in proving causation. It is unable to ascertain whether variations in environmental indices are a direct result of changes in glacier melt or whether the indices have an impact on glacier melt. Claims of causation may be complicated by unobserved factors, influencing these relationships. Furthermore, time lags between environmental changes and glacier melt are not taken into consideration in the conducted analysis, which means that delayed effects might not be recorded.

The analysis is limited by the time period and sample size, which might not accurately represent longterm trends. This restriction might lower statistical power, which would make it more challenging t o identify nuances in relationships or to extrapolate results. Another limitation emerges due to the fact that longterm data aggregates can mask short-term patterns, especially in dynamic settings like the GIS. The analysis may be further limited by the failure to fully capture regional variations and local vulnerabilities.

Oversimplified modeling techniques may underestimate or overestimate related risks by ignoring non-linear feedback effects in climate systems. The ability to generalize may be limited by analyses with low spatial resolution, which may overlook differences in socioeconomic conditions and climate impacts.

Alternative viewpoints may be excluded due to selection bias caused by the small number of macroeconomic indicators. Additionally, confounding variables or assumptions may be ignored in favor of interpreting the data in a way the confirms applied theories. The narrow focus on climate threats may ignore social or economic backgrounds and the historical focus may not account for current or future conditions.

A last important limitation is the comparison of two types of data. The GIS serves more as an inventory or kind of stock, whose value is determined over many years and depleted or increased over time. The analyzed indicators are flowing variables and change over time due to measured circumstanced. They represent the measurement of a state, but no inherent value compared to GIS.

6. Results

In this section the results of the analysis of the GIS basal melt rates from 2006 to 2020 are presented along with descriptive statistics. Several macroeconomic indices are presented and the assessment on how well they can represent longterm global welfare under climate change related x-risks. Theoretical foundations, real-world application and methodological approaches are examined.

The selected indicators are analyzed regarding their characteristics, advantages and disadvantages and their applicability in capturing the interrelated aspects regarding the underlying research objective.

Basal melt rates, as a key indicator regarding the maintenance and stabilization of ice sheets as well as their role in the rise of sea levels, have been investigated.

The results are arranged in the following manner: the chosen indicators are first presented and assessed according to how much emphasis they place on sustainability resilience and welfare aspects. Second, an analysis is conducted on how well they represent x-risks. Third, basal melt data's statistics are presented and contrasted with the indicator data. To conclude, suggestions regarding combination or improvement of given indicators are provided.

6.1. Introduction of the Selected Indicators & Evaluation of Sustainability And Resilience Dimensions

6.1.1. Genuine Progress Indicator (GPI)

An alternative to conventional economic measures like GDP, the GPI is intended to evaluate sustainability and societal well-being. The GPI was first introduced in the early

1990s and considers social, environmental and economic factors. By emphasizing welfare above economic output, it provides a more comprehensive view of progress.

The metric can be expressed as:

GPI = PCE + VNMA + PG - EC - SC - DE - IIA

***PCE** (Personal Consumption Expenditures):*	*The starting point representing household consumption.*
***VNMA** (Value of Non-Market Activities):*	*Includes unpaid labor like caregiving, household work, and volunteer efforts.*
***PG** (Public Goods Value):*	*Benefits from essential public services, such as education and healthcare.*
***EC** (Environmental Costs):*	*Subtractions for damages like pollution, deforestation, and biodiversity loss.*
***SC** (Social Costs):*	*Includes costs from crime, family breakdown, underemployment, and other societal disruptions.*
***DE** (Defensive Expenditures):*	*Spending that compensates for harms (e.g., healthcare costs due to pollution).*
***IIA** (Income Inequality Adjustment):*	*Adjusts PCE based on the distribution of income; higher inequality reduces the GPI.*

Costs as well benefits of economic activity are considered by the GPI. For instance, it subtracts expenses of illnesses brought on by pollution and accounts for beneficial contribution like volunteerism, unpaid domestic labor and fair income distribution aspects. Those are aspects which are overlooked by GDP. Deforestation, biodiversity loss and resource depletion are examples of ecological degradation that is taken into account, which highlights the trade-offs between immediate financial gain and longterm sustainability.

Even though it offers a more comprehensive picture of development, the GPI has drawbacks, such as methodological complexity, trouble putting monetary values on non-market activities and inconsistent measurement. It does not fully address resilience to global challenges like climate change, nor does it adequately capture multifaceted aspects of welfare like governance, education and health.

The GPI has been developed over time through methodological revisions and larger datasets, making it a useful instrument for assessing how policies affect well-being, particularly in situations where economic growth is not always correlated with higher standards of living. A more thorough evaluation of progress across economic, social and environmental dimensions might be possible with its integration with indicators like the EPI or the Human Development Index (HDI).

Resilience

The GPI offers an assessment of economic progress by including environmental and social costs, providing a broader perspective than traditional metrics like GDP. It adjusts for the negative impacts of economic activities, such as pollution and resource depletion, to account for the true cost to the environment. By integrating the effects of climate change, including extreme weather events and sea level rise, the GPI reflects the longterm environmental impacts of economic growth. It also considers climate protection measures, such as renewable energy adoption and emissions reductions, to capture efforts in mitigating climate-related risks.

By accounting for the delayed effects of climate shocks and assessing the sustainability of resource use, the GPI evaluates both immediate and longterm environmental impacts. It deducts expenses related to non-welfare-enhancing activities like pollution and resource depletion and monetizes environmental services like the advantages of renewable energy projects. The GPI's emphasis on intergenerational fairness highlights the significance of safeguarding future well-being and making sure that current economic activity does not jeopardize longterm prospects.

Despite its strengths, the GPI faces challenges in fully capturing the scope of climate change impacts and ensuring methodological accuracy. Issues such as potential double-counting and limitations in data selection highlight areas for improvement. Its sensitivity to environmental costs and the depletion of non-renewable resources suggests the need for refined methodologies to balance these factors effectively. Additionally, incorporating resilience metrics in key sectors like agriculture and supply chains could enhance the GPI's ability to measure economic sustainability comprehensively.

When it comes to gauging economic welfare, the GPI offers a more inclusive and sustainable method than conventional metrics. Expanding resilience metrics, improving data governance, and improving methodology would all help it better capture the intricate, longterm effects of climate change. With these improvements, the GPI may become a more useful instrument for well-informed policymaking that promotes resilience and sustainability for coming generations.

Specific global GPI data wasn’t available to include this indicator in the statistical analysis but evolved as one of the indicators with the highest value on the score card (overall: 119 points; welfare 71 points, x-risk 132 points) and has therefore been included in the theoretical analysis. Its score regarding welfare is 53, with the highest score regarding consideration of income, health and environment (10 points each). The GPI scores high regarding x-risks as well with a value of 132 points.

6.1.2. Social Progress Indicator (SPI)

SPI, which does not include economic indicators, gauges the well-being of society by concentrating only on social and environmental aspects. This method, which is organized around the three pillars of opportunity, foundations of wellbeing, and basic human needs, enables an impartial assessment of social outcomes. Personal rights, access to clean water and sanitation, and environmental quality are just a few of the 57 indicators and 12 components that make up these dimensions. For comparability, indicators are normalized to a scale from 0 to 100. Scores are then averaged within dimensions and added together to create a weighted overall score.

Figure 10. Pillars and their specifics considered for SPI calculation. Stern et al. (2024)

The SPI evaluates observable advancements in fields like environmental sustainability, education, and health by placing more emphasis on results than inputs. For instance, Foundations of Wellbeing emphasizes environmental quality and knowledge access, while Basic Human Needs covers necessities like food and shelter. Despite using metrics like clean water and sanitation to measure sustainability, the SPI does not specifically take into consideration more significant ecological issues like resource depletion or climate change.

The open framework of the SPI makes it possible to pinpoint particular areas that require improvement and provides policymakers with useful information. It is a useful tool for monitoring advancements in sustainability and equity because of its alignment with international goals such as the Sustainable Development Goals (SDGs) of the UN.

The assessment using the score chart resulted in a value of 187 overall (fourth rank). This means the combined score for welfare and X-Risk aspects.
The highest scores are met for Quality of Life (QOL), society, environmental indicators. Whereas the weakes aspects are health, implementation of climate protection measures, implementations for renewable energy and cultural adaptability.

By emphasizing on social and environmental results, the SPI also assesses how well climate protection policies are being implemented (Stern et al., 2024, p. 4ff). It monitors conservation of natural resources, pollution control and ecological sustainability. For example, metrics on air and water quality, biodiversity conservation as well as management of waste an pollution (*ibid*,, p. 21ff). These metrics aid in evaluating how well nations are implementing policies to mitigate climate risks and advance environmental sustainability. The index does not consider various impact horizons, but the underlying methodology considers those aspects through time-series and annual updates (*ibid*,, p. 17). Understanding how present environmental factors and policies will affect sustainability and resilience in the future is made possible by this method. Considered are resource management, longterm planning, environmental resilience. This is important due to future challenges, especially climate change. A framework for assessing how different climate events might impact social well-being and assisting policymakers in establishing priorities to reduce possible risks is also provided by the SPI, which also takes into account the likelihood of various climate events and their anticipated effects. Environmental resilience is considered through indicators which measure the capacity of communities and ecosystems to withstand and recover from environmental shocks (*ibid*,, p. 24). Intergenerational fairness is an important aspect of the SPI, with a focus on creating conditions that enable all individuals to reach their full potential while ensuring that future generations have access to the same resources and opportunities (*ibid*,, p. 27ff). The index incorporates indicators related to outdoor air pollution, lead exposure as well as education, therefore contributing to the maintenance of sustainability for future generations. By emphasizing the longterm health of ecosystems and social systems, the SPI aligns with sustainable development goals that advocate for equity and fairness across generations

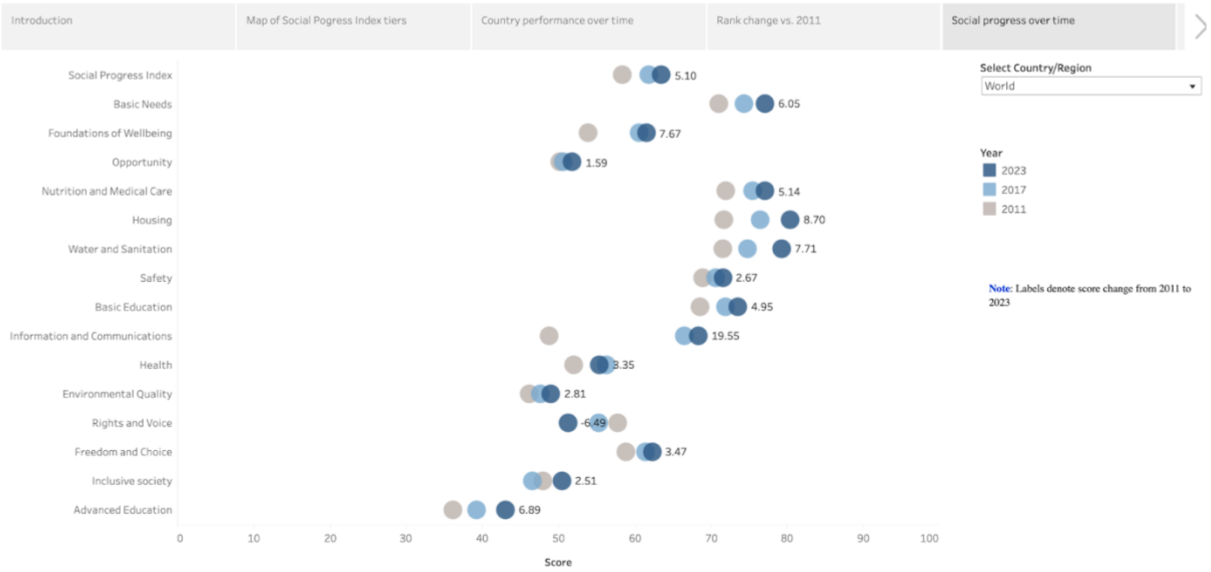

Figure 11 Development of specific aspects over time (2011-2023). Social Progress Imperative (2023

In figure 11 the progress of the specific aspects between 2011 and 2023 are visualized. This visualization has been provided on the homepage of the Social Progress Imperative. No datasets or raw data have been available. It is obvious that especially the areas of advanced education, information and communication, water and sanitation, housing and basic needs show strong improvements globally over time. The SPI in total shows an improvement of about 5.1 points over 12 years.

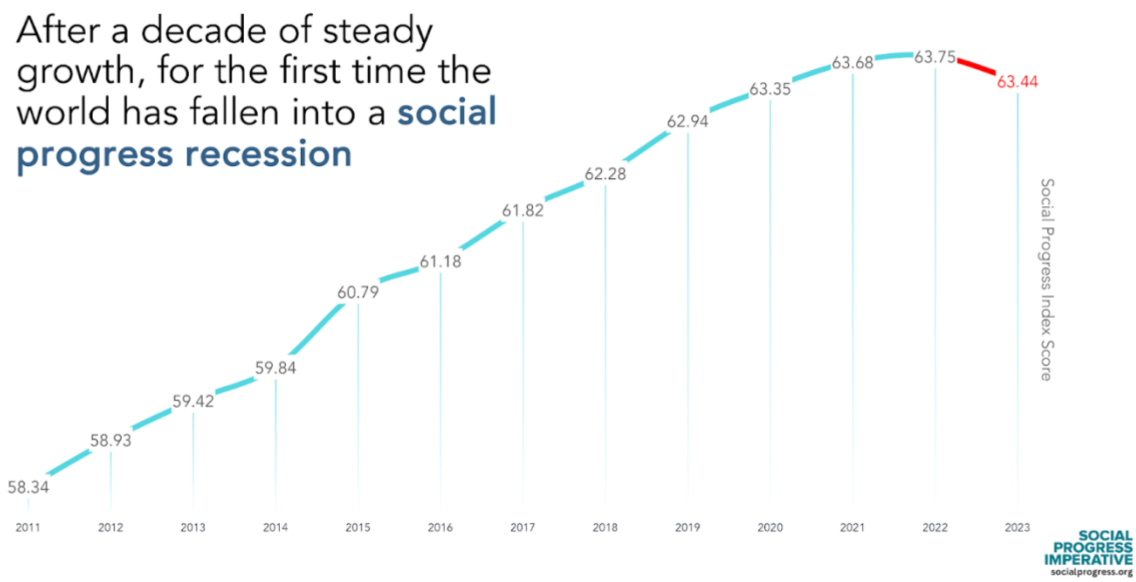

Figure 12. Development of the SPI over time. Social Progress Imperative (2023)

A statistical examination of SPI data from 2011 to 2023 shows a recent decline after years of consistent growth (figure 12). With an average annual increase of 0.54 points, the SPI peaked in 2021 at 63.75 after starting at 58.34 in 2011. With an average yearly decline of -0.31 points since 2021, it fell to 63.44 by 2023, the first decline ever noted. With total growth of 5.1 points over 12 years, this "social progress recession" highlights new difficulties in maintaining progress. Sustainability aspects are shown under the pillar of “Foundations of Wellbeing” and include air pollution, species protection, particulate matter pollution, lead exposure and recycling.

On the score card the SPI got 113 points overall (fourth rank); 112 points regarding X-Risk and 57 points regarding welfare.

Overall, the SPI offers a multifaceted evaluation of societal well-being that prioritizes social and environmental consequences over financial indicators. Its all-encompassing strategy encourages the creation of sustainable policies that enhance equity, environmental health, and social welfare.

Resilience

The SPI focuses on social and environmental indicators related to well-being and quality of life, offering a broad perspective on social progress. While it does not directly assess resilience to climate shocks, the SPI includes environmental factors such as access to clean water, sanitation, and environmental quality, which can indirectly reflect resilience to climate events like extreme weather and sea-level rise. These indicators provide insights into how well countries are prepared for climate-related challenges and their ability to adapt to changing conditions.

Emphasis on resilience is shown by measuring social and environmental performance without relying on economic indicators. This approach allows for a direct assessment of resilience through aspects like social stability and environmental sustainability. The SPI's comprehensive framework benchmarks social and economic performance, highlighting areas of strength and improvement that are critical to a country's resilience. By assessing how effectively countries convert economic progress into social outcomes, the SPI reflects resilience dimensions, indicating that nations adept at translating economic gains into social benefits are better equipped to handle challenges. With its 12 components and 57 indicators, the SPI covers a wide range of social and environmental factors, likely including key elements of resilience such as health, education, and environmental quality.

6.1.3. Legatum Prosperity Index (LPI)

The LPI is a comprehensive framework for measuring national prosperity, incorporating 12 pillars and 67 elements that assess economic, social, and governance factors. Unlike traditional metrics the LPI provides a multidimensional perspective, including income distribution, environmental quality, and social inclusivity.

Overall the LPI scores with 194 points (third rank), It highest scores were achieved in the areas of political stability and governance, public awareness and education, social integration, QOL, environmental indicators and sustainability.

Sustainability is reflected in the LPI through environmental quality indicators that examine air quality, biodiversity, and ecosystem health, linking natural resource management to longterm well-being (Legatum Institute Foundation, 2023, p. 8, 22). Health and education are key components, emphasizing their roles in building human capital and sustainable communities (*ibid*., p. 16). Those are relevant drivers to ensure knowledge and innovation in addressing sustainability challenges, which is benefitial to the nations prosperity. There is emphasis on economic performance when covering environmental, social, and governance aspects. Measured aspects are open markets and trade, macroeconmic environment and it's stability, regulatory environment, investment environment and the impact of the global economy (Legatum Institute Foundation, 2023, p. 7ff). The economic dimension focuses on fostering inclusive and responsible growth, driven by innovation and entrepreneurship. Governance evaluates political stability, regulatory quality, and the rule of law, essential for equitable and sustainable policy implementation

Social capital and personal freedom are emphasizing trust, community cohesion, and individual participation in societal development. These dimensions promote cooperation, effective governance, and inclusivity (*ibid*., p. 87, 92). Metrics related to health and education, like life expectancy and educational quality, highlight the importance of human capital in creating resilient and creative societies (*ibid*., p. 92).

Addressing global issues like inequality and climate change requires these elements. Additionally, the LPI supports global initiatives such as the Sustainable Development Goals (SDGs) of the United Nations, providing policymakers with useful information to align national strategies with international goals.

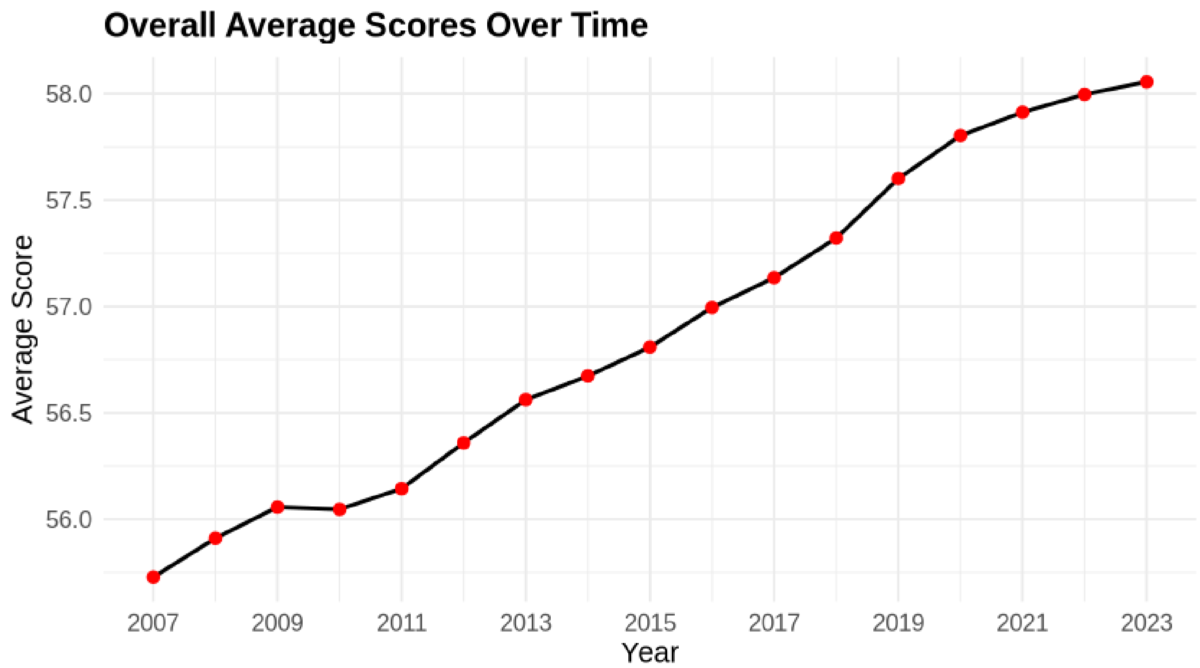

Figure 13 Development of the LPI between 2007-2023. Legatum Prosperity Initiative (2007-2023)

An analysis of LPI scores reveals a mean of 56.89 and a median of 56.81 (figure 13), indicating consistent trends with low variability (standard deviation: 0.79) and a narrow range (55.73 to 58).

This indicator offers a thorough grasp of how investments in environmental quality, health, and education support sustainable development by examining trends over time. Its all-encompassing strategy supports the notion that achieving prosperity involves more than just economic expansion; it also entails maintaining environmental stewardship, societal resilience, and general well-being. Because of this, the LPI is an essential instrument for directing policy choices that support sustainability and longterm success.

Resilience

Countries' prosperity is measured by the LPI in a number of ways, such as economic performance, governance, and environmental sustainability. Although it does not solely concentrate on climate resilience, it does capture aspects that demonstrate a nation's capacity to adopt climate protection policies, foster intergenerational equity, and adapt to climate shocks.

The LPI considers resilience by examining how countries withstand and adapt to economic and political shocks. It identifies pathways from poverty to prosperity, emphasizing resilience as key to maintaining and improving prosperity levels during challenging times. Indicators like GDP growth, employment rates, and fiscal health are measured. Nations with strong economic resilience are better equipped to support their populations in crises, boosting overall prosperity. The LPI highlights the value of diversified economies to cushion against sector-specific downturns and external shocks (*ibid*., p. 17ff). These elements aid in determining how ready a nation is for climate-related hazards like sea level rise and extreme weather. The index also assesses security and safety, which are also susceptible to climate shocks, providing an additional indirect indicator of resilience.

Recognizing the links between ecological health and human well-being, the LPI also takes environmental resilience into account. The index assesses environmental sustainability indicators like conservation efforts, pollution prevention, and resource management. Prioritizing environmental resilience puts a nation in a better position to handle the effects of natural disasters and climate change, which can have a big impact on social and economic stability. Countries can strengthen their resilience and guarantee the welfare of future generations by encouraging sustainable practices and safeguarding natural resources (*ibid*., p. 13, p. 21).

Through its evaluation of social networks, community involvement, and citizen trust, the LPI views social capital as essential to resilience. Through resource sharing and mutual support, communities with high social capital are better equipped to recover and adapt during emergencies. A society's capacity to react to and bounce back from unfavorable events is improved by strong social bonds and civic involvement (p. 68).

Resilience depends heavily on governance, and the LPI assesses how well institutions manage resources and handle difficulties. Implementing resilience-promoting policies, like social safety nets, environmental protection measures, and disaster preparedness, requires strong governance frameworks. In order to make sure that institutions can effectively respond to crises and support the well-being of their populations, the LPI evaluates indicators pertaining to political stability, rule of law, and government effectiveness. Nations with robust governance frameworks are better able to handle difficulties and promote sustained prosperity (*ibid*., p. 68).

With 16 years of data, it provides insights into whether resilience has strengthened or weakened over time, offering a longterm perspective on prosperity trends. By capturing a holistic view of prosperity, including social and environmental factors, the Index ensures resilience is assessed across multiple dimensions. Additionally, it facilitates comparative analysis, helping countries identify areas for resilience improvement relative to others.

6.1.4. Environmental Performance Index (EPI)

As data-driven tool for evaluating and ranking nations based on ecosystem vitality and environmental health, the EPI offers a thorough assessment of sustainability practices. The EPI was created by Yale University, Columbia University, the World Economic Forum, and the EU's Joint Research Centre. It employs more than 40 performance indicators in 11 categories, such as biodiversity, climate change, agriculture, forestry, fisheries, sustainable energy, air and water quality, and agriculture. These metrics are combined into two primary dimensions: Ecosystem Vitality (60%) and Environmental Health (40%) after being normalized using proximity-to-target techniques. A weighted combination of these dimensions is reflected in the final score, which ranges from 0 to 100.

The EPI scores on the score-chart overall with 197 points (2nd rank) and shows strong emphasis regarding society, environmental indicators and sustainability as well as, ecological health, governance, climate protection measures, CO2-emission measures, impact horizon, feedback loops and intergenerational fairness.

Environmental indicators are the core of the EPI. These indicators include metrics regarding air and water quality, biodiversity and the management of natural resources (Wolf et al., 2022, p. 8, IX). Countries are assessed regarding their performance in terms of pollution, conservation of ecosystems and sustainable practices (*ibid.*, p. VIII, IX). In this context, measurement of CO-emissions are assessed as well, as they are primary driver of climate change. Effectiveness of policies regarding transitioning to low-carbon economies and promotion of sustainable transportation options are assessed (p. II, IX, 34). Therefore, feedback loops are essential for the EPI and evaluates how changes in one area, e.g., biodiversity loss or pollution, can impact other areas.

Regarding possible impact horizons both short- and longterm outcomes are considered (*ibid.*, p. VIII, IX).

On the societal level lies emphasis on intergenerational fairness and the evaluation of policies that promote sustainable resource management to ensure that natural resources are available for future use (*ibid.*, p. 40).

Governance plays a critical role in the EPI. This due to the imprtance of implementation and enforcement of environmental policies. Therefore transparency, accountability and public participation are assessed (*ibid.*, p. 8, IX).

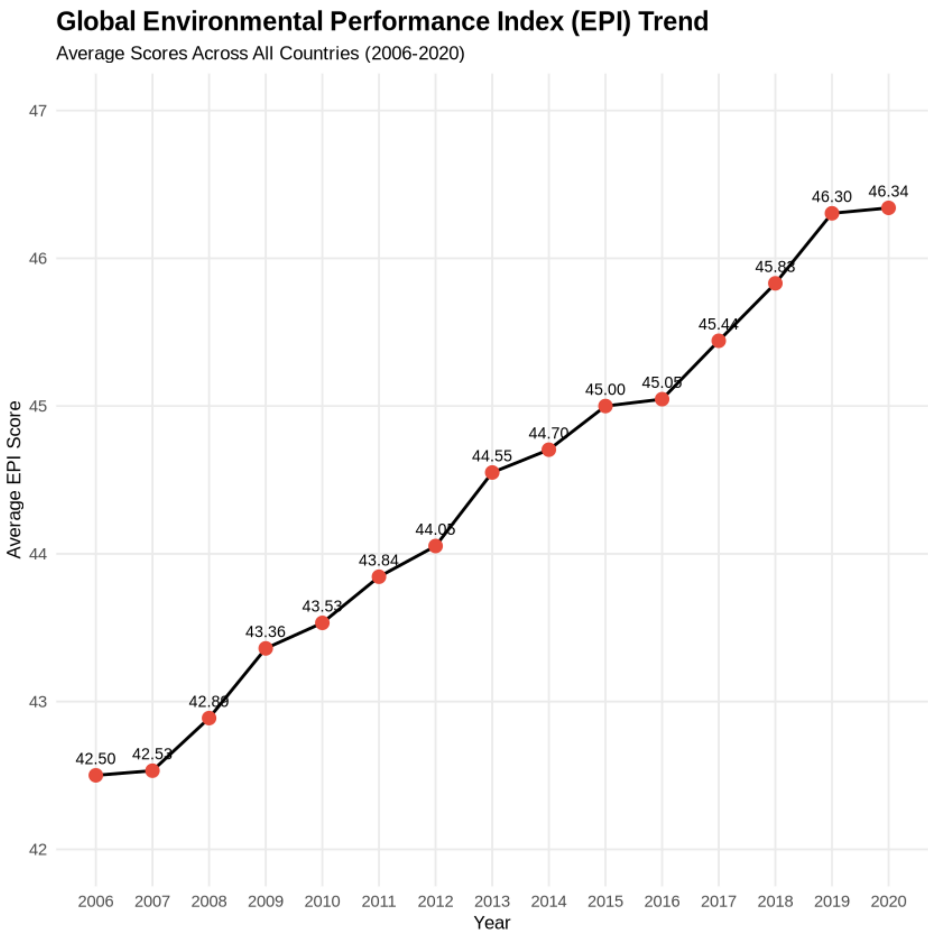

Figure 14. Development of the global EPI between 2006-2020

A balanced distribution is indicated by descriptive statistics, which show a global mean EPI score of 44.40 with a median of 44.55. A 1.28 standard deviation indicates a moderate level of variation across nations. With an overall improvement of 3.84 points between 2006 and 2020—or an average annual growth of 0.62%—scores range from 42.50 to 46.34 (figure 14). Between 2008 and 2009, there was the greatest improvement (1.10%), and between 2006 and 2007, there was the least improvement (0.07%). These results point to a slow improvement in environmental sustainability worldwide.

It’s strengths are societal aspects as well as environmental indicators and sustainability aspects. It scores high with regard to ecological health, governance challenges, implementation of climate protection as well as measurement of CO2-emissions and impact horizon, feedback loops and longterm considerations.

Resilience

The EPI is a composite measure designed to assess and rank countries based on their environmental performance, including factors related to climate change, sustainability, and resilience. It features indicators such as carbon dioxide and greenhouse gas emissions per capita, renewable energy adoption, emissions reduction, and natural resource management (*ibid.*, p. 2). These indicators reflect efforts to mitigate climate-related risks and maintain environmental quality. Although the EPI does not directly assess the likelihood of specific climate events, it evaluates a country's preparedness and response to environmental challenges, considering both short-term and longterm impacts. These indicators shed light on how resilient ecosystems and human health are to climate-related disasters. The EPI tracks how well nations are reducing emissions and embracing renewable energy sources, among other climate protection measures, to show how well they are adapting to the effects of climate change (*ibid.*, p. 2).

The EPI struggles to adequately capture the intricate relationships between climate change, sustainability, and resilience, despite its advantages. The accuracy and coverage of available data can vary among nations, which can impact the index's dependability. For instance, it is acknowledged that there is a dearth of thorough data regarding how well green infrastructure may increase resilience in the face of future climate scenarios. Furthermore, it has been argued that the EPI's weighting methodology introduces potential biases, as variations in country rankings result from the sensitivity of weight assignments.

Proposals to improve the EPI include adopting a more data-driven, objective framework, such as using unsupervised learning and Self-Organized Maps to assess environmental sustainability. This would allow countries to identify specific areas for improvement without relying on rankings or data transformations. Incorporating green technology innovations into environmental performance assessments could provide a more comprehensive view of sustainability efforts. Furthermore, adding more explicit resilience metrics, such as evaluating the adaptive capacity of infrastructure and agricultural systems to climate change, could improve the index's ability to measure resilience.

The EPI includes intergenerational fairness through its focus on longterm sustainability, resource management, and environmental health. By evaluating factors like biodiversity conservation and pollution control, the index highlights the importance of ensuring that future generations can meet their own needs. It also supports the achievement of the SDGs by promoting policies that foster equity and sustainability across generations.

6.1.5. Gross National Happiness (GNH)/World Happiness Report

The WHR and GNH take complementary approaches to sustainability. GNH, created in Bhutan, integrates economic, social, environmental and cultural aspects to provide a comprehensive perspective on well-being. The framework is built by good governance, environmental preservation, cultural preservation and sustainable and equitable socioeconomic development.

GNH and WHR have been chosen as substitutes to the higher ranked Better Life Index (185 points) due to data availability. GNH scores with 172 points overall, WHR with 150 points. In this case, both indicators have been considered as the GNH score is higher but restricted to just one location, Bhutan. The WHR is conducted globally. However, both indicators have very similar objectives and priorities.

Both indicators show a high score regarding subjective well-being and overall stronger emphasis on all welfare aspects on the score chart. GNH as well as WHR score relatively low regarding X-Risk-consideration. However, the GNH shows more emphasis on environmental indicators and sustainability than the WHR. Their score regarding X-Risks is nearly the same with GNH 99 and WHR 92. No specific numbers for the GNH have been available. Therefore the WHR has been examined.

The World Happiness Report, which uses survey data to assess happiness, public satisfaction, and mental health, places a strong emphasis on subjective well-being. The study measures how people view their lives using metrics like life evaluations, positive and negative affect, and social support (Helliwell et al., 2024, p. 12). The reported happiness scores, which represent the psychological and emotional aspects of well-being, are obtained from answers to questions concerning life satisfaction and emotional experiences.

Since the World Happiness Report recognizes the vital role that environmental quality plays in general well-being, environmental indicators are also taken into account. Evaluations of ecological sustainability, pollution prevention, and natural resource conservation are all included in the WHR as elements that affect happiness. For example, the study looks at how environmental factors, like the quality of the air and water, affect people's health and, in turn, their level of happiness. According to the research, nations with improved pollution control and environmental management typically have happier citizens (*ibid.,* p. 118ff).

Sustainability is a major theme in the World Happiness Report, which assesses the role that longterm planning and resource management play in happiness. The necessity of sustainable development strategies that strike a balance between environmental stewardship and economic growth is emphasized in the report. It emphasizes that nations that place a higher priority on sustainability—through efficient resource management, renewable energy projects, and laws meant to lower carbon emissions—generally have happier citizens (*ibid.,* p. 95, 108ff).

The WHR examines the connection between environmental sustainability and happiness, especially in light of climate change, and emphasizes the influence of

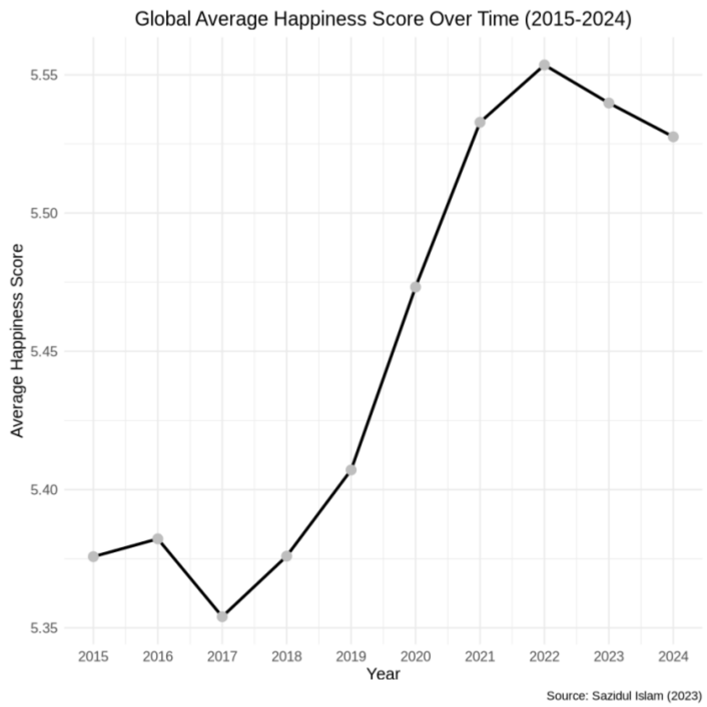

Figure 15 Global Average Happiness Score (2015-2024)

environmental quality both physical and mental health. It aims to show how happiness and social cohesiveness are weakened by environmental degradation and promoted laws that balance sustainability and human well-being. he WHR measures happiness using the Cantril ladder, where individuals rate their current life on a scale from 0 (worst possible life) to 10 (best possible life). Measured are aspects like life expectancy, social support and freedom, to rank nations according to subjective wellbeing.

The descriptive statistics reveal a stable and consistent trend in global happiness scores from 2015 to 2024, with an average score (μ) of 5.4522 and a median (Md) of 5.4402, suggesting a nearly symmetric distribution. The standard deviation (σ) of 0.0808 indicates minimal variability, with approximately 95% of scores falling within ±0.16 of the mean. The range spans a narrow 0.1996 points, with the lowest score recorded in 2017 (5.354) and the highest in 2020 (5.5536). Skewness (0.0895) and kurtosis (1.2382) confirm an almost symmetric, slightly platykurtic distribution, reflecting a uniform spread without significant outliers. Temporal analysis highlights year-over-year fluctuations, including a slight decline from 2016 to 2017 (−0.0282) and a marked recovery and growth from 2017 onwards, peaking with the largest increase in 2019-2020 (+0.0661) – shown in figure 14. The high consistency of scores, with a coefficient of variation of just 1.48%, and the overall upward trend underscore gradual improvements in global well-being measures despite occasional setbacks.

Resilience

Though in different ways, resilience is discussed as a critical component of happiness and well-being in both the World Happiness Report (WHR) and the Gross National Happiness (GNH) Index.

Through social support, mental health, and societal reactions to adversity, the WHR indirectly takes resilience into account while concentrating on subjective well-being. It implies that resilient communities improve well-being by highlighting the positive correlations between strong social ties and successful crisis management and increased happiness levels.

By focusing on sustainable development, environmental conservation, cultural preservation, and good governance, the GNH Index, on the other hand, specifically incorporates resilience into its framework. In order to increase community resilience, these pillars seek to establish strong economies, safeguard ecological health, fortify social ties, and guarantee efficient governance.

Both strategies emphasize how important resilience is to foster societal happiness and general well-being.

6.1.6. Index of Sustainable Economic Welfare (ISEW)

Compared to more conventional metrics like GDP, the ISEW offers a more comprehensive assessment of well-being by combining social and environmental factors. The ISEW, which was created in the 1980s by Herman Daly and John Cobb, addresses GDP's incapacity to account for negative externalities like pollution, resource depletion, and the loss of natural capital.

The ISEW scores with 181 points on the score-chart (7th rank). It's strongest scores are regarding sustainability, income and health.

The calculation of the ISEW is accounted as follows:

ISEW = *personal consumption* + *public non-defensive expenditures* - *private defensive expenditures* + *capital formation* + *services from domestic labour* - *costs of environmental degradation* - *depreciation of natural capital*

By taking into account environmental costs like pollution, climate change, and ecosystem degradation, the ISEW highlights sustainability (Schepelmann et al., 2010, p.24, 59). It also takes into consideration social factors that are crucial to the well-being of society but are frequently disregarded by traditional economic measures, such as income inequality and unpaid labor (Schepelmann et al., 2010, p. 59). Furthermore, the index accounts for social costs such as pollution control costs and health effects, guaranteeing a more accurate evaluation of the actual welfare contributions of economic activity (Schepelmann et al., 2010, p. 59). While excluding spending that does not directly improve well-being, the index gives priority to spending that improves welfare, such as investments in health and education. The ISEW's methodology has changed over time, incorporating elements from related indices such as the GPI, which allows it to be used in a variety of settings and nations.

The ISEW reveals enduring disparities in the distribution of welfare while capturing steady growth. Through the integration of social, environmental, and economic factors, it provides policymakers with a comprehensive understanding of sustainable welfare. In order to address environmental degradation and social inequality for the benefit of present and future generations, the ISEW emphasizes the significance of striking a balance between economic growth, sustainability, and equity.

Resilience

The ISEW reflects resilience to climate shocks by adjusting for environmental degradation, such as pollution, resource depletion, and carbon emissions. These adjustments indirectly capture the economic costs of climate impacts, such as extreme weather events and sea-level rise. The index considers both immediate costs, like pollution control, and longterm costs, such as the effects of climate change, ensuring it reflects the sustainability of economic welfare over time. However, while the ISEW accounts for some climate-related risks, it lacks a comprehensive framework for evaluating climate change risks and responses. By analyzing environmental practices and policies, such as emissions reductions and sustainable resource management, the ISEW also evaluates climate protection measures. The effectiveness of climate protection initiatives is indirectly captured by its adjustments for emissions and environmental degradation, even though it does not measure the adoption of renewable energy directly. This aids in comprehending how proactive actions support longterm resilience against risks associated with climate change.

The ISEW anticipates the potential impacts of climate events, aiding in the development of strategies to mitigate these effects. However, there is a need for the ISEW to incorporate more granular data on regional vulnerabilities and adaptive capacities, as demonstrated in studies on economic resilience to extreme weather events.

A key component of the ISEW is intergenerational justice, which emphasizes the sustainability of economic practices and the preservation of natural capital for future generations. Strong sustainability is promoted by the index, which guarantees that environmental resources will be accessible to future generations. The ISEW broadens its scope by taking into account longterm environmental and social well-being in addition to immediate financial gains. Although it has been criticized for lacking standardized methods for valuing these costs, the ISEW is a crucial tool for valuing longterm environmental damage, including the costs of resource depletion and climate change.

The selected indices incorporate climate change resilience through various approaches. The EPI directly assesses climate resilience by evaluating emissions, renewable energy adoption, and pollution control. The GNH and WHR focus on subjective well-being, with GNH emphasizing environmental sustainability as a core pillar. The ISEW adjusts economic indicators for environmental degradation and longterm climate costs, though it could benefit from more direct climate adaptation measures. The LPI and SPI reflect resilience through social stability, governance, and access to services, highlighting the importance of strong social networks. GNH also focuses on environmental conservation, balancing growth with sustainability, though challenges remain in fully integrating climate resilience.

Overall, while the EPI provides a direct assessment, indices like the ISEW, GNH, WHR, LPI, and SPI address resilience through broader social, economic, and environmental factors, emphasizing the integration of climate measures into national policies for longterm well-being.

6.1.7. Challenge X-Risk: the difficulty of quantification and implementation

Addressing x- risks from climate change is a multifaceted challenge involving philosophical, scientific, and institutional dimensions. These risks are often poorly defined and insufficiently understood, complicating their assessment and management. The interaction between natural and human systems, coupled with deep uncertainties about climate change, heightens the difficulty of identifying and evaluating threats to humanity's survival or essential needs.

While climate science can track gradual changes like rising temperatures and sea levels, extreme scenarios with catastrophic outcomes remain speculative and hard to predict. Institutional responses are further constrained by frameworks that overlook the systemic, longterm nature of these risks and lack interdisciplinary collaboration. Current economic models and policies often fail to address these complex challenges effectively.

6.2. Assessment: Indicator’s Ability to reflect X-Risks

6.2.1. Genuine Progress Indicator (GPI)

Tthe GPI considers the longterm consequences of environmental degradation and social inequalities. This aaporach accounts for the economic impacts of pollution, resource depletion, and other factors that threaten longterm sustainability.

By including environmental indicators like the costs of climate-related disasters and emphasizing sustainable practices, the GPI demonstrates its capacity to address the risks associated with climate change. By deducting the expenses of environmental harm from economic expansion, the GPI draws attention to the unsustainable elements of economic activity that may exacerbate existential threats. In order to evaluate a society's resilience to the effects of climate change, the GPI also incorporates climate protection metrics like emissions reductions and the use of renewable energy.

The GPI emphasizes social well-being, linking it to resilience against climate risks. By including indicators related to health, education, and social equity, the GPI underscores the importance of strong social networks and resources in helping communities adapt to climate impacts. Economic resilience is a critical component of the GPI, which evaluates the sustainability of economic practices and their ability to withstand shocks, including those related to climate change. The GPI promotes sustainable resource management and economic diversification to enhance resilience.

Additionally, the GPI advocates for longterm planning and climate adaptation by integrating sustainability into economic decision-making but does not accurately reflect the immediate and severe risks associated with phenomena like biodiversity loss or sea-level rise, nor does it directly forecast particular climatic events.. It highlights the importance of policies that address climate risks, such as investing in renewable energy and disaster preparedness.

The complexity of existential risks associated with climate change is difficult for the GPI to fully capture, despite these advantages. Although its methodology is thorough, it is not standardized, which may result in inconsistent interpretations of the data and recommendations for policy.

This indicator is not explicitly designed to measure existential risks from climate change, its integration of environmental, social, and economic factors provides a framework that can help assess these risks. Its emphasis on sustainability, the longterm impacts of environmental degradation, and intergenerational equity positions the GPI as a tool for guiding policies that enhance resilience and promote sustainable development in the face of climate challenges.

6.2.2. Environmental Performance Index (EPI)

According to ecosystem vitality and environmental health, the EPI assigns a ranking to nations. Despite not explicitly addressing existential risks, it does take into account elements associated with climate-related difficulties. A nation's susceptibility to climate change is determined by the EPI, which evaluates important environmental factors like biodiversity, water resources, and air quality. Even though the index emphasizes environmental governance and mitigation initiatives, existential risks like extreme climate events and biodiversity collapse are not given much attention.

The EPI uses a composite score derived from various indicators, but its methodology, based on the proximity-to-target approach, faces limitations. It often struggles with incomplete or imprecise data and might prioritize certain environmental factors over others. Although it evaluates climate-related elements like greenhouse gas emissions, it misses broader existential threats like irreversible sea level rise or total biodiversity loss. Thus, while the EPI is beneficial for assessing environmental performance, it does not fully capture existential risks that could endanger human survival. It assesses biodiversity and ecosystem health, recognizing their role in mitigating climate risks. It emphasizes sustainable resource management to reduce vulnerabilities and promote resilience. While primarily environmental, the EPI acknowledges social and economic factors, linking environmental health to better social outcomes and community resilience. It also encourages longterm planning Improvements in the EPI could make it more effective in addressing existential risks.

Expanding the range of indicators and refining the weighting system would enhance its ability to reflect complex risks. Moreover, its focus on longterm sustainability and effective policies can guide climate change mitigation efforts. With better data on existential threats and balanced indicator weighting, the EPI could become a stronger tool for understanding and managing significant environmental challenges.

6.2.3. Social Progress Indicator (SPI)

The SPI doesn't directly address existential climate risks, it includes elements like environmental quality and social resilience that indirectly reflect these risks. These components help gauge a nation's capacity to adapt to and mitigate climate threats, though the SPI doesn't comprehensively analyze risks like biodiversity loss or extreme climate events.

Indicators of environmental sustainability are included, highlighting the significance of a healthy environment in reducing risks such as social instability and resource scarcity. Recognizing that strong community ties increase resilience against crises, the SPI also places a strong emphasis on social cohesion. Indicators of health and wellbeing show how important it is to have strong healthcare systems in order to handle risks like pandemics and climate change. Employment opportunities and income equality are key indicators of economic stability and are essential for resiliency in the face of environmental and economic shocks. The SPI also assesses institutional capacity and governance, highlighting the importance of strong governance in addressing existential threats. In general, the SPI encourages social resilience, sustainable practices, and adaptive governance to tackle the interrelated problems brought on by existential risks.

While the SPI doesn't predict specific climate events, its focus on sustainability, social equity, and policy effectiveness provides insights into how current actions influence future resilience. By promoting intergenerational fairness and sustainability, the SPI aligns with sustainable development goals essential for addressing future climate risks.

6.2.4. Legatum Prosperity Index (LPI)

The LPI evaluates national prosperity across dimensions like governance, economic opportunity, health, and security. While it includes environmental indicators that indirectly reflect climate change effects, it doesn't specifically address existential climate risks. The LPI's measures of air quality, water resources, and biodiversity offer insights into a country's climate vulnerability but don't directly assess extreme weather events, crucial for understanding existential risks.

The LPI comprises sub-indices such as Governance, Health, and Natural Environment, providing a comprehensive view of prosperity. The Natural Environment sub-index reflects environmental quality and sustainability but indirectly assesses climate change risks. Governance factors indicate a nation's capacity to manage climate threats through policies and institutional resilience, crucial for understanding a country's response to climate risks.

Though the LPI doesn't directly analyze extreme weather impacts, it highlights environmental and governance trends influencing a country's ability to tackle climate challenges. It also evaluates climate protection measures like emissions reduction and renewable energy adoption, essential for longterm resilience and reducing existential risks.

The LPI emphasizes longterm sustainability and intergenerational fairness, advocating for practices that ensure future generations can meet their needs. By focusing on ecosystem health and social equity, the LPI supports policies that enhance current and future well-being, aligning with sustainable development goals.

While the LPI doesn't directly measure existential climate risks, its multi-dimensional approach provides a framework for understanding a country's climate vulnerability and resilience. Its focus on environmental sustainability, governance, and longterm prosperity offers indirect insights into how climate change may impact national prosperity and highlights the need for proactive risk mitigation.

6.2.5. Index of Sustainable Economic Welfare (ISEW)

The ISEW addresses existential risks by incorporating environmental sustainability, social well-being, economic stability, longterm planning, and governance into its assessment of economic welfare. It accounts for environmental costs like pollution and resource depletion, highlighting risks from climate change and ecological degradation.

The ISEW emphasizes social well-being and community resilience, recognizing that access to healthcare and education enhances adaptability to challenges. It also evaluates economic stability through income equality and employment opportunities, crucial for resilience against economic and environmental shocks. By promoting longterm planning and adaptive capacity, the ISEW encourages sustainable practices and proactive measures. Additionally, it underscores the importance of effective governance in managing existential threats, supporting policies that enhance community resilience.This approach shows that economic growth alone doesn't guarantee improved social welfare or resilience to climate risks.

However, the ISEW's ability to fully capture existential climate risks is limited by methodological complexities. Variations in calculation methods can lead to inconsistencies, and quantifying non-market factors like ecosystem services complicates its ability to measure climate change's existential threats definitively. Despite these challenges, its holistic approach offers valuable insights into climate change's broader impacts and underscores the need for sustainable development practices.

6.2.6. Gross National Happiness (GNH)/World Happiness Report (WHR)

The GNH and WHR focus on subjective well-being and life satisfaction, rather than directly addressing existential risks like those posed by climate change. While both indices consider environmental and social factors that relate to climate resilience, they do not fully capture specific risks such as extreme weather events, sea-level rise, or biodiversity loss.

GNH includes environmental indicators within its holistic approach to societal well-being, offering insights into how sustainability can mitigate climate risks. It emphasizes ecological health and resource management, indirectly reflecting climate change impacts. However, GNH does not specifically measure existential risks, focusing instead on broader issues like environmental conservation. Its multidimensional nature, covering community vitality, social connections, and sustainability, helps assess vulnerabilities related to climate risks. GNH also promotes longterm sustainability by encouraging policies that prioritize resilience, aligning with intergenerational fairness in addressing global risks.

Similarly, the WHR evaluates life satisfaction and acknowledges environmental factors like air quality and green spaces' influence on happiness. However, it focuses on broader well-being indicators rather than climate-related risks. While it highlights environmental quality's impact on life satisfaction, the WHR lacks detailed analysis of climate threats. It suggests that enhancing social support and community resilience could help societies adapt to such risks.

6.3. Greenland Ice Sheet Disintegration: Exemplary exploratory application for X-Risk consideration

6.3.1. Analysis Greenland Ice Sheet Melting Rates

The study investigates the impact of ice sheet dynamics, including basal melt rates, on GIS stability. The analysis centers on the need for action to address the challenges posed by climate change and the worldwide effects of accelerated ice sheet collapse.

Basal melt (Bmelt), the melting of ice at the base due to warmer temperatures, is key to understanding ice sheet dynamics and sea-level rise. Bmelt is measured through field observations and models that consider temperature, pressure, and water flow. Analysis of Bmelt data from 2006 to 2020 shows an increase in melt rates. The average Bmelt value is 23.04, with a range from 20.10 to 28.94.

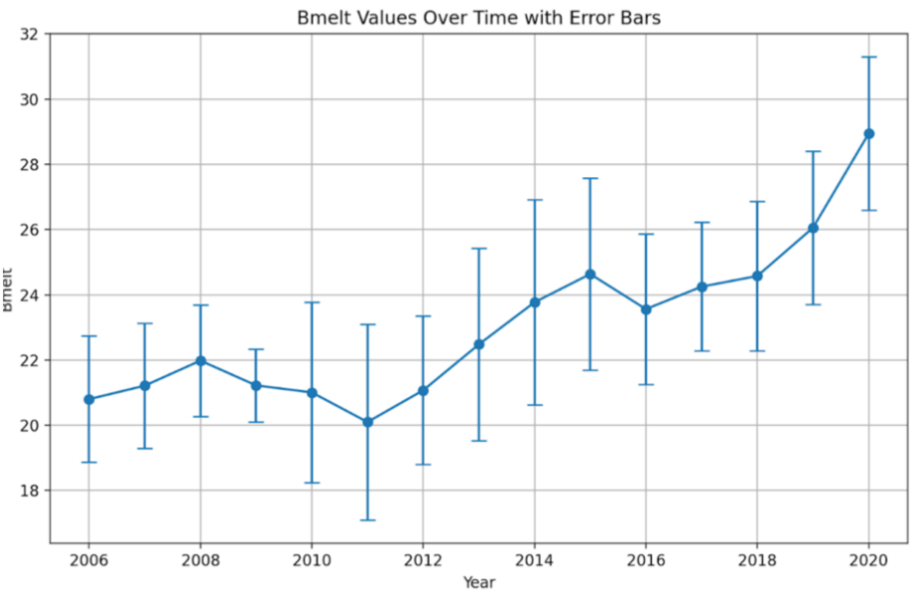

Figure 12. Development of the average basal melt of the GIS from 2006-2020

Error measurements quantify uncertainty in the Bmelt data, with an average error of 2.34 and a percentage error mean of 10.21%. The distribution of Bmelt data shows positive skewness, while error measurements exhibit slight negative skewness. Both have near-normal distributions, indicated by kurtosis values close to 3.

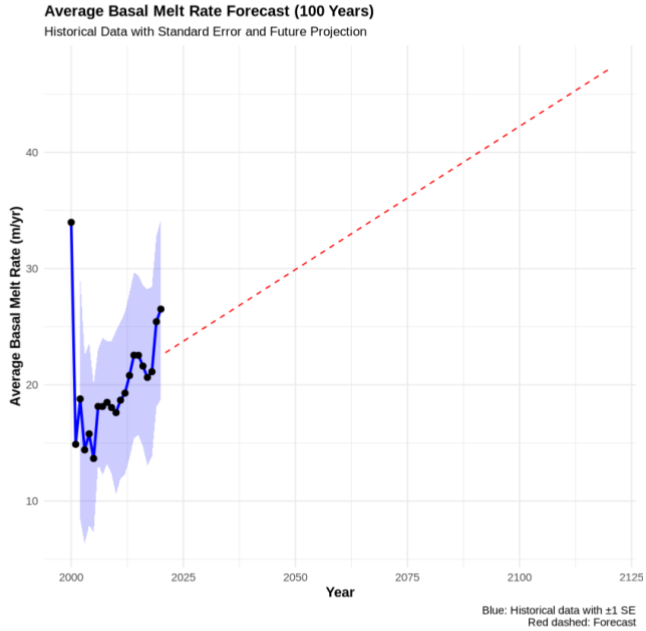

Figure 13. Attempted forecast for the ongoing melt of the GIS.

A forecast visualization presents historical Bmelt data and a 5-year forecast with confidence intervals. The forecast is based on a linear trend and does not account for factors like ice sheet depletion, feedback mechanisms, and broader climate impacts.

The findings include a positive linear trend in basal melt rates and significant variability between glaciers, reflecting natural and regional differences.

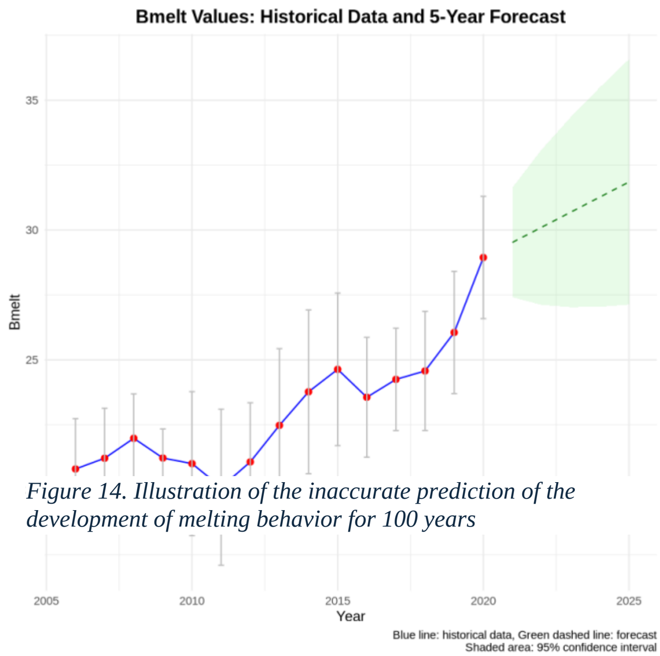

Figure 14. Illustration of the inaccurate prediction of the development of melting behavior for 100 years

Creating a 5-year forecast for the future melting of the Greenland Ice Sheet presents significant challenges due to the complex and dynamic nature of ice sheet behavior and climate systems. The Greenland Ice Sheet is influenced by a multitude of factors, including atmospheric temperatures, ocean currents, and feedback mechanisms, all of which interact in ways that are not fully understood. Additionally, the inherent variability in climate models and the limited historical data available for such projections contribute to the uncertainty. These models often rely on assumptions and simplifications that may not capture the full range of potential future scenarios. As a result, while forecasts can provide insights into possible trends, they are inherently imprecise and should be interpreted with caution. The wide confidence intervals in these projections reflect the uncertainties involved, underscoring the need for ongoing research and improved modeling techniques to enhance our understanding of ice sheet dynamics and their implications for global sea-level rise.

Creating forecasts for the melting of the Greenland Ice Sheet over 100 or 500 years involves significant challenges. Firstly, the climate models used for such longterm predictions are fraught with uncertainties because they rely on assumptions about future emissions, technological developments, and policy measures, which are difficult to predict over such extended periods. Secondly, the physical processes influencing ice sheet behavior are highly complex and not fully understood. Factors such as atmospheric temperatures, ocean currents, and feedback mechanisms interact in unpredictable ways. Moreover, the historical data used to calibrate and validate models are limited compared to the 100- or 500-year timescales, further constraining the accuracy of predictions. Uncertainties increase with the length of the forecast period, as small deviations in initial conditions or model assumptions can lead to significant discrepancies over time. These challenges make it difficult to produce precise and reliable longterm forecasts, highlighting the need for ongoing research and improved modeling techniques to enhance our understanding of ice sheet dynamics and their implications for global sea-level rise.

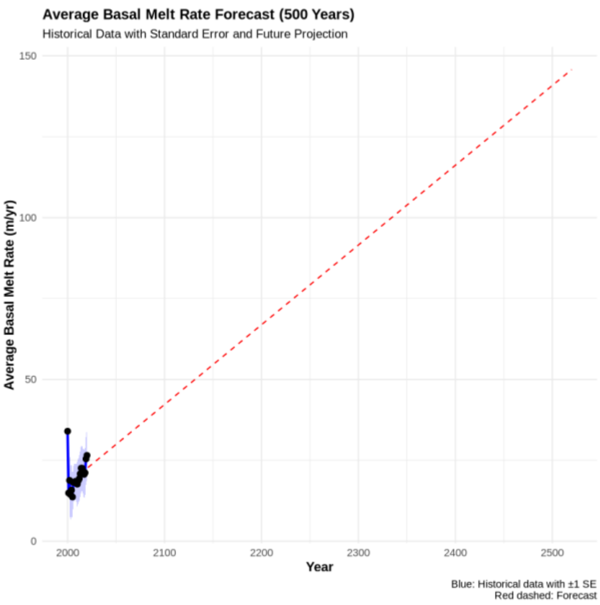

Figure 15. Illustration of the inaccurate prediction of the development of melting behavior for 500 years

6.3.2. Linking GIS and indicators: correlation analysis

The descriptive analysis highlights key trends in the variables studied. The average melt rate has a mean of 22.98, ranging from 20.64 to 26.51, reflecting moderate variability. The EPI exhibits a mean of 45.66 with a narrow range, indicating consistent values over time. Similarly, the LPI has a mean of 65.37 and shows moderate variability, while the SPI, with a mean of 75.37, demonstrates a steady upward trend. The WHR has a mean of 5.37 and remains stable across years, with minimal year-to-year changes.

Correlation analysis reveals several significant relationships. A strong positive correlation (0.91) between the melt rate and WHR suggests an alignment between increasing melt rates and higher happiness scores. Near-perfect correlations exist between EPI and SPI (0.99) and LPI and SPI (0.99), emphasizing the tight linkage between environmental performance, prosperity, and social progress. Moderate correlations include the melt rate with EPI (0.73) and WHR with SPI (0.73), indicating meaningful but less pronounced relationships.

Temporal trends show significant fluctuations in melt rates, particularly in the last two years, alongside consistent upward trends in EPI, LPI, and SPI, reflecting progress in these areas. In contrast, WHR remains stable, underscoring resilience in happiness levels. The correlation plot visually supports these findings, with darker, larger circles indicating stronger relationships.

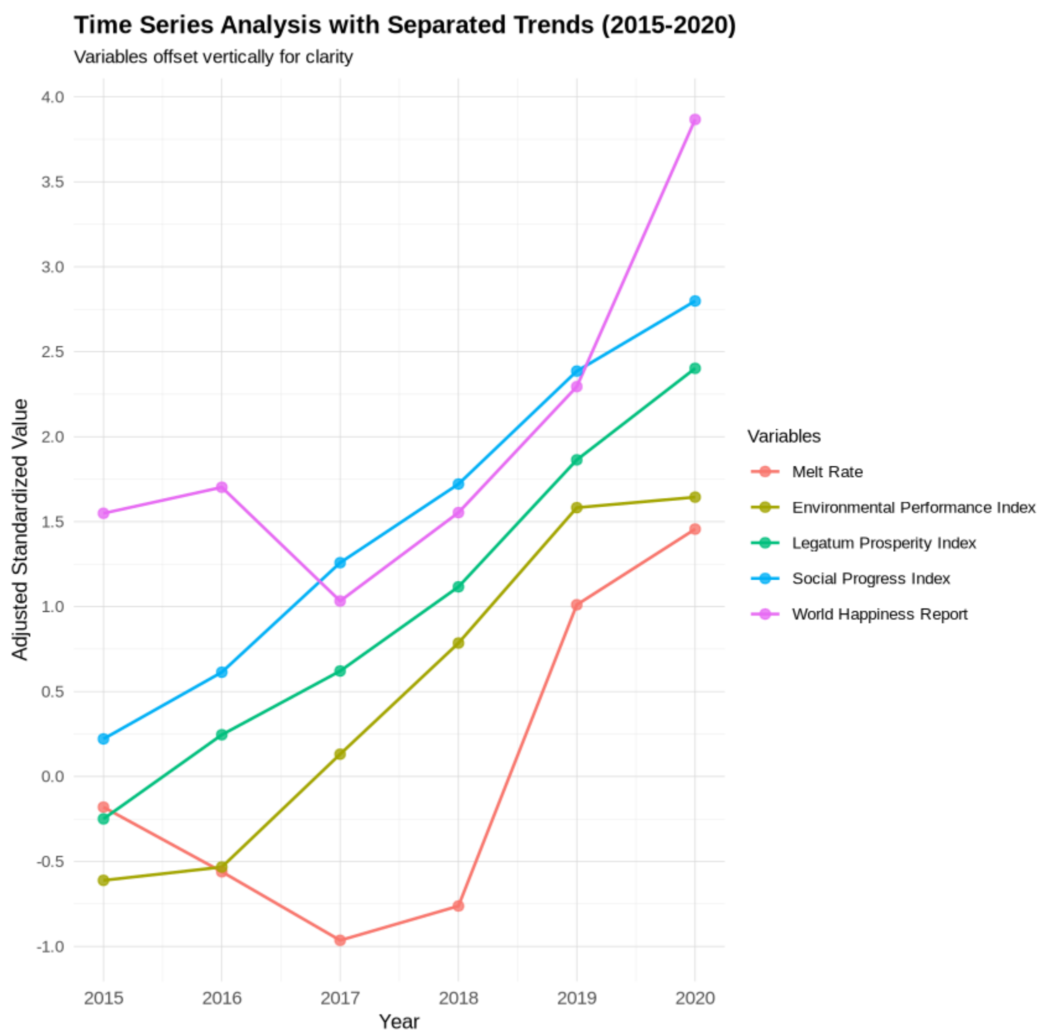

Figure 16. Time series analysis of EPI, LPI, SPI & WHR compared to GIS melting rates

These results collectively illustrate dynamic interconnections between environmental, social, and economic dimensions, while highlighting areas of stability and progress.

The analysis provides evidence of the dataset's validity and reliability. Normality tests using the Shapiro-Wilk method confirm that all variables are approximately normally distributed (p-values > 0.05), supporting the use of parametric tests like Pearson correlations. Pearson correlation coefficients reveal strong linear relationships, particularly between variables such as Average_Score and SPI_Score (0.99), indicating these measures are highly aligned. Spearman correlations similarly show strong monotonic relationships, with notable consistency even when the relationships deviate from perfect linearity, such as the correlation of average_melt with mean_score (0.83).

Cronbach's Alpha (0.96) reflects excellent internal consistency, highlighting that the variables collectively measure a cohesive construct. Additionally, Q-Q plots visually support the normality assumption, further validating the dataset's suitability for parametric analyses. Together, these results demonstrate the dataset's robustness, with high validity, strong interrelationships, and minimal measurement error, making it well-suited for further empirical analysis.

7. Discussion

Indices that integrate environmental sustainability and climate change are essential for shaping global development policies. By using metrics like biodiversity and carbon emissions, they evaluate sustainable development and guide efforts to mitigate climate risks.

This study uniquely combines macroeconomic indicators with climate change dynamics, focusing on existential risks such as the disintegration of the Greenland Ice Sheet (GIS). Over a 20-year period, basal melt rates of the GIS were analyzed, alongside a 5-year forecast model, to understand their implications for global welfare and climate risks. While basal melt offers critical insights into ice dynamics, this study links these findings to broader economic, psychological, and existential risks, including mental health impacts (e.g., climate anxiety), displacement, and social well-being.

The research also compares traditional GDP-centric indices with alternative indicators like the Genuine Progress Indicator (GPI), Social Progress Index (SPI), and Environmental Performance Index (EPI), illustrating the multidimensional impacts of climate-induced risks. By adopting an interdisciplinary approach, the study bridges climate science and macroeconomics, redefining global welfare metrics and providing actionable insights for policymakers and practitioners.

This chapter examines the findings, starting with the GIS's relevance to global welfare, summarizing basal melt data, and interpreting results. It aims to contribute to the ongoing dialogue on climate risks and welfare measurement, emphasizing the need for a holistic framework to address these complex challenges.

7.1. Risk: Ice-Sheet Disintegration of Greenland Glacier

The analysis of basal melt rates from 2006 to 2020 showed a positive linear trend indicating a steady increase over time. Significant variability among glaciers highlights the complex nature of ice sheet dynamics. A positive skewness of 0.84 suggests higher outlier values, and a mean percentage error of 10.21% indicates moderate measurement uncertainty. These findings (chapter 6.3) align with the scientific consensus on the accelerating impact of climate change on ice sheet melt.

Forecasting efforts combined historical data with a 5-year projection, revealing wide confidence intervals that highlight the challenges of predicting the Greenland Ice Sheet's behavior. The linear model offers a baseline for trends but simplifies underlying processes and is limited by the dataset's timeframe, introducing uncertainty into longterm projections. It does not account for factors like ice sheet depletion, feedback mechanisms, or evolving climate impacts, limiting its reliability.

The potential destabilization of the Greenland Ice Sheet has significant implications for coastal regions globally, emphasizing the need for welfare indicators that consider transboundary climate risks. The risk of catastrophic collapse exemplifies a climate-induced existential threat, highlighting the importance of integrating such scenarios into macroeconomic evaluations. The uncertainty in projections underscores the need for precautionary measures in economic indicators and decision-making.

These results demonstrate how challenging it is to create reliable global welfare proxies because of the intricate dynamics of ice sheets and forecasting difficulties. Building resilient, sustainable societies requires better macroeconomic indicators that take into consideration the complex effects of climate change, as the study emphasizes.

7.2. Assessment: Suitability of indicators

The **Genuine Progress Indicator (GPI)** offers a comprehensive alternative to GDP by including environmental and social factors crucial for understanding longterm welfare and sustainability. Unlike GDP, which measures only economic output, the GPI adjusts for environmental degradation, resource depletion, and social inequalities, emphasizing intergenerational equity and sustainable development. This makes it particularly relevant in the context of climate change risks, such as the disintegration of the Greenland Ice Sheet (GIS).

It's strength lies in its ability to reflect environmental and social costs, capturing the true impacts of climate change on welfare. It accounts for localized climate impacts like natural disasters and biodiversity loss and adjusts for income inequality and non-market activities, highlighting social cohesion and equity. This is vital for assessing the differential impacts of climate change on vulnerable populations.

However, the GPI has limitations in addressing longterm systemic risks, particularly those posed by GIS disintegration. It lacks explicit resilience metrics to assess adaptive capacity to climate shocks and struggles to account for intangible losses like cultural heritage erosion. The reliance on monetary valuation introduces subjectivity and potential inaccuracies, failing to capture the cascading effects of climate tipping points.

Advanced climate risk metrics and scenario-based modeling, which are necessary for addressing uncertainties like sea-level rise and GIS tipping points, are not included in the GPI. Freshwater salinization and increased migration are two significant environmental and social costs of GIS melt that are not adequately addressed by the GPI's current framework.

The GPI could use scenario-based modeling and resilience metrics to better capture climate-related risks and better account for longterm effects. With these improvements, the GPI would be a more useful instrument for directing sustainable development policies that are in line with societal resilience and intergenerational equity. The GPI needs to be improved in order to properly address existential risks like GIS disintegration, even though it goes beyond GDP in terms of progress measurement.

The **Social Progress Index (SPI)** serves as a crucial tool for evaluating longterm global welfare and climate-induced risks. Unlike GDP, which focuses on economic output, the SPI integrates social, environmental, and economic factors, offering a comprehensive measure of human well-being. It includes dimensions like basic needs, well-being foundations, and opportunities, effectively capturing the social consequences of climate change.

The indicator is particularly valuable for its indicators that reflect the social impacts of environmental degradation, such as access to clean water and sanitation. These metrics align with welfare economics by considering how environmental changes affect human welfare. By linking social progress to environmental factors, the SPI underscores how degradation exacerbates inequalities and impedes welfare.

Incorporating resilience dimensions, the SPI aligns with sustainability economics, balancing economic activity with environmental preservation and social equity. It tracks renewable energy adoption and emissions reductions, providing insights into how countries address climate change. While it doesn't explicitly assess resilience to climate shocks, it emphasizes environmental quality and resource management, key to sustainability and intergenerational equity.

The SPI's multi-horizon approach helps policymakers anticipate and address future climate risks, aligning with existential risk theories. It emphasizes intergenerational fairness, protecting future generations from climate-induced harms. The SPI also highlights social equity, capturing disparities worsened by climate change and supporting policies that mitigate inequalities.

Despite its strengths, the SPI has limitations in addressing intangible well-being aspects like mental health, influenced by climate uncertainty. Integrating qualitative assessments or psychological metrics could enhance its relevance. While the SPI improves on GDP by focusing on social outcomes, it lacks ecological factors like biodiversity loss, limiting its ability to fully account for climate risks.

To better address these risks, the SPI could refine its "Foundations of Well-Being" dimension by incorporating indicators related to climate tipping points and government actions. This would make the SPI more proactive in addressing climate risks. Although the SPI shows moderate success in environmental quality and social equity, it lags in climate resilience areas like renewable energy adoption. Integrating resilience metrics could make the SPI a more robust framework for evaluating climate impacts.

The **Legatum Prosperity Index (LPI)** offers a comprehensive framework for assessing global welfare by incorporating governance, economic performance, health, and environmental sustainability. This approach is crucial as climate change accelerates, posing risks like sea-level rise and extreme weather. While the LPI provides valuable insights, it has both strengths and limitations in addressing climate-induced risks from a welfare economics and sustainability perspective.

The LPI captures climate resilience indirectly through its focus on environmental sustainability and governance. Indicators like access to clean water and air quality provide data on a country's preparedness for climate shocks. The index's safety and security dimension highlight the socio-political impacts of climate events, linking to the social cost of carbon by emphasizing the broader welfare consequences of environmental disruptions. The governance pillar assesses institutional effectiveness in managing climate risks, underscoring the importance of resilient institutions.

It's objectives align with those of SE by emphasizing intergenerational fairness and responsible resource management, supporting the prosperity of future generations. This perspective is vital for addressing the longterm welfare implications of climate change, which traditional economic measures like GDP cannot fully capture. The focus on environmental protection reinforces the interconnectedness of governance, social equity, and sustainability.

The LPI is limited, though, in its ability to address certain resilience dimensions that are essential for reducing climate risks. The short-, medium-, and longterm impact horizons—which are essential for comprehending global warming and the breakdown of environmental systems—are not specifically included. Its usefulness in enhancing resilience against future shocks is limited because, although it evaluates policy outcomes, it is unable to assess the probability and severity of particular climate events.

The LPI underrepresents intangible dimensions of well-being like social disruption and climate anxiety. The resilience of society is significantly impacted by these non-market factors. The index's dependence on data availability poses problems, particularly in climate change-vulnerable areas where data infrastructure is frequently deficient. This restriction may cause evaluations of resilience and prosperity to be distorted.

The LPI's average score of 5.6 in resilience-related dimensions indicates moderate success in addressing climate risks. Improvements could include expanding the focus on cultural adaptability and CO2 emissions measurement. By incorporating indicators for extreme weather events, government action efficacy, and societal shifts toward sustainability, the LPI could better capture longterm resilience.

The **Environmental Performance Index (EPI)** is a key tool for evaluating environmental health and sustainability, incorporating indicators like greenhouse gas emissions, ecosystem vitality, and disaster preparedness. Its multidimensional approach assesses a country's resilience to environmental challenges and capacity for sustainable development, aligning with welfare and sustainability economics. Indicators such as renewable energy adoption and emissions reduction reflect efforts to mitigate climate risks and promote longterm welfare, emphasizing the importance of sustainability for current and future generations.

It captures both short- and longterm environmental impacts, assessing the resilience of human and natural systems to climate shocks. It includes air quality, water resources, and ecosystem health, which are crucial for adapting to environmental challenges. By tracking biodiversity conservation and pollution control, the EPI incorporates intergenerational fairness, aligning with the United Nations Sustainable Development Goals (SDGs).

But when it comes to addressing the entire range of climate change risks, especially those pertaining to the Greenland Ice Sheet (GIS), the EPI is limited. Although it assesses immediate environmental effects like sea level rise, it finds it difficult to take into consideration more significant social and psychological repercussions like displacement and the loss of cultural heritage. Although the EPI does not adequately account for these non-market effects, they are essential to comprehending resilience.

The EPI's dependence on publicly available data poses difficulties, particularly in developing nations that are susceptible to climate change. Due to a lack of comprehensive data infrastructure, these areas frequently have gaps in assessments and may underestimate vulnerability. This restriction may lead to unfair resource distribution and poorly informed policy decisions.

Despite these challenges, the EPI links environmental performance with longterm economic and social well-being. Its focus on sustainability measures provides insights into how environmental health impacts prosperity. However, the emphasis on present conditions rather than future resilience metrics highlights a gap in capturing evolving climate risks.

To enhance the EPI's relevance for longterm resilience, improvements could include integrating resilience metrics that assess adaptive capacity across sectors like infrastructure and agriculture. Expanding the framework to evaluate green infrastructure effectiveness under future climate scenarios would offer a more comprehensive view of resilience. Developing an Environmental & Societal Performance Index (ESPI) could bridge the gap between environmental performance and societal well-being, addressing psychological and social climate impacts.

Descriptive statistics of the EPI suggest gradual improvements in global environmental performance, reflecting advancements in emissions reduction and ecosystem preservation. However, the EPI does not fully capture existential climate risks, such as potential tipping points like glacier melt. While it tracks environmental management trends, it does not account for the full scale of these risks, which are critical from an existential risk and sustainability economics perspective.

Integrating the **Gross National Happiness (GNH)** and **World Happiness Report (WHR)** frameworks into climate change discussions highlights the impact of environmental degradation on subjective happiness and social cohesion. These frameworks add dimensions often overlooked in economic indices, such as emotional, psychological, and cultural well-being, crucial to understanding the socio-economic effects of climate change beyond GDP. However, they face limitations in capturing the existential risks from extreme climate events, like the potential disintegration of the Greenland Ice Sheet (GIS).

The GNH and WHR align with welfare economics by including both material and non-material factors in well-being. They focus on elements like social support, community resilience, and psychological welfare, extending beyond wealth accumulation. GNH emphasizes holistic well-being, exploring how climate risks erode security and increase anxiety, crucial for a complete welfare analysis. Social cohesion, another GNH focus, is threatened by climate-induced displacement and instability.

WHR reflects perceptions of economic stability and community support affected by climate change, stressing community resilience as a key factor in longterm well-being. Strong social networks help withstand the psychological impacts of extreme weather, directly affecting happiness. WHR also considers environmental quality, revealing its destabilizing impact on health and happiness.

However, both frameworks struggle to address the full scope of climate change's existential risks. They inadequately quantify indirect effects like the psychological toll on displaced populations and fail to capture the broader ecological consequences. Governance issues and uncertainties in climate change are also inadequately addressed. While GNH focuses on community resilience, it overlooks large-scale risks such as population displacement, and WHR doesn't account for longterm ecological impacts.

From a sustainability economics perspective, both frameworks incorporate intergenerational fairness, promoting sustainable practices. GNH emphasizes environmental sustainability, vital for longterm happiness, while WHR benefits from including environmental performance indicators to better capture climate adaptation efforts.

The disintegration of GIS illustrates global catastrophic risks that disrupt ecosystems and societies in unpredictable ways. Welfare economics struggles to account for these risks, highlighting the need for interdisciplinary approaches integrating resilience and existential risk assessments.

The **Index of Sustainable Economic Welfare (ISEW)** offers a comprehensive approach to assessing economic welfare by integrating environmental and social dimensions, addressing the limitations of traditional measures like GDP. This approach supports the idea that indices incorporating environmental degradation and social inequities provide a better understanding of longterm welfare, especially when considering climate change risks like sea-level rise and extreme weather events.

From a welfare economics perspective, the ISEW captures the economic impact of climate change by accounting for factors like pollution, resource depletion, and carbon emissions. This allows the ISEW to measure the economic costs associated with climate-related events, such as the disintegration of the Greenland Ice Sheet (GIS). By adjusting national income figures to reflect these costs, the ISEW offers a holistic view of welfare losses from climate change, aligning with the social cost of carbon framework. However, traditional measures often fail to account for longterm, low-probability, high-impact events like GIS melting, which can lead to mass displacement and ecosystem collapse. The ISEW, in contrast, includes these longterm risks.

The ISEW also considers the social dimensions of climate change, addressing income inequality and the welfare of marginalized groups disproportionately affected by climate-induced disasters. By integrating these social indicators, the ISEW provides a comprehensive assessment of welfare, particularly in the context of intergenerational equity. This concept emphasizes the responsibility of current generations to consider the well-being of future generations, who will face the longterm consequences of environmental degradation.

Within the sustainability economics framework, the ISEW challenges traditional economic growth models, especially given the limits to growth in the face of climate change. The disintegration of the GIS underscores these limits, as continued economic expansion based on fossil fuel consumption is unsustainable. The ISEW recognizes that the depletion of natural capital, like the GIS, has significant implications for human well-being and economic stability.

Furthermore, the ISEW critiques the practice of discounting the future, which often underestimates the longterm impacts of climate change. By adjusting for longterm environmental damage and acknowledging natural capital depletion, the ISEW advocates for a lower discount rate, aligning with sustainability principles that emphasize resource preservation for future generations.

The ISEW frames the risks associated with GIS melt as global catastrophic risks, which, while not directly leading to human extinction, could cause widespread societal disruption and resource conflicts. This highlights the need for comprehensive risk assessments and management strategies that capture tipping points and irreversible changes. The ISEW's ability to account for these cascading risks supports its role in assessing longterm welfare in the context of climate change.

But the ISEW is limited in its ability to address intangible losses, like the loss of cultural heritage or the psychological effects of displacement brought on by climate change. These elements need to be further refined because they are frequently underrepresented and challenging to measure in the ISEW. Furthermore, incomplete data can distort the ISEW's assessment and result in an inadequate understanding of climate risks, especially in developing nations. The ability of the ISEW to reflect resilience would be improved by filling in these gaps and adding direct climate risk indicators, particularly in sectors that are vulnerable like agriculture and fisheries.

7.3. Interpretation of Results

Accelerated basal melt significantly contributes to global sea-level rise, directly impacting coastal economies. For example, the National Oceanic and Atmospheric Administration (NOAA) estimates that by 2100, sea-level rise could cause over $1 trillion in annual damages worldwide. This economic burden stems from the destruction of infrastructure, real estate loss, and increased flooding. Indices like the LPI captures these impacts under metrics related to economic stability and resilience.

Sea-level rise also disrupts global trade and supply chains, as critical infrastructure like ports and shipping lanes become vulnerable. Ports in cities like

Shanghai and Rotterdam handle significant global trade; their impairment could lead to cascading economic losses. This aligns with the EPI and the SPI, which consider environmental sustainability and societal well-being as key components of global welfare (Pezzy & Burke, 2014).

Socially, rising seas displace millions, particularly in low-lying nations like Bangladesh and the Maldives, straining social systems like healthcare and housing. Regions like the Sundarbans have already seen forced relocations, affecting quality of life and social cohesion. Indices like the WHR capture these changes by incorporating subjective well-being and socio-economic stability.

Environmentally, rising seas lead to biodiversity loss and habitat destruction, affecting ecosystems that provide essential services like carbon sequestration and food security. Saltwater intrusion can devastate agriculture in regions like the Mekong Delta, reducing food availability and economic output. The ISEW reflects such challenges by integrating environmental degradation and resource sustainability.

The study's results highlight the limitations of traditional and alternative macroeconomic indices in measuring longterm global welfare, especially in the context of climate change. While traditional indicators like GDP are inadequate for capturing climate-induced risks, indices like the GPI, ISEW, and SPI show promise by incorporating environmental and social factors. However, they still fall short in accounting for the uncertainties and nonlinear dynamics of climate change, particularly catastrophic events like the Greenland Ice Sheet disintegration. This gap underscores the need for refining welfare measurement frameworks to include dynamic models that better reflect longterm climate effects (Gallardo-Abarrán, 2019; Shrotryia & Singh, 2020).

In order to capture longterm climate risks, the study demonstrates that traditional economic indicators such as GDP are inadequate (Chamberlin, 2011; Dong, 2023; Gallardo-Abarrán, 2019; Thibault, 2016; Méndez, 2016; Pais et al., 2019; Schmidt & Wichardt, 2018; Shrotyia & Singh, 2020; Thinlex & Hartz-Karp, 2019; Jevrejeva et al., 2014; Hallegatte et al., 2010). In the context of climate change, it also partially confirms that indices such as the ISEW and GPI more accurately reflect welfare. Unexpected results illustrate the shortcomings of existing models and the difficulties in capturing the nonlinear dynamics of climate change, such as increased uncertainty in Greenland Ice Sheet projections.
The research supports the body of literature that calls for strong welfare indices that

take social and environmental factors into account. However, it introduces new perspectives, notably the higher uncertainty in Greenland Ice Sheet projections, emphasizing the need to refine models for better climate risk prediction.

By highlighting the fact that conventional measures do not take into consideration the complex effects of climate change, the study adds to the conversation about calculating welfare. The ISEW, SPI, and GPI are partially validated, but it also identifies shortcomings in capturing the nonlinear dynamics of climate change. In order to improve welfare indices, future studies should incorporate scenario-based risk assessments, resilience indicators, and sophisticated climate models.

Its thorough analysis, which links findings to previous studies and acknowledges both confirmations and deviations, is one of the study's strong points. The examination of uncertainty in Greenland Ice Sheet projections challenges presumptions regarding the predictability of climate risk and adds an important dimension.

Further exploration could address the SPI’s exclusion of psychological factors like mental health and existential anxiety, increasingly important in climate discourse. Additionally, exploring solutions for data gaps in vulnerable regions, particularly in developing countries, would strengthen the application of welfare indices like the SPI in areas most at risk from climate change.

Key insights include the following:

1. **Multidimensional Indices appear to be effective**: Indices like LPI and the GPI prove to be more effective in reflecting the complexities of global welfare when considering climate change. Unlike traditional metrics like GDP, which focus solely on economic output, these multidimensional indices incorporate a broader range of factors, including governance, health, social capital, and environmental performance. By integrating these elements, they offer a more holistic view of welfare, allowing for a better understanding of how climate change impacts various facets of human well-being. This broader approach is essential for capturing the nuanced effects of climate change, which extend beyond economics to include social and environmental considerations.
2. **Unaddressed Intangible Aspects**: One critical limitation of many welfare indices, including the LPI and GPI, is their exclusion of intangible aspects of welfare, such as psychological impacts. While these indices capture physical health, economic stability, and environmental risks, they often overlook the

mental health consequences of climate change, including anxiety, uncertainty, and existential insecurity. These intangible dimensions are increasingly recognized as essential to understanding longterm welfare, particularly as climate change continues to create significant psychological stress and existential risks. Addressing these factors is crucial for a more complete and accurate measure of global welfare.

3. **Psychological and Existential Risks**: The study reveals that no single welfare index can fully encapsulate the complexity of climate-induced existential risks. These risks include not only environmental degradation but also the longterm psychological toll of displacement, social disruption, and the erosion of community resilience. The existential insecurity stemming from climate change—exemplified by fear of catastrophic events, loss of livelihoods, and disruption of communities—cannot be captured by traditional welfare metrics. Therefore, it is imperative to integrate these psychological and existential dimensions into welfare measurements to fully grasp the breadth of climate change's impacts on human well-being.
4. **Limitations of Existing Data and Methodologies**: A significant challenge highlighted by this research is the gap in data availability and reliability, particularly in developing countries and climate-vulnerable regions. Many of the indices reviewed rely on data that may not accurately reflect local realities or may be incomplete, leading to potential biases in welfare assessments. This issue is particularly problematic when assessing the impacts of climate change, as the regions most affected often lack the necessary data infrastructure. The data gaps emphasized in this study point to the urgent need for improved data collection systems, especially in regions that are disproportionately affected by climate risks. Strengthening data availability is key to enhancing the accuracy and inclusiveness of welfare indices.
5. **A Call for Comprehensive Reform**: Considering the identified limitations, the study calls for significant reform of existing welfare indices to better capture the full range of climate-induced existential risks. This includes the integration of more comprehensive measures that address psychological well-being, cultural resilience, and social disruption, which are critical to understanding the true impact of climate change on human welfare. Furthermore, the study emphasizes the need to improve the methodologies used to measure these

factors, ensuring that they are adequately accounted for in future welfare assessments. Such reforms are essential for developing indices that can more accurately reflect the complex and multifaceted nature of climate change and its longterm implications for global welfare.

The literature suggests that climate change poses an existential threat due to its potential to disrupt global security and human prosperity. Specifically, this research emphasizes the significance of critical thresholds in climate change impacts, beyond which risks escalate nonlinearly. For instance, substantial and timely reductions in greenhouse gas emissions are highlighted as crucial to mitigating the existential threat posed by climate change. The interconnected nature of climate change with global financial systems and the potential for unrest, conflict, and even war in vulnerable regions underscores the nonlinear dynamics of climate risk escalation. This nonlinear relationship emphasizes the urgency of comprehensive analyses and frameworks to enhance resilience and inform effective strategies, especially in the face of critical thresholds that could further exacerbate existential risks.

These findings underscore the need for a more comprehensive approach to measuring global welfare, one that incorporates both tangible and intangible factors. A nuanced understanding of the data and methodologies used in welfare assessments is essential for capturing the full spectrum of climate change's impacts on human well-being (Pezzy & Burke, 2014). Future research should focus on refining existing indices and developing new frameworks that can better account for climate risks and their socio-economic consequences.

In terms of advancements in understanding global welfare and climate risk, policymakers are encouraged to adopt indices such as the GPI and ISEW to gain a deeper understanding of climate risks and socio-economic impacts. This can enhance decision-making and the development of policies that are more responsive to the challenges posed by climate change. Climate-sensitive sectors, on the other hand, should integrate climate risk assessments into their strategic planning to ensure long-term sustainability and resilience against climate-related disruptions. The integration of environmental data with macroeconomic analyses highlights the limitations of traditional welfare metrics, advocating for the development of indices that can capture climate-induced risks in a more comprehensive way.

The practical implications of these advancements are also significant. Policymakers can use refined indices to make more informed decisions regarding sustainability and resilience, leading to more effective policy frameworks. Similarly, businesses that integrate climate risks into their strategies are better equipped to ensure long-term sustainability, enabling them to navigate the challenges of a changing climate with greater resilience.

An attempt to expand or combine the examined indicators to measure longterm global welfare, incorporating climate change-related X-Risks, could look as follows:

Indicator Combination	Objective	Benefit
GPI + SPI	Integration of ecological, social, and economic dimensions	Comprehensive measurement of welfare, including social and ecological costs
LPI + EPI	Linking prosperity with environmental performance	Considering the impact of environmental policies on prosperity
EPI + SPI	Linking environmental performance with social welfare indicators	Capturing the interactions between environmental changes and social conditions

Table 4 Example for further improvement of alternative indicator

What if? Impacts of a Policy Shift towards Alternative Indicators

Shifting policy focus from GDP per capita to alternative indicators like GPI, EPI, SPI, LPI, ISEW, and GNH/WHR can lead to more comprehensive and sustainable outcomes. This transition broadens the evaluation of societal progress to include well-being, environmental sustainability, and social equity, influencing policy design to emphasize longterm resilience and sustainability, especially in addressing existential risks like climate change.

These alternative indicators provide a more rounded assessment of progress by integrating environmental and social dimensions with economic performance. For example, GPI and ISEW adjust for environmental degradation and social costs, offering a clearer picture of sustainable economic welfare. EPI and SPI focus on environmental quality and social progress, aligning with sustainable development goals and providing insights into how countries manage climate challenges. This broader scope enables policymakers to make informed decisions that prioritize longterm sustainability over short-term economic gains.

The impact of this policy shift is evident in how these indicators capture climate change effects and other existential risks. EPI measures environmental performance, including emissions and resource management, making it relevant for climate risk assessment. GPI accounts for environmental and social costs, depicting a nation's well-being amid ecological degradation. SPI and GNH emphasize social cohesion and community resilience, highlighting vulnerabilities and supporting adaptation policies.

These presented indicators facilitate evidence-based decision-making, guiding strategies that prioritize sustainability, resilience, and well-being. By considering factors like happiness, social support, and environmental sustainability, governments can develop more balanced and equitable policies. This approach aligns with international sustainability goals, providing a framework for assessing progress toward longterm resilience and prosperity.

This work contributes to the discourse on measuring global welfare in the context of climate change, highlighting the limitations of current macroeconomic indices in capturing existential risks. It recommends enhancing frameworks by incorporating psychological and social impacts to better reflect climate-induced risks and assess longterm welfare. These improvements are crucial for developing robust measures that guide policy and decision-making in the climate change era.

Existential Risks in Economic Governance

It is becoming more widely acknowledged that integrating existential risks associated with climate change into economic governance is crucial to promoting sustainability and resilience. The scientific literature lacks a clear definition and analysis of existential risks, which are threats to the survival or basic needs of people, communities, or humanity. This hinders effective engagement with the systemic implications of these risks (Huggel et al., 2022). The urgency of addressing these risks is obscured by this lack of clear framing, which frequently causes confusion between well-verified science and speculative claims, especially for high-end climate risks (Beard et al., 2021).

The uncertainty inherent in climate change paradoxically amplifies its potential as a global catastrophic risk. Baum (2024) emphasizes that this uncertainty arises from the complex interactions within socio-ecological systems, even under moderate climate scenarios. The irreversible and catastrophic nature of such risks challenges traditional economic models, necessitating innovative frameworks and methodologies to capture their scope and impact.

In economic governance, longtermism shifts policy focus toward the far-reaching consequences of decisions (Boyd & Wilson, 2021b; Hicks & Janus, 2023; Ord, 2023).

For example, longterm investments in renewable energy enhance energy security and economic stability while mitigating climate change effects (Battiston et al., 2021; Ord, 2023). While ecological conservation protects biodiversity and essential ecosystem services, disaster preparedness lessens the economic and human costs of natural disasters, strengthening the basis of economic activity (Cotton-Barratt et al., 2020; Kind et al., 2019). These tactics show how longterm planning is essential for successfully tackling interrelated global issues.

Addressing existential risks also requires reimagining governance frameworks to accommodate these poorly understood yet critical threats. McLaughlin (2024) highlights the need to integrate existential risks into justice frameworks and resistance practices, emphasizing the importance of interdisciplinary collaboration to manage deep uncertainties. Bridging gaps between natural and social sciences, as advocated by Rising et al. (2022), ensures that unquantified risks are incorporated into decision-making.

Institutions are essential to this process because they manage the complexity and unpredictability of existential risks by striking a balance between value-based risk management and scientific analysis (Iacobucci & Trebilcock, 2022).

In order to effectively govern existential risks, methodological developments are essential. According to Huggel et al. (2022), standardized instruments such as color-coded risk scales are necessary to convey the extent of worldwide catastrophic hazards.

A Multi-Dimensional Approach to Resilience and Sustainability

A thorough method of incorporating existential risks into governance frameworks includes classifying and defining threats, differentiating between risks related to technology, the environment, and climate change, and ranking initiatives according to likelihood and seriousness. Effective resource allocation requires taking into account both direct and indirect effects, such as social collapse.

Longermism complements this multi-dimensional strategy by promoting policies that address existential risks like pandemics, climate change, and technological disruptions. By integrating longterm thinking into economic governance, societies can build resilient systems capable of adapting to future crises while ensuring sustainable prosperity (MacAskill, 2022). This approach aligns closely with the SDGs and demonstrates the global recognition of longterm thinking as a critical tool for addressing complex challenges.

7.4. Conducted Research: Critical Assessment

The theoretical framework combining welfare economics, sustainability economics, and existential risk offers a comprehensive approach to understanding longterm global welfare, but it also presents several limitations and challenges. Recognizing these constraints enhances the credibility and depth of the analysis.

The interdependence of welfare, sustainability, and existential risks makes it difficult to isolate specific impacts or establish clear causal relationships. This complexity complicates the development of practical metrics that capture the nuanced interactions between socio-economic and environmental factors. The relationship between economic growth and welfare is debated in the literature. While welfare economics emphasizes subjective well-being and equitable resource distribution, some argue that economic growth alone can enhance welfare without redistribution. These conflicting viewpoints require careful examination to avoid oversimplifications. The framework relies on comprehensive data across various domains, but data availability can be inconsistent, especially for sustainability and existential risk indicators. This inconsistency may lead to biased or incomplete welfare assessments, affecting the accuracy of policy recommendations. The framework involves significant ethical dilemmas, particularly concerning intergenerational equity and resource allocation in the face of climate change. Navigating the ethical debates between utilitarian and deontological approaches is necessary to avoid biased interpretations. The unpredictable nature of existential risks, such as climate change, complicates the inclusion of future risks in current welfare metrics. These evolving risks require adaptive methodologies, as static indicators may fail to capture changing contexts or new threats. While integrating these frameworks provides valuable insights into longterm welfare in the context of climate change, addressing these limitations and challenges is crucial for ensuring a more transparent, adaptable, and comprehensive analysis. This will strengthen the study's relevance and contributions to policy discussions.

A significant strength of this research lies in its innovative integration of macroeconomic indicators and climate change dynamics through the lens of existential risk considerations. This perspective is often underrepresented in traditional economic analyses, making this study a valuable contribution to the discourse on welfare measurement. It highlights the indirect but profound impacts of climate change, such as mental health effects from climate anxiety, existential threats posed by displacement, and the social and cultural consequences of extreme climate events. These dimensions enhance the understanding of welfare beyond conventional metrics, offering a more holistic perspective.

Another strength is the comparative analysis of various welfare indices, such as the GPI, GNH, and WHR. By juxtaposing these indices with traditional measures like GDP, the study underscores their potential to better capture the multidimensional nature of welfare, particularly in the context of existential risks posed by climate change. For instance, the focus on basal melt rates of the Greenland Ice Sheet (GIS) introduces a novel environmental metric that links physical climate phenomena with longterm welfare outcomes. This integration highlights how GPI and ISEW outperform GDP in reflecting the complex, longterm consequences of environmental degradation, such as rising sea levels or the social costs of displaced communities.

By focusing on basal melt as a critical factor in GIS stability, the study sheds light on a pivotal environmental process. This focused approach not only elucidates the link between basal melt rates and broader climate risks but also underscores the cascading impacts on both environmental systems and human welfare.

The study's qualitative methodology is ideal for investigating theoretical and conceptual problems, but it is limited by the lack of quantitative analysis. Including data-driven techniques, like climate scenario simulations (e.g., sea-level rise, extreme weather events), may offer a more thorough assessment of how various indices function in various scenarios. By providing actual data demonstrating the usefulness of using particular indices over others, such a method would bolster the case. The accuracy of longterm trend projection is limited by the dependence on short-term basal melt data. The complex, non-linear feedback loops that define ice sheet disintegration and its wider effects are not taken into consideration by this constraint and the linear modeling of GIS dynamics. Critical factors like surface melt and ice flow dynamics were excluded, further narrowing the analysis and potentially introducing biases. Additionally, the lack of spatial and temporal granularity in the data hinders a comprehensive assessment of how these macroeconomic indices perform across different regions and timeframes. Without higher-resolution data, it becomes challenging to fully understand the real-world applicability and robustness of these indices in diverse contexts.

A more thorough examination of the theoretical foundations of welfare measurement would be beneficial to the study. It does not thoroughly address the ethical and philosophical underpinnings of welfare theories, such as utilitarianism, capabilities theory, or theories of justice, even though it successfully criticizes the shortcomings of the current indices. The study could offer a more robust theoretical framework by relating the analysis to these frameworks, elucidating the significance of particular dimensions, such as existential and psychological factors, in assessing longterm welfare. Furthermore, non-monetary components of welfare that are greatly impacted by climate change, like cultural identity and community cohesion, are difficult for current economic models to account for. Filling in these gaps could improve the criticism of conventional methods and open the door to more thorough welfare measures.

The analysis was constrained by computational limitations and the unavailability of comprehensive data. For example, interactions between surface melt and ice flow dynamics, which are crucial for understanding GIS stability, were not included due to resource constraints. These omissions reduce the study's ability to capture the full range of factors influencing GIS disintegration and its associated risks.

Many climate models rely on global averages, which may not adequately capture regional variations or localized impacts of GIS changes. This limitation undermines the study's ability to fully account for the localized welfare impacts of climate change on vulnerable communities.

The absence of quantitative analysis and granular data limits the study's ability to draw definitive conclusions about the relative performance of different macroeconomic indices. This limitation makes it challenging to demonstrate the practical superiority of indices like GPI and ISEW over GDP in capturing existential risks, potentially reducing the persuasiveness of the argument for policymakers and skeptics. Theoretical gaps also weaken the critique of current indices. Without a thorough engagement with welfare theories, the study's arguments risk being perceived as less grounded, reducing its academic rigor and the strength of its call for refined macroeconomic indicators.

Finally, practical constraints related to data availability and computational resources may introduce biases or uncertainties in the results. The exclusion of critical factors like ice flow dynamics or the reliance on short-term data could lead to an underestimation of the severity and immediacy of climate-related risks.

Despite these limitations, this research serves as a contribution by emphasizing the need for a more holistic approach to welfare measurement in the context of climate change. By integrating environmental data, such as basal melt rates, with macroeconomic analyses, the study highlights the shortcomings of traditional metrics and advocates for indices that better capture the multidimensional impacts of climate-induced risks.

Future research might aim to incorporate quantitative analyses, expand the scope to include other critical factors (e.g., surface melt, regional variations), and engage more deeply with welfare theories. These improvements would not only strengthen the academic foundation of the work but also make a more compelling case for developing robust indicators that address the existential and psychological dimensions of climate change, ensuring that human well-being remains at the forefront of economic and environmental policy discussions.

7.5. Implications

This study highlights the urgent need to integrate climate change considerations into policy and economic frameworks. Policymakers are encouraged to adopt macroeconomic indices like the GPI or the Index of ISEW to better understand climate risks and their socio-economic impacts. Monitoring and modeling ice sheet dynamics, especially basal melt processes, are crucial for developing adaptive policies to mitigate sea-level rise and other environmental consequences. For businesses, particularly in climate-sensitive sectors like insurance, infrastructure, and global supply chains, integrating climate risks into strategic decision-making is essential for enhancing resilience and ensuring longterm sustainability.

The research critiques GDP-based models for neglecting the psychological, social, and existential aspects of climate risks. By integrating environmental science with macroeconomic theory, the study advocates for interdisciplinary approaches aligned with sustainability economics and the capabilities approach. It emphasizes the importance of incorporating resilience, risk management, and longterm sustainability into welfare measurement to address climate change challenges effectively.

The study demonstrates the value of linking physical climate indicators, such as basal melt rates, with macroeconomic indices to connect environmental and economic systems. While effective in highlighting limitations, the methodology suggests areas for refinement, including:

- **Incorporating Non-Linear Models:** To better capture complex interactions and feedback loops between climate processes and socio-economic outcomes.
- **Enhancing Data Quality:** Using higher-resolution, longterm datasets to improve projection accuracy and reliability.
- **Expanding Scope:** Including additional processes like atmospheric circulation patterns and ocean-current interactions for a comprehensive understanding of climate risks.

7.6. Outlook

This study provides insights into the intersection of macroeconomic indices and climate change risks but also identifies areas for further research. A deeper understanding is needed of how physical climate indicators can be integrated into macroeconomic frameworks to capture longterm risks effectively. Questions remain about the sensitivity of existing indices to abrupt climate events and their adaptability to regional and temporal variations in vulnerability (Kerry, 2024). Additionally, exploring trade-offs in prioritizing climate-related risks over other socio-economic dimensions, such as inequality and public health, is necessary.

Suggestions for Future Research:

1. **Development of New Indices:** Refining existing indices like the ISEW or creating new indicators that reflect existential risks, incorporating physical climate variables and socio-economic factors like inequality and resilience.
2. **Non-Linear Modeling:** Using non-linear models to capture complex interactions between climate systems and socio-economic outcomes, providing a better understanding of tipping points and feedback loops.
3. **Expanded Scope:** Investigating other critical processes affecting ice sheet stability, such as atmospheric circulation patterns and ocean currents, for a holistic view of climate risks.

Bridging the gap between climate science and macroeconomics is crucial for developing comprehensive risk management strategies. By integrating physical and socio-economic indicators into unified frameworks, future research can better inform policies that promote resilience and sustainability. This interdisciplinary effort is essential for addressing the multifaceted challenges of climate change and ensuring that welfare frameworks reflect both current prosperity and future sustainability.

Advancing the field requires addressing open questions, refining methodologies, and developing robust indicators that prioritize longterm global welfare. By doing so, we can achieve a more comprehensive understanding of existential risks and better equip society to mitigate the impacts of climate change effectively.

8. Conclusion

This research aims to enhance the understanding of global welfare and climate risks by evaluating macroeconomic indices and their ability to capture the complex impacts of climate change, particularly existential risks like the disintegration of the Greenland Ice Sheet. The study contributes to existing literature by providing a detailed analysis of macroeconomic indices such as the EPI, LPI, WHR/GNH, SPI and the ISEW, highlighting their strengths and limitations. By emphasizing the integration of environmental sustainability and social dimensions with economic output, it contributes to the ongoing discussion about developing more holistic welfare measurement approaches.

This study investigates the integration of empirical climate data, such as the Greenland Ice Sheet's basal melt and discharge rates, into macroeconomic welfare measures. This first stage provides a means of linking physical climate indicators to economic models, laying the groundwork for future studies and real-world implementation. The study stresses risk management and resilience in welfare measurement by fusing insights from economics and climate science. This viewpoint supports calls to develop metrics that take into account the interdependence of ecological, social, and economic systems and to move beyond conventional GDP-focused paradigms.

A more nuanced assessment of human needs and climate change risks is advocated by this investigation, which points out shortcomings in current welfare frameworks. Although preliminary, the goal of these findings is to improve welfare theories in order to better address both immediate and longterm issues. Adopting better macroeconomic indices, according to the findings, may help policymakers make better decisions, particularly when it comes to sustainability and resilience objectives. It is essential to incorporate climate data into policy frameworks in order to prioritize investments in climate impact monitoring and adaptive strategies. In order to ensure longterm resilience, the analysis emphasizes how crucial it is for businesses to incorporate climate risk assessments into strategic planning.

By highlighting topics that require more investigation, such as non-linear models and the incorporation of various climate variables into welfare metrics, the study contributes to the groundwork for future research. Although it is incremental, the goal of this work is to provide information to interdisciplinary discussion and exploring new areas in the field current economic analysis. By providing insights to help stakeholders, researchers, and policymakers tackle urgent issues, this work helps to improve our understanding of global welfare and climate risks. It draws attention to how conventional GDP-centric models fall short in capturing the longterm effects of events like the melting of the Greenland Ice Sheet. By examining alternative indices and combining socioeconomic factors with physical climate indicators, the study highlights how urgent it is to incorporate existential risk assessments into economic and policy frameworks.

The findings advocate for a shift towards indices or combination of the which like the GPI and SPI, LPI and EPI or EPI and SPI, enabling a more nuanced understanding of climate risks and their cascading consequences for human well-being. The work refines welfare measurement frameworks by highlighting overlooked psychological, social, and existential dimensions of climate change. It highlights interdisciplinary approaches, bridging environmental science and macroeconomic theory to develop comprehensive indicators. Looking ahead, future research should prioritize developing new or refined indices that incorporate both physical climate variables and socio-economic factors, enabling a holistic assessment of risk and vulnerability. Using non-linear models and expanding research scope to encompass additional climate processes are crucial for capturing complex interactions and feedback loops within the climate-economy nexus. Ultimately, bridging the gap between climate science and macroeconomics is essential for developing effective risk management strategies and policies that promote longterm resilience and sustainability. This interdisciplinary effort ensures that welfare frameworks reflect not only current prosperity but also the capacity to safeguard it for future generations, effectively mitigating the multifaceted challenges of climate change and ensuring a sustainable future for all.

Afterword

As I conclude this thesis, I reflect on the journey it represents—both the accomplishments and the challenges. On a positive note, I am pleased that I managed to complete the thesis within the semester, adhering to the timeline I had set for myself. Additionally, I was fortunate to have the supervisor of my choice, whose guidance was invaluable throughout the process. Overcoming my initial sense of overwhelm, I was able to develop a thesis that, while not perfect, is at least readable and coherent.

That said, I cannot claim to be fully satisfied with the outcome. While this thesis serves as a foundational overview of the topic, it falls short in terms of practical applicability. The field of macroeconomic indicators proved to be far more expansive and nuanced than I had initially anticipated. The diversity and specificity of many indicators made it challenging to identify strong candidates, as each one emphasized different aspects. Although I devised a scoring chart to aid my selection process, I acknowledge that this method lacked scientific rigor due to its subjectivity. While the chart helped me navigate the overwhelming number of options, I now question whether my assessments were entirely accurate. Engaging with more experts in the field could have provided valuable insights and enhanced the credibility of my evaluations. I fear that readers might find my scoring approach difficult to follow or unconvincing, which does not align with the principles of good scientific practice.

The statistical analysis in this thesis is another area where I recognize significant shortcomings. The connection between the disintegration of the Greenland Ice Sheet and macroeconomic indicators may not be immediately clear, and I admit that attempting to link existential risks (X-Risks) to these indicators, particularly over long future time horizons, was perhaps overly ambitious. The complexity of this task was compounded by my limited knowledge of statistical methods and economic modeling. My approach to quantitative methods was largely a "learning by doing" process, as tools like R and the analysis of such complex systems were not part of my academic training. This lack of experience made my methodological approach feel uncertain and precarious at times.

Nonetheless, I take pride in the learning process this thesis entailed. It pushed me to critically engage with both the subject matter and the methodologies I employed. I challenged myself thematically and methodologically, and while the journey was far from smooth, it was undeniably rewarding. I now recognize the value of narrowing the scope of analysis—focusing on a smaller set of indicators or delving deeper into established theories such as X-Risk theory, Maxipok, or DICE would have likely resulted in a more focused and robust thesis.

One of the most valuable lessons I have learned is the importance of openness and flexibility. I approached this project with a relatively fixed mindset regarding the methods, data, and outcomes, which, as my supervisor Prof. Cunat had cautioned, was not ideal. Throughout the process, I had to adjust my research question, the indicators I analyzed, and even my methodology multiple times to accommodate time constraints and data availability. This adaptability, though challenging, was a critical skill I developed during this project.

Looking ahead, I recognize the need to improve my statistical skills and my proficiency in R. Additionally, I would approach future research with greater humility, recognizing the limits of my knowledge and seeking more collaboration and feedback from experts.

If I were to undertake a similar project again, I would focus on a narrower scope, prioritize depth over breadth, and allow more time for mastering the necessary methods and tools. This thesis has been an invaluable learning experience, and I am grateful for the challenges it presented, as they have undoubtedly contributed to my growth as a researcher.

References

Al-habash, M. A., Buraik, O., Yousef, M., Alali, A. M. F., Al_Shukri, K. S., & Fraihat, B. A. M. (2023). The Effect of Sustainable Entrepreneurship on Economic Development in Jordan: The Mediating Role of Environmental Performances. *Migration Letters*, *20*(6). https://doi.org/10.59670/ml.v20i6.3472

Alimohammadlou, M., & Khoshsepehr, Z. (2023). The role of Society 5.0 in achieving sustainable development: A spherical fuzzy set approach. *Environmental Science and Pollution Research*, *30*(16), 47630–47654. https://doi.org/10.1007/s11356-023-25543-2

Aliukov, S., & Buleca, J. (2022). Comparative Multidimensional Analysis of the Current State of European Economies Based on the Complex of Macroeconomic Indicators. *Mathematics (Basel)*, *10*(5), 847-.

Alshehry, A., & Belloumi, M. (2024). The Symmetric and Asymmetric Impacts of Energy Consumption and Economic Growth on Environmental Sustainability. *Sustainability*, *16*(1), Article 1. https://doi.org/10.3390/su16010205

Altmann, B. (2013). *Measuring Welfare An Alternative to GDP*.

Andernach, M., Kapsch, M.-L., & Mikolajewicz, U. (2024). Impact of Greenland Ice Sheet Disintegration on Atmosphere and Ocean Disentangled. *Earth System Dynamics Discussions*, 1–40. https://doi.org/10.5194/esd-2024-24

Anderson, K., Corong, E., Strutt, A., & Valenzuela, E. (2023). The Relative Importance of Global Agricultural Subsidies and Tariffs, Revisited. *World Trade Review*, *22*(3–4), 382–394. https://doi.org/10.1017/S1474745623000101

Andriantiatsaholiniaina, L. A., Kouikoglou, V. S., & Phillis, Y. A. (2004). Evaluating strategies for sustainable development: Fuzzy logic reasoning and sensitivity analysis. *Ecological Economics*, *48*(2), 149–172. https://doi.org/10.1016/j.ecolecon.2003.08.009

Arifin, S., Anisa, N. A., Siswohadi, S., Megasari, A. D., & Darim, A. (2020). The Effect of Consumption On The Society Welfare In Sampang District. *Quantitative Economics and Management Studies*, *1*(2). https://doi.org/10.35877/454ri.qems88

Armstrong McKay, D. I., Staal, A., Abrams, J. F., Winkelmann, R., Sakschewski, B., Loriani, S., Fetzer, I., Cornell, S. E., Rockström, J., & Lenton, T. M. (2022). Exceeding 1.5°C global warming could trigger multiple climate tipping points. *Science*, *377*(6611), eabn7950. https://doi.org/10.1126/science.abn7950

Arnscheidt, C. W., Beard, S. J., Hobson, T., Ingram, P., Kemp, L., Mani, L., Marcoci, A., Mbeva, K., hÉigeartaigh, S. Ó., Sandberg, A., Sundaram, L., & Wunderling, N. (2024). *Systemic contributions to global catastrophic risk*. OSF. https://doi.org/10.31235/osf.io/wcj9e

Arora-Jonsson, S., McAreavey, R., Waldenström, C., Stiernström, A., Asztalos Morell, I., Kuns, B., Sandström, E., González-Hidalgo, M., Cras, P., & Alarcon-Ferrari, C.

(2023). Multiple dimensions of sustainability: Towards new rural futures in Euope. *Sociologia Ruralis*. https://doi.org/10.1111/soru.12447

Arrhenius, G., & Rodhe, H. (1997). *Carbon dioxide warming of the early Earth*. *26*(1). https://usearch.uaccess.univie.ac.at

Assa, J. (2021). Less is more: The implicit sustainability content of the human development index. *Ecological Economics*, *185*, 107045. https://doi.org/10.1016/J.ECOLECON.2021.107045

Atkinson, A. B. (2011). The Restoration of Welfare Economics. *American Economic Review*, *101*(3), 157–161. https://doi.org/10.1257/aer.101.3.157

Backhouse, R. E., Baujard, A., & Nishizawa, T. (Eds.). (2021). *Welfare Theory, Public Action, and Ethical Values: Revisiting the History of Welfare Economics*. Cambridge University Press. https://doi.org/10.1017/9781108882507

Bacon, H., Vigors, B., Shaw, D., Waran, N., Dwyer, C. M., & Bell, C. (2021). Is Animal Welfare an Internationally Understood Concept in the Zoo World? Thematic Analysis of Two Regional Groups of Zoo Staff. *Animals*, *11*(7). https://doi.org/10.3390/ani11072059

Bagstad, K. J., & Shammin, M. R. (2012). Can the Genuine Progress Indicator better inform sustainable regional progress?—A case study for Northeast Ohio. *Ecological Indicators*, *18*, 330–341. https://doi.org/10.1016/j.ecolind.2011.11.026

Bansal, R., Ochoa, M., & Kiku, D. (2016). *Climate Change and Growth Risks* (Working Paper No. 23009). National Bureau of Economic Research. https://doi.org/10.3386/w23009

Battiston, S., Dafermos, Y., & Monasterolo, I. (2021). Climate risks and financial stability. *Journal of Financial Stability*, *54*, 100867. https://doi.org/10.1016/j.jfs.2021.100867

Baum, S. D. (2024). Climate change, uncertainty, and global catastrophic risk. *Futures*, *162*, 103432. https://doi.org/10.1016/j.futures.2024.103432

Beard, S. J., Holt, L., Tzachor, A., Kemp, L., Avin, S., Torres, P., & Belfield, H. (2021). Assessing climate change's contribution to global catastrophic risk. *Futures*, *127*, 102673. https://doi.org/10.1016/j.futures.2020.102673

Beard, S. J., & Kemp, L. (2024). 14. Existential Change: Lesson from Climate Change for Existential Risk. *AN ANTHOLOGY OF GLOBAL RISK*, 401.

Beça, P., & Santos, R. (2010). Measuring sustainable welfare: A new approach to the ISEW. *Ecological Economics*, *69*(4), 810–819. https://doi.org/10.1016/j.ecolecon.2009.11.031

Beckstead, N. (2013). *ON THE OVERWHELMING IMPORTANCE OF SHAPING THE FAR FUTURE*. The State University of New Jersey.

Beckstead, N. (2019). A Brief Argument for the Overwhelming Importance of Shaping the Far Future. In H. Greaves & T. Pummer (Eds.), *Effective Altruism: Philosophical Issues* (p. 0). Oxford University Press. https://doi.org/10.1093/oso/9780198841364.003.0006

Begum, N., Tariq, M., Jehan, N., & Khan, F. (2024). Subjective assessment of women's economic welfare in public sector organizations of Mardan, Northern Pakistan. *International Journal of Social Economics*, *51*(9), 1151–1166. https://doi.org/10.1108/IJSE-04-2023-0246

Bentham, J. (1843). *The Works of Jeremy Bentham*. W. Tait.

Bentham, J. (1999). *Political Tactics*. Clarendon Press.

Berlian, N., Bahari, A. M. F., Ramdani, J., Candra, R., Sari, I. P., & Aditya, M. (2023). Welfare Classification of Muslim Majority Communities using Decision Tree Algorithm. *Khazanah Journal of Religion and Technology*, *1*(1). https://doi.org/10.15575/kjrt.v1i1.160

Bonoli, G. (2005). *The politics of the new social policies: Providing coverage against new social risks in mature welfare states*. https://doi.org/10.1332/0305573054325765

Boston, P., & Mount, B. M. (2006). The Caregiver's Perspective on Existential and Spiritual Distress in Palliative Care. *Journal of Pain and Symptom Management*, *32*(1). https://doi.org/10.1016/j.jpainsymman.2006.01.009

Bostrom, N. (2002). *Existential Risks: Analyzing Human Extinction Scenarios*. https://nickbostrom.com/existential/risks

Bostrom, N. (2013). Existential Risk Prevention as Global Priority. *Global Policy*, *4*(1), 15–31.

Bostrom, N. (2014). *Crucial Considerations and Wise Philanthropy – Nick Bostrom's Home Page*. https://nickbostrom.com/lectures/crucial-considerations/

Botzen, W., Bergh, J. C. J. M. van den, & Chichilnisky, G. (2018). Climate Policy Without Intertemporal Dictatorship: Chichilnisky Criterion Versus Classical Utilitarianism in Dice. *Climate Change Economics*, *09*(02). https://doi.org/10.1142/s2010007818500021

Boyd, M. (Philosopher), & Wilson, N. (2021). Anticipatory governance for preventing and mitigating catastrophic and existential risks (B). *Policy Quarterly*, *17*(4), 20–31.

Boyd, M., & Wilson, N. (2021). Optimizing Island Refuges against global Catastrophic and Existential Biological Threats: Priorities and Preparations (a). *Risk Analysis*, *41*(12). https://doi.org/10.1111/risa.13735

Brennan, A. J. (2008). Theoretical foundations of sustainable economic welfare indicators—ISEW and political economy of the disembedded system. *Ecological Economics*, *67*(1), 1–19. https://doi.org/10.1016/j.ecolecon.2008.05.019

Bressler, R. D. (2021). The mortality cost of carbon. *Nature Communications*, *12*(1). https://doi.org/10.1038/s41467-021-24487-w

Büchs, M. (2021). Sustainable welfare: Independence between growth and welfare has to go both ways: *Global Social Policy*, *21*(2), 323–327. https://doi.org/10.1177/14680181211019153

Butler, C. D. (2018). Climate Change, Health and Existential Risks to Civilization: A Comprehensive Review (1989–2013). *International Journal of Environmental Research and Public Health*, *15*(10), 2266. https://doi.org/10.3390/ijerph15102266

Castellacci, F. (2023). Innovation and social welfare: A new research agenda. *Journal of Economic Surveys*, *37*(4), 1156–1191. https://doi.org/10.1111/joes.12537

Cevik, S., & Jalles, J. T. (2020). Feeling the Heat. *IMF Working Papers*, *20*(286). https://doi.org/10.5089/9781513564548.001

Chacon-Hurtado, D., Kazerounian, K., Hertel, S., Mellor, J., Barry, J. J., & Ravindran, T. (2024). Engineering for Human Rights: The Theory and Practice of a Human Rights–based Approach to Engineering. *Science, Technology, & Human Values*, *49*(4), 898–934. https://doi.org/10.1177/01622439231211112

Clerc, M., Gaini, M., & Blanchet, D. (2011). Recommendations of the Stiglitz-Sen-Fitoussi report: A few illustrations. *Research Papers in Economics*. https://typeset.io/papers/recommendations-of-the-stiglitz-sen-fitoussi-report-a-few-2xre7xserm

Cockburn, J., Duclos, J.-Y., & Zabsonré, A. (2014). Is global social welfare increasing? A critical-level enquiry. *Journal of Public Economics*, *118*, 151–162. https://doi.org/10.1016/j.jpubeco.2014.06.013

Colander, D. (2007). Retrospectives: Edgeworth's Hedonimeter and the Quest to Measure Utility. *Journal of Economic Perspectives*, *21*(2). https://doi.org/10.1257/jep.21.2.215

Collins, D. G., Holman, A. R., & Hsu, T. S. (2024). The psychological impact of the COVID-19 pandemic on Black social workers. *The Journal of Humanistic Counseling*, *63*(2), 143–159. https://doi.org/10.1002/johc.12227

Collste, D., Cornell, S. E., Randers, J., Rockström, J., & Stoknes, P. E. (2021). Human well-being in the Anthropocene: Limits to growth. *Global Sustainability*, *4*, e30. https://doi.org/10.1017/sus.2021.26

Comiskey, J., Larrañaga, M. D., & Carlson, C. (2021). Climate Security: Challenges and Opportunities for Homeland Security. *Handbook of Security Science*. https://doi.org/10.1007/978-3-319-51761-2_55-1

Conable, J. E., Newman, J., & Olsson, I. (2024). Understanding the Dynamics of Life Satisfaction in the Swedish Welfare State: A Multifaceted Analysis Integrating Quantitative, Qualitative, and Discourse Approaches. *Journal of Social Science Studies*, *11*(1), Article 1. https://doi.org/10.5296/jsss.v11i1.21793

Cotton-Barratt, O., Daniel, M. G., & Sandberg, A. (2020). Defence in Depth Against Human Extinction: Prevention, Response, Resilience, and Why They All Matter. *Global Policy*, *11*(3). https://doi.org/10.1111/1758-5899.12786

Cotton-Barratt, O., & Ord, T. (2015). Existential Risk and Existential Hope. *Technical Report*.

Dalton, P., & Ghosal, S. (2017). Self-Fulfilling Mistakes: Characterisation and Welfare. *The Economic Journal*, *128*(609). https://doi.org/10.1111/ecoj.12409

Danil, L. R. (2020). On facing the crucial psychosocial and political-economic dimensions of anthropogenic global warming. *Psychoanalysis, Culture & Society*, *25*(2), 271–282. https://doi.org/10.1057/s41282-020-00165-6

Dar, T., Rai, N., Kumar, S., & Bhat, M. A. (2024). Understanding hydrological processes of glacierized catchments in the western Himalayas by a multi-year tracer-based hydrograph separation analysis. *Hydrological Processes*, *38*(2), e15083. https://doi.org/10.1002/hyp.15083

Deeming, C., & Hayes, D. (2012). Worlds of Welfare Capitalism and Wellbeing: A Multilevel Analysis. *Journal of Social Policy*, *41*(4), 811–829. https://doi.org/10.1017/S0047279412000499

del Carmen Pérez-Peña, M., Pérez-Peña, M., Ruiz-Chico, J., & eña-Sánchez, ntonio R. (2021). Analysis of research on the sdgs: The relationship between climate change, poverty and inequality. *Applied Sciences*, *11*(19), 8947. https://doi.org/10.3390/APP11198947

Dietz, S., Rising, J., Stoerk, T., & Wagner, G. (2021). Economic impacts of tipping points in the climate system. *Proceedings of the National Academy of Sciences*, *118*(34). https://doi.org/10.1073/pnas.2103081118

Embrett, M., Bielska, I. A., Manis, D. R., Cooper, R., Agarwal, G., Nartowski, R., Moore, E., Lopatina, E., Conway, A., & Clark, K. (2021). Outcomes for Implemented Macroeconomic Policy Responses and Multilateral Collaboration Strategies for Economic Recovery After a Crisis: A Rapid Scoping Review. *International Journal of Health Services*, *51*(3), 337–349. https://doi.org/10.1177/00207314211007100

Farnsworth, A., Lo, Y. T. E., Valdes, P. J., Buzan, J. R., Mills, B. J. W., Merdith, A. S., Scotese, C. R., & Wakeford, H. R. (2023). Climate extremes likely to drive land mammal extinction during next supercontinent assembly. *Nature Geoscience*, *16*(10), 901–908. https://doi.org/10.1038/s41561-023-01259-3

Fellner, W., & Goehmann, B. (2019). Human needs, consumerism and welfare. *Cambridge Journal of Economics*, *44*(2). https://doi.org/10.1093/cje/bez046

Ferryono, B., Pudjihardjo, M., & Prasetyia, F. (2022). The Impact of Financial Accountability, Internal Control and Government Expenditure on Social Welfare. *Journal of International Conference Proceedings*, *5*(2). https://doi.org/10.32535/jicp.v5i2.1678

Fleurbaey, M., Fouquin, M., & Gaulier, G. (2011). Going Beyond GDP – But How Far? *La Lettre Du CEPII*, *312*. https://ideas.repec.org//a/cii/cepill/2011-312.html

Fleurbaey, M., & Zuber, S. (2021). Fair Utilitarianism. *American Economic Journal: Microeconomics*, *13*(2). https://doi.org/10.1257/mic.20170234

Foa, R. S., & Welzel, C. (2023). Existential insecurity and deference to authority: The pandemic as a natural experiment. *Frontiers in Political Science*, *5*. https://doi.org/10.3389/fpos.2023.1117550

Fogel, R. (1987). *Some Notes on the Scientific Methods of Simon Kuznets* (No. w2461; p. w2461). National Bureau of Economic Research. https://doi.org/10.3386/w2461

Fourier. (1999). Joseph Fourier, the 'greenhouse effect', and the quest for a universal theory of terrestrial temperatures. *Endeavour*, *23*, 72–75. https://doi.org/10.1016/S0160-9327(99)01210-7

Fox, M.-J. V., & Erickson, J. D. (2020). Design and meaning of the genuine progress indicator: A statistical analysis of the U.S. fifty-state model. *Ecological Economics*, *167*, 106441. https://doi.org/10.1016/J.ECOLECON.2019.106441

Galgóczi, B. (2022). From a 'just transition for us' to a 'just transition for all'. *Transfer: European Review of Labour and Research*, *28*(3). https://doi.org/10.1177/10242589221125066

Gantayat, P., Banwell, A. F., Leeson, A. A., Lea, J. M., Petersen, D., Gourmelen, N., & Fettweis, X. (2023). A new model for supraglacial hydrology evolution and drainage for the Greenland Ice Sheet (SHED v1.0). *Geoscientific Model Development*, *16*(20), 5803–5823. https://doi.org/10.5194/gmd-16-5803-2023

Gao, T., Zhang, Y., Wei, D., Zhao, Y., Liu, Z., & Sillanpää, M. (2023). *Cryospheric melting enhances methane emissions from inland waters on the Tibetan Plateau*. Research Square. https://doi.org/10.21203/rs.3.rs-2936325/v1

Gawda, B., & Korniluk, A. (2024). The Protective Role of Curiosity Behaviors in Coping with Existential Vacuum. *Behavioral Sciences*, *14*(5), Article 5. https://doi.org/10.3390/bs14050391

Gehringer, A., & Kowalski, S. (2023). Delimitating Sustainability and Its Dimensions. In A. Gehringer & S. Kowalski (Eds.), *Mapping Sustainability Measurement: A Review of the Approaches, Methods, and Literature* (pp. 15–22). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-47382-1_3

Giannetti, B. F., Agostinho, F., Almeida, C. M. V. B., & Huisingh, D. (2015). A review of limitations of GDP and alternative indices to monitor human wellbeing and to manage eco-system functionality. *Journal of Cleaner Production*, *87*, 11–25. https://doi.org/10.1016/j.jclepro.2014.10.051

Gillet-Chaulet, F., Gagliardini, O., Seddik, H., Nodet, M., Durand, G., Ritz, C., Zwinger, T., Greve, R., & Vaughan, D. G. (2012). Greenland ice sheet contribution to sea-level rise from a new-generation ice-sheet model. *The Cryosphere*, *6*(6), 1561–1576. https://doi.org/10.5194/tc-6-1561-2012

Gong, H., Hassink, R., Foster, C., Hess, M., & Garretsen, H. (2022). Globalisation in reverse? Reconfiguring the geographies of value chains and production networks. *Cambridge Journal of Regions, Economy and Society*, *15*(2), 165–181. https://doi.org/10.1093/cjres/rsac012

Gowdy, J. (2005). Toward a new welfare economics for sustainability. *Ecological Economics*, *53*(2), 211–222. https://doi.org/10.1016/j.ecolecon.2004.08.007

Greve, B. (2017). How to Measure Social Progress? *Social Policy & Administration*, *51*(7), 1002–1022. https://doi.org/10.1111/spol.12219

Gruen, C., & Klasen, S. (2008). Growth, inequality, and welfare: Comparisons across space and time. *Oxford Economic Papers*, *60*(2), 212–236. https://doi.org/10.1093/oep/gpm042

Gunathilaka, R. P. D., Smart, J. C. R., Fleming, C., & Hasan, S. (2018). The impact of climate change on labour demand in the plantation sector: The case of tea production in Sri Lanka. *Australian Journal of Agricultural and Resource Economics*, *62*(3). https://doi.org/10.1111/1467-8489.12262

Haigh, M., Holland, P. R., & Jenkins, A. (2023). The Influence of Bathymetry Over Heat Transport Onto the Amundsen Sea Continental Shelf. *Journal of Geophysical Research: Oceans*, *128*(5), e2022JC019460. https://doi.org/10.1029/2022JC019460

Hämäläinen, J., Pihlainen, K., & Vornanen, R. (2020). Sustainable Family Life and Child Welfare: A Conceptual Framework. *Sustainability*, *12*(21). https://doi.org/10.3390/su12219112

Hasanaj, V. (2023). Global Patterns of Contemporary Welfare States. *Journal of Social Policy*, *52*(4), 886–922. https://doi.org/10.1017/S0047279421001033

Hayden, A., & Wilson, J. (2016). Is It What You Measure That Really Matters? The Struggle to Move beyond GDP in Canada. *Sustainability*, *8*(7). https://doi.org/10.3390/su8070623

He, Q., Kuang, X., Ma, E., Chen, J., Feng, Y., & Zheng, C. (2023). Reconstructing runoff components and glacier mass balance with climate change: Niyang river basin, southeastern Tibetan plateau. *Frontiers in Earth Science*, *11*. https://doi.org/10.3389/feart.2023.1165390

Helliwell, J. F., Layard, R., Sachs, J. D., De Neve, J.-E., Aknin, L. B., & Wang, S. (2024). *World Happiness Report Data Dashboard*. University of Oxford: Wellbeing Research Centre. https://worldhappiness.report/data/

Heys, R., Martin, J., & Mkandawire, W. (2019). *GDP and Welfare: A spectrum of opportunity* (Discussion Paper Nos. 2019–16). https://escoewebsite.s3.amazonaws.com/wp-content/uploads/2020/07/14160047/ESCoE-DP-2019-16-V1.pdf

Hicks, S. F., & Janus, D. (2023). The Threat of Longtermism: Is Ecological Catastrophe an Existential Risk? Disillusioned Ideals for a Bold, New Future. *Filozofia*, *78*(10S), 133–148. https://doi.org/10.31577/filozofia.2023.78.10.Suppl.11

Höning, D., Willeit, M., Calov, R., Klemann, V., Bagge, M., & Ganopolski, A. (2023). Multistability and Transient Response of the Greenland Ice Sheet to Anthropogenic CO2 Emissions. *Geophysical Research Letters*, *50*(6), e2022GL101827. https://doi.org/10.1029/2022GL101827

Howarth, C. (2020). Informing UK governance of resilience to climate risks: Improving the local evidence-base. *Climatic Change*, *163*(1), 499–520.

Huggel, C., Bouwer, L. M., Juhola, S., Mechler, R., Muccione, V., Orlove, B., & Wallimann-Helmer, I. (2022). The existential risk space of climate change. *Climatic Change*, *174*(1), 8. https://doi.org/10.1007/s10584-022-03430-y

Hysa, E., Kruja, A., Rehman, N. U., & Laurenti, R. (2020). Circular Economy Innovation and Environmental Sustainability Impact on Economic Growth: An Integrated Model for Sustainable Development. *Sustainability*, *12*(12), Article 12. https://doi.org/10.3390/su12124831

Iacobucci, E., & Trebilcock, M. J. (2022). Existential threats: Climate change, pandemics and institutions. *Canadian Public Administration*, *65*(4). https://doi.org/10.1111/capa.12504

IPCC, I. P. O. C. C. (2001). *CLIMATE CHANGE 2001: IMPACTS, ADAPTATION AND VULNERABILITY", THE CONTRIBUTION OF WORKING GROUP II TO THE IPCC THIRD ASSESSMENT REPORT* (No. 3d). https://www.ipcc.ch/site/assets/uploads/2001/04/doc3d.pdf

Jacobs, G., & Šlaus, I. (2010). *Indicators of Economics Progress-The Power of Measurement and Human Welfare*. *1*(1). https://www.cadmusjournal.org/files/pdfreprints/vol1issue1/Indicators%20of%20Economics%20Progress-The%20Power%20of%20Measurement%20and%20Human%20Welfare,%20Jacobs,%20Garry%20et%20al.pdf

Jakob, M., & Steckel, J. C. (2013). How climate change mitigation could harm development in poor countries. *WIREs Climate Change*, *5*(2). https://doi.org/10.1002/wcc.260

Järvelä, M. (2023). Dimensions of cultural sustainability—Local adaptation, adaptive capacity and social resilience. *Frontiers in Political Science*. https://doi.org/10.3389/fpos.2023.1285602

Jones, C. I. (2022). The End of Economic Growth? Unintended Consequences of a Declining Population. *American Economic Review*, *112*(11), 3489–3527. https://doi.org/10.1257/aer.20201605

Jones, C. I., & Klenow, P. J. (2016). Beyond GDP? Welfare across Countries and Time. *American Economic Review*, *106*(9), 2426–2457. https://doi.org/10.1257/aer.20110236

Jones, N. (2023). *4. Beyond 'Error and Terror': Global Justice and Global Catastrophic Risk*. 79–100. https://doi.org/10.11647/obp.0336.04

Kaimovs, M., & Skarupins, A. (2024). INTEGRITY OF VARIOUS ASPECTS OF SUSTAINABILITY. *Economics & Education*, *9*(2), Article 2. https://doi.org/10.30525/2500-946X/2024-2-1

Kalimeris, P., Bithas, K., Richardson, C., & Nijkamp, P. (2020). Hidden linkages between resources and economy: A "Beyond-GDP" approach using alternative welfare indicators. *Ecological Economics*, *169*, 106508. https://doi.org/10.1016/j.ecolecon.2019.106508

Kandrács, C., & Ritter, átó. (2024). Sustainability Indicators – the Boundaries and Alternatives of GDP. *Financial and Economic Review*, *23*(2), 31–55. https://doi.org/10.33893/fer.23.2.31

Kar, M. (2022). New Indicators and Measurement Methods for Welfare in the Global Economy Era. In *Redefining Global Economic Thinking for the Welfare of Society* (pp. 8–32). IGI Global. https://doi.org/10.4018/978-1-7998-8258-9.ch002

Karlson, C. W., Morsut, C., & Engen, O. A. H. (2023). Politics of climate risk management in local government: A case study of the municipality of Stavanger. *Frontiers in Climate*, *5*. https://doi.org/10.3389/fclim.2023.1136673

Kemp, L., Xu, C., Depledge, J., Ebi, K. L., Gibbins, G., Kohler, T. A., Rockström, J., Scheffer, M., Schellnhuber, H. J., Steffen, W., & Lenton, T. M. (2022). Climate Endgame: Exploring catastrophic climate change scenarios. *Proceedings of the National Academy of Sciences*, *119*(34), e2108146119. https://doi.org/10.1073/pnas.2108146119

Khabarov, N., Obersteiner, M., & Smirnov, A. (2022). Social cost of carbon: A revisit from a systems analysis perspective. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.923631

Khadka, A., Brun, F., Wagnon, P., Shrestha, D., & Sherpa, T. C. (2024). *Surface energy and mass balance of Mera Glacier (Nepal, Central Himalaya) and their sensitivity to temperature and precipitation*. https://eartharxiv.org/repository/view/7289/

Kiley, M. T. (2023). Growth at risk from climate change. *Economic Inquiry*, *62*(3). https://doi.org/10.1111/ecin.13206

Kind, J., Botzen, W., & Aerts, J. C. J. H. (2019). Social vulnerability in cost-benefit analysis for flood risk management. *Environment and Development Economics*, *25*(2). https://doi.org/10.1017/s1355770x19000275

Kinslow, C. J., Kumar, P., Olfson, M., Wall, M. M., Petridis, P. D., Horowitz, D. P., Wang, T. J. C., Kachnic, L. A., Cheng, S. K., Prigerson, H. G., Yu, J. B., & Neugut, A. I. (2024). Prognosis and risk of suicide after cancer diagnosis. *Cancer*, *130*(4), 588–596. https://doi.org/10.1002/cncr.35118

Kirezci, E., Young, I. R., Ranasinghe, R., Muis, S., Nicholls, R. J., Lincke, D., & Hinkel, J. (2020). Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st Century. *Scientific Reports*, *10*(1), 11629. https://doi.org/10.1038/s41598-020-67736-6

Kobus, M., Półchłopek, O., & Yalonetzky, G. (2019). Inequality and Welfare in Quality of Life Among OECD Countries: Non-parametric Treatment of Ordinal Data. *Social Indicators Research*, *143*(1), 201–232. https://doi.org/10.1007/s11205-018-1962-8

Kot, S. M., & Paradowski, P. R. (2024). *A CONSISTENT ASSESSMENT OF SOCIAL WELFARE BY TWO METHODOLOGIES. THE THEORY AND EVIDENCE FROM THE LUXEMBOURG INCOME STUDY DATABASE*.

Kraay, A., Lakner, C., Özler, B., Decerf, B., Jolliffe, D., Sterck, O., & Yonzan, N. (2023). *A New Distribution Sensitive Index for Measuring Welfare, Poverty, and Inequality*. Washington, DC: World Bank. https://doi.org/10.1596/1813-9450-10470

Kreinin, H., & Aigner, E. (2022). From “Decent work and economic growth” to “Sustainable work and economic degrowth”: A new framework for SDG 8. *Empirica*, *49*(2), 281–311. https://doi.org/10.1007/s10663-021-09526-5

Kubiszewski, I., Costanza, R., Franco, C., Lawn, P., Talberth, J., Jackson, T., & Aylmer, C. (2013). Beyond GDP: Measuring and achieving global genuine progress. *Ecological Economics*, *93*. https://doi.org/10.1016/j.ecolecon.2013.04.019

Kulp, S. A., & Strauss, B. H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature Communications*, *10*(1), 4844. https://doi.org/10.1038/s41467-019-12808-z

Kumar, A., Nagar, S., & Anand, S. (2021). 1—Climate change and existential threats. In S. Singh, P. Singh, S. Rangabhashiyam, & K. K. Srivastava (Eds.), *Global Climate Change* (pp. 1–31). Elsevier. https://doi.org/10.1016/B978-0-12-822928-6.00005-8

Kwarciński, T., & Turek, K. M. (2021). Can Normative Economics Be Convincing without the Notion of Well-Being? *Filozofia Nauki*, *29*(3), Article 3. https://doi.org/10.14394/filnau.2021.0018

Laenen, T., Rossetti, F., & Oorschot, W. van. (2019). Why deservingness theory needs qualitative research: Comparing focus group discussions on social welfare in three welfare regimes. *International Journal of Comparative Sociology*, *60*(3). https://doi.org/10.1177/0020715219837745

Lenton, T. M. (2023). Climate Change and Tipping Points in Historical Collapse. In *How Worlds Collapse*. Routledge.

Li, C. (2023). Impacts of Global Warming on Economy. *Highlights in Business, Economics and Management*, *5*, 101–104. https://doi.org/10.54097/hbem.v5i.5036

Liu, G., Brown, M., & Casazza, M. (2017). Enhancing the Sustainability Narrative through a Deeper Understanding of Sustainable Development Indicators. *Sustainability*, *9*(6), 1078. https://doi.org/10.3390/su9061078

Lovrinčević, Ž., Mikulić, D., & Galić Nagyszombaty, A. (2013). IS GDP AN APPROPRIATE INDICATOR OF SUSTAINABLE ECONOMIC DEVELOPMENT? *Ekonomski Pregled*, *64*(5), 474–493.

Luc, D. T. (2008). Pareto Optimality. In A. Chinchuluun, P. M. Pardalos, A. Migdalas, & L. Pitsoulis (Eds.), *Pareto Optimality, Game Theory And Equilibria* (pp. 481–515). Springer. https://doi.org/10.1007/978-0-387-77247-9_18

MacAskill, W. (2022). *What We Owe The Future: The Sunday Times Bestseller*. Simon and Schuster.

Magnan, A. K., O'Neill, B. C., & Garschagen, M. (2023). Further understanding "severe" climate risk. *Climate Risk Management*, *42*, 100538. https://doi.org/10.1016/j.crm.2023.100538

Malay, O. E. (2021). How to Articulate Beyond GDP and Businesses' Social and Environmental Indicators? *Social Indicators Research*, *155*(1), 1–25. https://doi.org/10.1007/s11205-020-02583-6

Mäntyneva, P. (2023). Do welfare regimes matter? Perceptions of welfare in contemporary word. *International Journal of Sociology and Social Policy*, *44*(1/2), 236–248. https://doi.org/10.1108/IJSSP-09-2023-0236

Marcos, M., & Amores, A. (2014). Quantifying anthropogenic and natural contributions to thermosteric sea level rise. *Geophysical Research Letters*, *41*(7), 2502–2507. https://doi.org/10.1002/2014GL059766

McCarthy, G. D., & Caesar, L. (2023). Can we trust projections of AMOC weakening based on climate models that cannot reproduce the past? *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *381*(2262), 20220193. https://doi.org/10.1098/rsta.2022.0193

McLaughlin, A. (2024). Existential Risk, Climate Change, and Nonideal Justice. *The Monist*, *107*(2), 190–206.

McNamara, K. E., & Jackson, G. V. H. (2018). Loss and damage: A review of the literature and directions for future research. *WIREs Climate Change*, *10*(2). https://doi.org/10.1002/wcc.564

McPherson Frantz, C., Ezimora, I., Petersen, J. E., Edminster, A., Shammin, M. R., & Chi, Y. (2024). Measuring Social Dimensions of Sustainability at the Community Level: An Illustrative but Cautionary Tale. *Sustainability*. https://doi.org/10.3390/su16104197

Meire, L., Paulsen, M. L., Meire, P., Rysgaard, S., Hopwood, M. J., Sejr, M. K., Stuart-Lee, A., Sabbe, K., Stock, W., & Mortensen, J. (2023). Glacier retreat alters downstream fjord ecosystem structure and function in Greenland. *Nature Geoscience*, *16*(8), 671–674. https://doi.org/10.1038/s41561-023-01218-y

Méjean, A., Pottier, A., Fleurbaey, M., & Zuber, S. (2020). Catastrophic climate change, population ethics and intergenerational equity. *Climatic Change*, *163*(2), 873–890. https://doi.org/10.1007/s10584-020-02899-9

Menegaki, A. (2018). The Basic, the Solid, the Site-Specific and the Full or Total Index of Sustainable Economic Welfare (ISEW) for Turkey. *Economies*, *6*(2), Article 2. https://doi.org/10.3390/economies6020024

Mill, J. S. (2009). *Utilitarismus*. Felix Meiner Verlag.

Millan, R., Jager, E., Mouginot, J., Wood, M. H., Larsen, S. H., Mathiot, P., Jourdain, N. C., & Bjørk, A. (2023). Rapid disintegration and weakening of ice shelves in North Greenland. *Nature Communications*, *14*(1), 6914. https://doi.org/10.1038/s41467-023-42198-2

Millner, A. (2013). On welfare frameworks and catastrophic climate risks. *Journal of Environmental Economics and Management*, *65*(2), 310–325. https://doi.org/10.1016/j.jeem.2012.09.006

Mitsui, T., & Boers, N. (2023). *Statistical precursor signals for Dansgaard-Oeschger cooling transitions*. https://eartharxiv.org/repository/view/5038/

Monadiyan, N. E., & Haris, F. (2022). Development of The Welfare Index at Sub-district Level in West Java 2020: A Small Area Estimation Approach. *Proceedings of the International Conference on Data Science and Official Statistics*, *2021*(1). https://doi.org/10.34123/icdsos.v2021i1.144

Mostue, I. A., Hofer, S., Storelvmo, T., & Fettweis, X. (2024). Cloud- and ice-albedo feedbacks drive greater Greenland Ice Sheet sensitivity to warming in CMIP6 than in CMIP5. *The Cryosphere*, *18*(1), 475–488. https://doi.org/10.5194/tc-18-475-2024

Muehlhauser, L. (2019). How Feasible Is Long-range Forecasting? *Open Philanthropy*. https://www.openphilanthropy.org/research/how-feasible-is-long-range-forecasting/

Mutongwizo, T., Shearing, C., & Blaustein, J. (2024). Resilience Policing and Climate Change: Adaptive Responses to Crises and Emergencies. In *Routledge International Handbook of Policing Crises and Emergencies*. Routledge.

Nakamura, L., & Hulten, C. (2022). *Is GDP Becoming Obsolete? The 'Beyond GDP' Debate*. 37th IARIW General Conference.

Nguyen, T. V. H. (2022). Welfare impact of climate change on capture fisheries in Vietnam. *Plos One*, *17*(4). https://doi.org/10.1371/journal.pone.0264997

Nicholls, R. J., & Cazenave, A. (2010). Sea-Level Rise and Its Impact on Coastal Zones. *Science*, *328*(5985), 1517–1520. https://doi.org/10.1126/science.1185782

Noël, B., Berg, W. J. van de, Lhermitte, S., Wouters, B., Machguth, H., Howat, I. M., Citterio, M., Moholdt, G., Lenaerts, J. T. M., & Broeke, M. R. van den. (2017). A tipping point in refreezing accelerates mass loss of Greenland's glaciers and ice caps. *Nature Communications*, *8*(1). https://doi.org/10.1038/ncomms14730

Nordhaus, W. (2006). *The 'Stern Review' on the Economics of Climate Change* (No. w12741; p. w12741). National Bureau of Economic Research. https://doi.org/10.3386/w12741

Nordhaus, W. (2019). Economics of the disintegration of the Greenland ice sheet. *Proceedings of the National Academy of Sciences*, *116*(25), 12261–12269. https://doi.org/10.1073/pnas.1814990116

Nordhaus, W. D. (2017). Revisiting the social cost of carbon. *Proceedings of the National Academy of Sciences*, *114*(7). https://doi.org/10.1073/pnas.1609244114

Nordhaus, W. D. (2018). Evolution of modeling of the economics of global warming: Changes in the DICE model, 1992–2017. *Climatic Change*, *148*(4). https://doi.org/10.1007/s10584-018-2218-y

Nyberg, D., Wright, C., & Kirk, J. (2018). Fracking the Future: The Temporal Portability of Frames in Political Contests. *Organization Studies*, *41*(2). https://doi.org/10.1177/0170840618814568

Offer, A. (2000). *Economic Welfare Measurements and Human Well-Being.* https://ora.ox.ac.uk/objects/uuid:c9dae321-0e7c-4390-9671-5580c5087d23

Ord, T. (2020). *The Precipice: Existential Risk and the Future of Humanity* (1st ed.). Bloomsbury Publishing. https://www.amazon.de/Precipice-Existential-Risk-Future-Humanity/dp/0316484911

Ord, T. (2023). *Shaping Humanity's Longterm Trajectory*.

Pais, D. F., Afonso, T. L., Marques, A. C., & Fuinhas, J. A. (2019). Are Economic Growth and Sustainable Development Converging? Evidence From the Comparable Genuine Progress Indicator for Organisation for Economic Co-Operation and Development Countries. *International Journal of Energy Economics and Policy*, *9*(4). https://doi.org/10.32479/ijeep.7678

Panton, A. (2020). Climate Hysteresis and Monetary Policy. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3679771

Pardhan, S., & Drydakis. (2021). Associating the Change in New COVID-19 Cases to GDP per Capita in 38 European Countries in the First Wave of the Pandemic. *Frontiers in Public Health*, *8*, 582140–582140. https://doi.org/10.3389/FPUBH.2020.582140

Paulvannan Kanmani, A., Obringer, R., Rachunok, B., & Nateghi, R. (2020). Assessing Global Environmental Sustainability Via an Unsupervised Clustering Framework. *Sustainability*, *12*(2), 563. https://doi.org/10.3390/su12020563

Phillips, R. (2023). Practising Feminism for Social Welfare—A Global Perspective. Ruth. *British Journal of Social Work*. https://doi.org/10.1093/bjsw/bcad127

Pigou, A. (2017). *The Economics of Welfare*. Routledge. https://doi.org/10.4324/9781351304368

Pinar, M. (2022). Sensitivity of environmental performance index based on stochastic dominance. *Journal of Environmental Management*, *310*, 114767. https://doi.org/10.1016/j.jenvman.2022.114767

Pissourios, I. A. (2013). An interdisciplinary study on indicators: A comparative review of quality-of-life, macroeconomic, environmental, welfare and sustainability indicators. *Ecological Indicators*, *34*, 420–427.

Pita, I., Goes, M. P., Volkov, D. L., Dong, S., Goni, G. J., & Cirano, M. (n.d.). *An ARGO and XBT observing system for the Atlantic Meridional Overturning Circulation and Meridional Heat Transport (AXMOC) at 22.5ºS*. https://doi.org/10.22541/essoar.168565447.73440086/v1

Posner, R. A. (2004). *Catastrophe: Risk and Response*. Oxford University Press, USA.

Powell, & Chen, S. (2012). Globalization and Global Welfare: A Critical Excursion | Fast Capitalism. *Fast Capitalism*, *9*. https://fastcapitalism.journal.library.uta.edu/index.php/fastcapitalism/article/view/264

Pryimak, V., Holubnyk, O., Ucieklak-Jeż, P., Kubicka, J., Urbańska, K., & Babczuk, A. (2021). Fuzzy Technologies Modeling the Level of Welfare of the Population in the System of Effective Management. *European Research Studies Journal*, *XXIV*(Issue 3). https://doi.org/10.35808/ersj/2382

Ravallion, M., & Chen, S. (2019). Global poverty measurement when relative income matters. *Journal of Public Economics*, *177*, 104046. https://doi.org/10.1016/j.jpubeco.2019.07.005

Ren, X., Liu, W., Allen, R. J., & Song, S.-Y. (2024). Distinct anthropogenic greenhouse gas and aerosol induced marine heatwaves. *Environmental Research: Climate*, *3*(1), 015004. https://doi.org/10.1088/2752-5295/ad13ac

Rezai, A. (2010). Recast the Dice and Its Policy Recommendations. *Macroeconomic Dynamics*, *14*(S2). https://doi.org/10.1017/s1365100510000428

Ricardo, D. (2012). *The Principles of Political Economy and Taxation*. Dover Publications.

Rising, Tedesco, Piontek, & Stainforth. (2022). *Data for The missing risks of climate change* [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.7343488

Robinson, K. M., Flowers, G. E., Baraër, M., & Rounce, D. R. (2024). *Modelling glacier mass balance and runoff in the Kaskawulsh River headwaters of southwest Yukon, Canada, 1980-2022*. https://eartharxiv.org/repository/view/8149/

Roser, M. (2022). The future is vast – what does this mean for our own life? *Our World in Data*. https://ourworldindata.org/the-future-is-vast

Sabetan, F. (1997). An Exploration into the Political Economy of Global Prosperity. *The Journal of Bahá'í Studies*, *7*(4), 43–68. https://doi.org/10.31581/jbs-7.4.271(1997)

Salehie, O., Jamal, M. H. bin, Ismail, T. bin, Harun, S. B., & Shahid, S. (2024). Projection of future water availability in the Amu Darya Basin. *International Journal of Climatology*, *44*(9), 2948–2961. https://doi.org/10.1002/joc.8490

Sandmo, A. (2007). *The Welfare Economics of Global Public Goods* (SSRN Scholarly Paper No. 1550703). Social Science Research Network. https://doi.org/10.2139/ssrn.1550703

Schepelmann, P. & Wuppertal Institut für Klima, Umwelt, Energie (Eds.). (2010). *Towards sustainable development: Alternatives to GDP for measuring progress*. Wuppertal-Inst. für Klima, Umwelt, Energie.

Schleussner, C.-F., Pfleiderer, P., Andrijevic, M., Vogel, M. M., Otto, F. E. L., & Seneviratne. (2021). Pathways of climate resilience over the 21st century. *Environmental Research Letters*, *16*(5), 054058. https://doi.org/10.1088/1748-9326/ABED79

Schubertová, M. M., & Antalová, M. (2023). *Social Quality and Working Poverty in the European Union and Slovakia in Particular*. https://doi.org/10.3167/IJSQ.2023.130107

Schuller, B.-J. (2014). Is GDP a suitable indicator of welfare? How to define and measure welfare. *Applied Economics: Systematic Research*, *8*(2), 13–26. https://doi.org/10.7220/AESR.2335.8742.2014.8.2.1

Schuur, E. a. G., McGuire, A. D., Schädel, C., Grosse, G., Harden, J. W., Hayes, D. J., Hugelius, G., Koven, C. D., Kuhry, P., Lawrence, D. M., Natali, S. M., Olefeldt, D., Romanovsky, V. E., Schaefer, K., Turetsky, M. R., Treat, C. C., & Vonk, J. E. (2015). Climate change and the permafrost carbon feedback. *Nature*, *520*(7546), 171–179. https://doi.org/10.1038/nature14338

Sears, N. A. (2020). Existential Security: Towards a Security Framework for the Survival of Humanity. *Global Policy*, *11*(2). https://doi.org/10.1111/1758-5899.12800

Sen, A. (1979). Equality of What. *The Tanner Lecture on Human Values*.

Sen, A. (2000). *Development as Freedom* (1st ed.). Anchor Books. https://global.oup.com/academic/product/development-as-freedom-9780198297581

Sen, A. (2009). *The Idea of Justice*. Harvard University Press. https://doi.org/10.4159/9780674054578

Shivanna, K. R. (2022). Climate change and its impact on biodiversity and human welfare. *Proceedings of the Indian National Science Academy*, *88*(2), 160–171. https://doi.org/10.1007/s43538-022-00073-6

Shoqeir, J. H. (2022). Existential risk-Danger Extinction Humanity or Reducing permanent of Potential Humanity. *Al-Quds Journal for Natural Sciences*, *1*(2). https://aquja.alquds.edu/index.php/science/article/view/143

Shulman, C., & Thornley, E. (2024). *How Much Should Governments Pay to Prevent Catastrophes? Longtermism's Limited Role*.

Singer, M. (2013). A Comparison of the Rates of Growth of Post-Transformation Economies: What Can (Not) Be Expected From GDP? *Prague Economic Papers*, *22*(1), 3–27.

Singh, V., Jain, S. K., Nagale, D. S., & Singh, J. (2023). Glacier changes and their impacts on the melt runoff in high and moderate elevation ranges of Himalayan Upper Ganges Basin. *Hydrological Processes*, *37*(5), e14897. https://doi.org/10.1002/hyp.14897

Smith, A. (2018). *The Wealth of Nations*. CreateSpace Independent Publishing Platform.

Soupart, C., & Bleys, B. (2024). *Dataset on the Index of Sustainable Economic Welfare for the EU27 and beyond.* (Version Version 1) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.13365452

SPIERRE, S. G., SEAGER, T. P., & SELINGER, E. (2013). The Diminishing Returns to the 2010 Human Development Index: Implications for Climate Policy and Sustainable Development. *Journal of Sustainable Development*, *6*(6), 34–47. https://doi.org/10.5539/jsd.v6n6p34

Stern, S., Harmacek, J., Krylova, P., & Htitich, M. (2024). *2024 Social Progress Index—Methodology Report*. Social Progress Imperative. https://cdn.prod.website-files.com/6650cb66e461b93f1a906cf2/6685c121d87e1ee17b3cd555_Methodology%20Report_Global%20Social%20Progress%20Index_0.pdf

Stevanović, M., Popp, A., Lotze-Campen, H., Dietrich, J. P., Müller, C., Bonsch, M., Schmitz, C., Bodirsky, B. L., Humpenöder, F., & Weindl, I. (2016). The impact of high-end climate change on agricultural welfare. *Science Advances*, *2*(8), e1501452. https://doi.org/10.1126/sciadv.1501452

Stevenson, B., & Wolfers, J. (2008). *Economic Growth and Subjective Well-Being: Reassessing the Easterlin Paradox* (Working Paper No. 14282). National Bureau of Economic Research. https://doi.org/10.3386/w14282

Stiglitz, J. E. (1981). Pareto Optimality and Competition. *The Journal of Finance*, *36*(2), 235–251. https://doi.org/10.1111/j.1540-6261.1981.tb00437.x

Stiglitz, J. E., Fitoussi, J.-P., & Durand, M. (2020). *Jenseits des BIP: Was bei der wirtschaftlichen und sozialen Entwicklung wirklich zählt*. OECD. https://doi.org/10.1787/80cca758-de

Stiglitz, J. E., Sen, A., & Fitoussi, J.-P. (2009). The measurement of economic performance and social progress revisited. *OFCE*, *33*.

Stojkoski, V., Koch, P., & Hidalgo, C. A. (2023). Multidimensional economic complexity and inclusive green growth. *Communications Earth & Environment*, *4*(1), 1–12. https://doi.org/10.1038/s43247-023-00770-0

Stollberg, J., & Jonas, E. (2021). Existential threat as a challenge for individual and collective engagement: Climate change and the motivation to act. *Current Opinion in Psychology*, *42*, 145–150. https://doi.org/10.1016/j.copsyc.2021.10.004

Sun, A., Chen, B., & Doan, X. V. (2022). Equitability and welfare maximization for allocating indivisible items. *Autonomous Agents and Multi-Agent Systems*, *37*(1). https://doi.org/10.1007/s10458-022-09587-1

Suresh, K. G., & Banerjee, P. (2016). An Econometric Investigation of the Determinants of Sustainable Wellbeing of Countries. *Journal of International Business and Economy*, *17*, 39–57. https://doi.org/10.51240/jibe.2016.1.3

Swarnkar, S., & Mujumdar, P. (2023). Increasing Flood Frequencies Under Warming in the West-Central Himalayas. *Water Resources Research*, *59*(2), e2022WR032772. https://doi.org/10.1029/2022WR032772

The Legatum Institute. (2023). *Legatum Prosperity Institute Foundation*. Legatum Prosperity Index 2023. https://www.prosperity.com/about/resources

Thiry, G., & Cassiers, I. (n.d.). *ALTERNATIVE INDICATORS TO GDP: VALUES BEHIND NUMBERS ADJUSTED NET SAVINGS IN QUESTION*∗.

Tsara, I. K. (2024). The Index of Sustainable Economic Welfare (ISEW) as a proxy for sustainable GDP: Revisited and recapitulated. *Discover Sustainability*, *5*(1), 158–16.

Turchin, A., & Denkenberger. (2018). Global catastrophic and existential risks communication scale. *Futures : The Journal of Policy, Planning and Futures Studies*, *102*, 27–38.

Ura, K., Alkire, S., Wangdi, K., & Zangmo, T. (2023). *GNH 2022 | OPHI*. Centre for Bhutan and GNH Studies. https://ophi.org.uk/publications/Bhutan-GNH-2022

Ureta, C., Ramírez-Barahona, S., Calderón-Bustamante, Ó., Cruz-Santiago, P., Gay-García, C., Swingedouw, D., Defrance, D., & Cuervo-Robayo, Á. P. (2022). Evaluation of animal and plant diversity suggests Greenland’s thaw hastens the biodiversity crisis. *Communications Biology*, *5*(1). https://doi.org/10.1038/s42003-022-03943-3

Valente, D., & Stilwell, G. (2022). Applying a New Proposed Welfare Assessment Protocol to Suckler Herds from Three Different Autochthonous Breeds. *Animals*, *12*(19). https://doi.org/10.3390/ani12192689

van de Ven, P. (2018). *Measuring-Economic-Welfare-A-Practical-Agenda-for-the-Present-and-the-Future-Draft-Version* (6th IMF Statistical Forum No. 6th IMF Statistical Forum). https://www.sipotra.it/old/wp-content/uploads/2018/11/Measuring-Economic-Welfare-A-Practical-Agenda-for-the-Present-and-the-Future-Draft-Version.pdf

van den Bergh, J. C. J. M. (2022). A procedure for globally institutionalizing a 'beyond-GDP' metric. *Ecological Economics*, *192*, 107257. https://doi.org/10.1016/j.ecolecon.2021.107257

Van Der Slycken, J., & Bleys, B. (2020). A Conceptual Exploration and Critical Inquiry into the Theoretical Foundation(s) of Economic Welfare Measures (b). *Ecological Economics*, *176*, 106753. https://doi.org/10.1016/j.ecolecon.2020.106753

Vincent, & et al. (2023, January 27). *Speculative scenarios for climate-caused existential catastrophes*. https://forum.effectivealtruism.org/posts/BG4DiascCzKzBpB5t/speculative-scenarios-for-climate-caused-existential

Walden, J., Jacquemart, M., Higman, B., Hugonnet, R., Manconi, A., & Farinotti, D. (2024). A regional analysis of paraglacial landslide activation in southern coastal Alaska. *EGUsphere*, 1–38. https://doi.org/10.5194/egusphere-2024-1086

Wang, Y.-T., Liu, B.-J., & Tsai, P.-L. (2022). Trade Policy and Economic Integration in a Cournot Duopoly Model. *The Pakistan Development Review*. https://doi.org/10.30541/v43i3pp.239-251

Weisbrod, B. A., & Hansen, W. L. (1968). An Income-Net Worth Approach to Measuring Economic Welfare. *The American Economic Review*, *58*(5), 1315–1329.

Weitzman, M. L. (2009). On Modeling and Interpreting the Economics of Catastrophic Climate Change. *The Review of Economics and Statistics*, *91*(1), 1–19. https://doi.org/10.1162/rest.91.1.1

Weitzman, M. L. (2011). Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change. *Review of Environmental Economics and Policy*, *5*(2), 275–292. https://doi.org/10.1093/reep/rer006

Weitzman, M. L. (2014). Fat Tails and the Social Cost of Carbon. *American Economic Review*, *104*(5), 544–546. https://doi.org/10.1257/aer.104.5.544

Wolf, M. J., Emerson, J. W., Esty, D. C., de Sherbinin, A., & Wendling, Z. A. (2022). *2022 Environmental Performance Index*. CT: Yale Center for Environmental Law & Policy. epi.yale.edu

Yan, J., & Wang, R. (2024). Green Fiscal and Tax Policies in China: An Environmental Dynamic Stochastic General Equilibrium Approach. *Sustainability*, *16*(9), Article 9. https://doi.org/10.3390/su16093533

Yang, L., Chuan, T., Lingfeng, G., & Jiang, X. (2023). The evolution of glacial lake and glaciers and their potential impact on glacial debris flow activity in the Palong Zangbu catchment in Southeastern Tibet. *Frontiers in Earth Science*, *11*. https://doi.org/10.3389/feart.2023.1265852

Zhai, L., & Lee, Jae. E. (2024). Investigating Vulnerability, Adaptation, and Resilience: A Comprehensive Review within the Context of Climate Change. *Atmosphere*. https://doi.org/10.3390/atmos15040474

Zhang, F., Xiao, F., & Yu, P. (2024). A model of sustainable development in economic, social, and environmental aspects: The role of social capital in China. *Environmental Research Communications*, *6*(4), 045001. https://doi.org/10.1088/2515-7620/ad37a8

Zhang, S., & Zhu, D. (2022). Incorporating "relative" ecological impacts into human development evaluation: Planetary Boundaries–adjusted HDI. *Ecological Indicators*, *137*, 108786–108786. https://doi.org/10.1016/j.ecolind.2022.108786

Zheng, S., Wang, K., Fu, X., Zhang, A., & Ge, Y.-E. (2022). The effects of information publicity and government subsidy on port climate change adaptation: Strategy and social welfare analysis. *Transportation Research Part B: Methodological*, *166*, 284–312. https://doi.org/10.1016/j.trb.2022.11.001

Zhou, N., Zhao, Y., Smith, K. V., Killikelly, C., Stelzer, E., Maercker, A., Xi, J., & Helm, P. J. (2023). Existential isolation and prolonged grief in bereaved people: The moderating role of culture. *Clinical Psychology & Psychotherapy*, *30*(4), 862–872. https://doi.org/10.1002/cpp.2846

Zhu, X., Fang, X., & Liu, Y. (2021). Revisiting the Sustainable Economic Welfare Growth in China: Provincial Assessment Based on the ISEW. *Social Indicators Research*, 1–28. https://doi.org/10.1007/S11205-021-02832-2

Ziegler, R. (2007). Political Perception and Ensemble of Macro Objectives and Measures: The Paradox of the Index for Sustainable Economic Welfare. *Environmental Values*, *16*(1). https://doi.org/10.3197/096327107780160364

Appendices

Appendix A: Score Chart Global Welfare

Score-Chart Global Welfare

Score-Chart Global Welfare

X-Risk	SGW	SE	WE		Key concept	GDP	HDI	I-HDI	SPI	GNH	EPI	ISEW	GPI	HPI	MPI	IWI	BLI	GII	QOL	N-Sewi	WHR	MI	WI	LPI	HCI	EF	MPI_2	very good 10-9	good 8-7	mediocre 6-5	poor 4-3	very poor 2-0
	[illegible]		[illegible]	[illegible]	Income Distribution (Equity in wealth distribution and accessibility to economic opportunities)	1	5	9	5	6	1	8	[illegible]	3	6	3	7	4	3	9	3	2	[illegible]	6	2	1	2	The index provides comprehensive data on income distribution and takes into account the Gini coefficient and poverty rates.	The index takes into account basic aspects of income distribution, but lacks detailed data.	The index mentions income distribution but offers no specific data or indicators on this.	The index ignores income distribution or refers only to general data without specific indicators.	The index contains no information on income distribution.
	[illegible]		[illegible]	[illegible]	Health (Availability of healthcare, life expectancy, and overall health outcomes)	2	5	9	4	4	2	8	[illegible]	4	6	3	8	4	3	9	5	2	[illegible]	6	2	2	2	The index takes comprehensive account of life expectancy, access to health services and child mortality.	The index covers important health indicators, but has weaknesses in data collection.	The index mentions some health indicators but does not provide complete data.	The index contains minimal information on health indicators and is inadequate.	The index does not include any health indicators.
[illegible]	[illegible]		[illegible]	[illegible]	Education (Literacy levels, quality of education, and accessibility to learning resources.)	2	[illegible]	[illegible]	9	8	0	5	3	2	9	2	9	7	9	7	6	0	0	8	[illegible]	0	9	Comprehensive consideration of educational indicators such as literacy rate and educational qualifications.	Refers to key education indicators, but without full data analysis.	Mentions some aspects of education, but does not provide in-depth analysis.	Minimal consideration of education, with no specific indicators.	Completely ignores the education issue.
	[illegible]		[illegible]	[illegible]	Quality of Life (Living standards, housing conditions, and overall community well-being)	2	6	6	[illegible]	9	7	5	5	6	9	3	9	4	9	8	8	2	2	8	6	4	2	Takes comprehensive account of aspects of quality of life, including access to water, environmental conditions and general well-being.	Refers to relevant quality of life aspects, but not comprehensively.	Mentions some aspects of quality of life, but does not provide comprehensive data.	Only minimally considers quality of life indicators.	Ignores quality of life factors completely.
	[illegible]	[illegible]		[illegible]	Social Integration (Inclusiveness, societal cohesion, and cultural acceptance)	2	4	4	[illegible]	8	[illegible]	6	8	6	4	8	6	2	4	4	4	2	2	8	2	[illegible]	2	Includes comprehensive social indicators that measure equality of opportunity and access to social services.	Takes significant social aspects into account, but not completely.	Mentions social factors but does not provide in-depth analysis.	Minimal consideration of social integration.	Completely ignores social aspects.
	[illegible]		[illegible]	[illegible]	Economic Stability (Resilience to economic shocks, steady growth, and financial security)	[illegible]	7	7	5	5	0	5	5	0	5	5	7	5	5	5	5	[illegible]	5	7	5	0	[illegible]	The index provides comprehensive data on the unemployment rate, inflation and GDP growth, which contribute to economic stability.	The index takes into account key stability factors, but has weaknesses in data collection.	Mentions some economic stability indicators, but does not provide a complete analysis.	Minimal consideration of economic stability, insufficient data.	Completely ignores economic stability.
	[illegible]			[illegible]	Political stability and governance (Institutional strength, policy effectiveness, and trust in governance)	0	4	4	8	7	3	5	6	3	4	5	7	5	4	7	6	4	4	[illegible]	4	2	2	Takes comprehensive account of aspects of political stability, including civil rights and the rule of law.	Refers to significant aspects of political stability, but without complete data.	Mentions some governance aspects, but does not provide in-depth analysis.	Minimal consideration of political stability indicators.	Completely ignores political stability.
	[illegible]			[illegible]	Subjective well-being (Levels of happiness, public satisfaction, and mental health)	2	5	5	6	[illegible]	2	5	6	9	4	4	7	4	5	5	[illegible]	3	4	7	4	2	3	Includes comprehensive life satisfaction and happiness index data to measure subjective well-being.	Relates to relevant aspects of subjective well-being, but not comprehensive.	Mentions some aspects of well-being, but does not provide a complete analysis.	Minimal consideration of subjective well-being.	Completely ignores subjective well-being.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Environmental Indicators (Conservation of natural resources, pollution control, and ecological sustainability)	2	2	2	[illegible]	8	[illegible]	8	8	6	4	8	8	2	4	4	4	2	2	8	2	[illegible]	2	Includes comprehensive data on CO2 emissions, biodiversity and renewable energies.	Covers some environmental aspects, but has gaps in data collection.	Mentions environmental aspects but does not provide a complete analysis.	Minimal reference to environmental factors, insufficient data.	Completely ignores environmental factors.
	[illegible]	[illegible]	[illegible]		Sustainability (Resource management, long-term planning, and environmental resilience)	0	6	6	8	8	[illegible]	[illegible]	[illegible]	8	7	9	7	6	7	7	7	0	6	8	6	[illegible]	0	Comprehensive consideration of all SDGs with specific sustainability measurements	Takes many SDGs into account, but has weaknesses in data collection.	Mentions some SDGs but does not provide comprehensive data analysis.	Minimal consideration of sustainability indicators.	Completely ignores sustainability issues.

Appendix B: Score Chart Existential Risk

Score-Chart Global Welfare

Key concept: X-Risk | SGW | SE | WE

Score-Chart Existential Risk (Climate Change)

Criterion	GDP	HDI	I-HDI	SPI	GNH	EPI	ISEW	GPI	HPI	MPI	IWI	BLI	GII	QOL	N-Sewi	WHR	MI	WI	LPI	HCI	EF	MPI_2	very good 10-9	good 8-7	mediocre 6-5	poor 4-3	very poor 2-0
Extreme weather events (frequency, intensity and damage caused by events such as hurricanes, floods and forest fires)	2	4	4	5	3	[illegible]	6	6	3	5	6	5	3	5	6	4	5	5	6	4	6	4	Comprehensive analysis of the frequency, intensity, and damage from extreme weather events (e.g., hurricanes, floods, wildfires), with empirical data and detailed modeling.	Good coverage, but without full coverage of all event types or their impacts.	Partial analysis with limited quantitative assessment of the impacts on various sectors.	Superficial consideration with no detailed analysis or measurements of the impacts.	No or highly inaccurate consideration of extreme weather event impacts.
Sea-Level Rise: Impacts on coastal populations, land loss, and ecosystem disruption.	2	4	4	5	4	8	6	[illegible]	4	5	6	5	3	5	5	4	2	5	6	4	6	2	Detailed consideration of sea-level rise impacts on coastal populations, land loss, and ecosystem changes, including long-term projections.	Good analysis, but lacking in some aspects, such as specific data for most vulnerable regions.	Incomplete analysis with few quantitative assessments and limited long-term consideration.	Very limited or no analysis of sea-level rise and its impacts.	Complete neglect or inaccurate consideration of the issue.
Ecological Health: Biodiversity loss, changes in land use, and water resource depletion.	2	5	5	5	5	[illegible]	7	7	5	5	5	5	5	5	5	5	2	5	6	4	6	2	Comprehensive consideration of biodiversity loss, land-use changes, and water resource depletion.	Good consideration, but missing some critical ecological impacts or data.	Partial consideration, lacking deeper analysis of interactions or specific ecosystems.	Minimal consideration of ecosystems, or only general statements with no detailed evidence.	No consideration of ecological health.
Governance Challenges: Adaptive capacity of institutions, effectiveness in managing resources, and societal responses.	2	5	5	6	6	[illegible]	5	6	5	5	6	6	3	5	5	4	2	5	8	4	6	2	Very detailed analysis of institutional adaptive capacity, resource management, and societal responses to climate impacts.	Good coverage of governance issues, but not all dimensions are addressed.	Insufficient analysis of governance and societal responses to climate change.	Poor consideration of institutional or societal responses to climate impacts.	No consideration of governance challenges.
Public Awareness and Education: Levels of climate literacy and preparedness for climate adaptation.	2	5	5	6	5	6	5	5	5	4	5	6	3	5	5	4	2	4	[illegible]	6	[illegible]	2	Comprehensive consideration of climate literacy and preparedness for adaptation, including	Good consideration, but with limited data on specific programs or societal impacts.	General discussion without in-depth analysis of education and public perception.	Very little or no analysis of climate literacy or public awareness.	No consideration of public knowledge or education.
Security Perspective: The extent to which climate change is framed as a security issue influencing governance responses.	2	5	5	6	5	6	5	5	5	5	5	6	5	5	5	5	2	4	6	6	[illegible]	2	Climate change thoroughly framed as a security issue, with comprehensive analysis of political responses and long-term governance implications.	Good analysis of security aspects, but not all potential security threats or political responses are integrated.	Partial coverage, lacking deeper exploration of security dimensions.	Minimal to no consideration of security aspects related to climate change.	No consideration of security perspectives.
Implementation of Climate Protection Measures	2	3	3	4	4	[illegible]	6	6	5	5	6	5	5	5	5	5	2	5	5	4	7	2	Detailed and comprehensive consideration of implemented climate protection measures, including specific initiatives and political programs.	Good coverage, but without fully detailing all relevant measures or initiatives.	Insufficient or partial consideration of climate protection measures with no in-depth analysis.	Very little or no discussion of actual climate protection measures.	No or erroneous discussion of climate protection measures.
Implementations to generate renewable energy	0	3	3	4	5	[illegible]	5	5	5	5	6	5	4	5	5	5	3	3	5	3	6	0	Full analysis of renewable energy generation efforts, including political initiatives, technologies, and investments.	Good coverage of renewable energy, but missing some relevant initiatives or policies.	Insufficient analysis of renewable energy, lacking deeper exploration of investments or policy frameworks.	Very little or no analysis of renewable energy generation.	No consideration of renewable energy.
Measurement of CO2-Emission	0	3	3	3	5	[illegible]	5	5	5	5	5	5	2	5	5	5	0	2	3	3	9	0	Very detailed and accurate measurements of CO2 emissions, with well-supported datasets and clear connections to climate protection measures.	Good measurements, but not covering all relevant sectors or regions.	Partial measurement, without full integration of all CO2 emission sources.	Superficial measurement of CO2 emissions without deeper analysis.	No or inaccurate measurement of CO2 emissions.
Immediate, Delayed, and Long-Term Effects: Assessments over time (short, medium, long-term).	4	6	6	6	5	[illegible]	6	7	5	6	[illegible]	5	2	6	6	5	3	5	6	6	[illegible]	3	Excellent analysis of immediate, medium-term, and long-term effects of climate change and climate protection measures.	Good coverage, but not all timeframes are fully addressed.	Insufficient consideration of long-term consequences of climate change.	Very weak analysis of time dimensions of climate impacts and measures.	No consideration of effects across different time periods.
Vulnerability Assessment: Population, economic sectors, and ecological systems' susceptibility to climate impacts.	3	5	5	6	4	8	6	7	5	6	7	5	3	5	5	4	2	4	6	6	[illegible]	1	Thorough assessment of population, economic sectors, and ecological systems' susceptibility to climate impacts, based on strong empirical data and modeling. Detailed analysis of specific vulnerabilities.	Good coverage of vulnerabilities, but some regions or sectors may lack sufficient detail or consideration.	Partial coverage of vulnerabilities, lacking in-depth analysis of key sectors or specific regions.	Incomplete or superficial analysis, missing many vulnerable populations or sectors.	No or highly inaccurate vulnerability assessment.

Score-Chart Global Welfare

[illegible]

X-Risk	SGW	SE	WE		Key concept	GDP	HDI	I-HDI	SPI	GNH	EPI	ISEW	GPI	HPI	MPI	IWI	BLI	GII	QOL	N-Sewi	WHR	MI	WI	LPI	HCI	EF	MPI_2	very good 10-9	good 8-7	mediocre 6-5	poor 4-3	very poor 2-0
				[illegible]	Climate Adaptation and Mitigation Investments: Support for renewable energy, sustainable infrastructure, and climate protections.	2	4	4	6	5	7	6	7	6	5	6	6	3	5	5	4	2	3	5	4	[illegible]	2	Comprehensive consideration of investments in renewable energy, sustainable	Solid coverage of investments, but may lack detail in some areas or omit certain types of	Insufficient analysis of investments, with limited coverage of specific programs or financial	Weak or no coverage of investments in climate adaptation and mitigation.	No consideration of climate adaptation and mitigation investments.
[illegible]					Economic Vulnerabilities: Measurement of economic damage, resource costs, and climate impacts	3	5	5	6	5	8	6	[illegible]	5	5	6	5	4	5	5	4	3	5	6	6	8	2	Detailed analysis of economic damage, resource costs, and climate impacts, with clear metrics	Good analysis, but some economic sectors or regions may not be fully covered. The analysis may	Superficial analysis, missing key economic sectors, or with limited data on economic	Very limited coverage, with only general statements about economic vulnerabilities	No or highly inaccurate analysis of economic vulnerabilities.
				[illegible]	Scale of Impact: Metrics capturing the number of people affected (e.g., climate displacement risks).	2	5	5	6	5	[illegible]	6	[illegible]	5	5	5	6	4	5	5	4	2	3	6	6	6	2	Clear metrics for the scale of impact, including precise estimates of affected populations, climate displacement risks, and	Good metrics for scale of impact, though some aspects may lack depth or precision, such as specific regions or populations.	General or incomplete metrics, with vague estimates and lack of data on the most affected populations or	Weak or no metrics, with unclear estimates of scale and no clear focus on the populations or regions most affected.	No or highly inaccurate metrics for scale of impact.
					Likelihood: Probability of various climate events and their anticipated effects.	2	5	5	6	5	8	6	[illegible]	5	5	7	6	2	5	5	4	2	5	6	6	[illegible]	2	Comprehensive analysis of the likelihood of climate events, with detailed projections and a wide range of scenarios,	Good assessment of likelihood, but may lack coverage of some possible events or scenarios, or may not fully account for	Inadequate coverage of likelihood, with limited scenarios or over-simplified assumptions.	Poor or incomplete analysis of likelihood, with few scenarios or missing uncertainty factors.	No consideration of likelihood or inaccurate assumptions about future events.
				[illegible]	Feedback Loops: Potential cascading effects from changes in CO2 emissions, land use, biodiversity, etc.	2	5	5	6	5	[illegible]	6	[illegible]	5	5	7	6	3	5	5	4	2	5	6	6	[illegible]	2	Thorough analysis of cascading feedback effects, such as the impact of CO2 emissions, land use, and biodiversity changes, with clear models and empirical data.	Good coverage of feedback loops, though not all potential cascading effects are integrated or thoroughly modeled.	Partial analysis of feedback loops, with some key interactions or impacts missing.	Weak consideration of feedback effects, with few or no detailed models or evidence.	No or highly inaccurate discussion of feedback loops.
				[illegible]	Uncertainty Factors: Consideration of unpredictability in climate projections and associated risk assessments.	0	4	4	6	4	[illegible]	5	[illegible]	4	4	6	5	2	4	4	4	4	2	5	5	5	2	Excellent consideration of uncertainty factors in climate projections, including modeling limitations, variability, and sensitivity analysis. Comprehensive treatment of risk assessments.	Good treatment of uncertainty, but some aspects of unpredictability or variability may not be fully addressed or quantified.	Limited consideration of uncertainty, with a lack of sensitivity analysis or variability in the projections.	Weak consideration of uncertainty, with oversimplified or incomplete models and risk assessments.	No consideration of uncertainty factors or grossly inaccurate modeling.
[illegible]				[illegible]	Long-term Considerations: Focus on future generations and sustainability of resources.	3	5	5	6	5	[illegible]	5	7	5	5	[illegible]	5	5	5	5	5	3	5	6	5	6	2	Detailed focus on future generations, sustainability of resources, and long-term policy implications. Clear long-term projections and consideration of future sustainability	Good long-term analysis, but may lack detailed projections or the consideration of some long-term risks and sustainability issues.	Insufficient focus on long-term considerations, with limited projections or a short-term focus in analysis.	Minimal consideration of long-term sustainability, with short-term focus or poor modeling of future risks.	No long-term consideration or a focus only on the immediate future.
[illegible]					Intergenerational Fairness: Commitment to equitable resource distribution and risk management.	2	4	4	5	4	[illegible]	5	6	5	5	6	5	4	5	5	5	3	5	6	5	[illegible]	2	Comprehensive analysis of intergenerational fairness, with a focus on equitable resource distribution, risk	Good treatment of fairness, but may lack depth in how it applies to policy or resource	Partial coverage of fairness issues, with limited analysis of intergenerational justice	Weak or incomplete analysis of fairness, with minimal attention to resource equity.	No consideration of intergenerational fairness or fairness principles.
[illegible]				[illegible]	Public Beliefs and Climate Knowledge: Reflects psychological awareness and belief in climate science.	2	4	4	5	4	4	5	5	5	5	5	5	2	5	5	5	2	2	5	4	[illegible]	2	In-depth consideration of public understanding of climate science, beliefs, and psychological factors influencing climate adaptation and action.	Good consideration of public beliefs and knowledge, but with limited exploration of psychological factors or climate literacy programs.	Superficial treatment of public beliefs, with little exploration of how they affect adaptation or mitigation actions.	Minimal or no consideration of public knowledge and beliefs, with no psychological or social context.	No consideration of public beliefs or climate knowledge.
[illegible]					Cultural Adaptability: Sensitivity to cultural influences in climate adaptation and mitigation strategies.	2	3	3	4	[illegible]	3	4	2	4	3	3	3	3	3	3	3	3	3	4	2	2	2	Excellent consideration of cultural influences on climate adaptation and mitigation strategies, including region-specific	Good attention to cultural adaptability, though some regions or cultures may not be fully explored in the analysis.	Partial consideration, with limited focus on the role of culture in shaping climate strategies.	Weak consideration of culture, with little focus on region-specific needs or cultural differences in adaptation.	No consideration of cultural adaptability in climate strategies.
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					

Declaration on the use of generative AI tools[15]

I am informed about the possibilities and limitations of gen-AI used for this concept.
I have verified and checked the results provided by the AI regarding correctness and corrected/edited information, if needed. I always made sure to provide my ideas to the AI and that they've been kept in any situation or editing in case of improvements.
I acknowledge that the responsibility for this concept lies with me, the author (Annika Martin) and not with the tools.

Activity	**Description**	**Tools used**	**Description of the use of AI**
Structuring and planning of concept		Chat GPT 4.o mini	Providing my initial idea of a structure and what I want to address under each point. I asked the algorithm to provide me with any improvements or suggestions.
Translation en-ger/ger-en	Improvement of translation, wording and grammar	Grammarly Pro Deepl.com Claude 3.5 Sonnet	I wrote my sections and provided it then to first Deepl.com for translation & used their suggestion tool to improve wording. Secondly, I provided the written section to Grammarly to improve my writing (grammar mainly). In some cases, to streamline my argumentation and smoothen out my language, I provided my text then to Claude 3.5 Sonnet and asked for feedback on my text regarding conciseness and clarity.
Coding	Consultation to correct and explain code for analysis in R. Either to correct errors or to help with thought patterns and possible implementations.	Jasper.ai ChatGPT	Submitting my code to get feedback regarding mistakes or errors

[15] Implemented according to the template:
https://portal.fh-campuswien.ac.at/webservices/portaltoenabler/enablergetdocument.aspx?id=2489#page=5.10

Review of the overall concept	Feedback on the overall structure, clarity, language and grammar	jenni.ai	I provided my paper to jenni.ai and used the following prompt: I’m a Master’s student, and I’m researching the topic of Global Welfare Metrics in the Context of Decarbonization – Economic Growth vs Sustainability Goals. You are a professor who has a lot of expertise in this field. I want you to provide constructive feedback on my concept - which is included in the open document. Specifically, I want you to provide insights on: Clarity and Structure: Is my main argument clear and well-structured? Are there areas where I could improve the flow or coherence of my ideas? What counter-arguments could be made against my ideas? Relevance and Depth: Does my writing engage with the key literature and debates in the field adequately (make sure to look at the literature collection you have)? Are there any gaps in my discussion? Style and Language: Is my writing concise and consistent? Are there specific areas where I can improve readability or adopt a more scholarly tone? Overall Impact: Does this document sufficiently address the ‘so what’ question? How could I strengthen its significance or impact? Please provide detailed, constructive feedback.