

Review

# The Climate Change Challenge: A Review of the Barriers and Solutions to Deliver a Paris Solution

Filipe Duarte Santos <sup>1</sup>, Paulo Lopes Ferreira <sup>1</sup>  and Jiesper Strandsbjerg Tristan Pedersen <sup>1,2,\*</sup>

<sup>1</sup> Climate Change Impacts, Adaptation and Modelling (CCIAM), Centre for Ecology, Evolution and Environmental Changes (cE3c), Faculdade de Ciências, Universidade de Lisboa (Faculty of Sciences, University of Lisbon) (FC-UL), Campo Grande 016, C1, 2.39, 1749-016 Lisbon, Portugal; fdsantos@fc.ul.pt (F.D.S.); plferreira@fc.ul.pt (P.L.F.)

<sup>2</sup> Instituto de Ciências Sociais, Universidade de Lisboa (ICS-UL) (Social Science Institute, University of Lisbon), Av. Professor Aníbal de Bettencourt 9, 1600-189 Lisbon, Portugal

\* Correspondence: japedersen@fc.ul.pt; Tel.: +45-2628-0426

**Abstract:** Global greenhouse gas (GHG) emissions have continued to grow persistently since 1750. The United Nations Framework Convention on Climate Change (UNFCCC) entered into force in 1994 to stabilize GHG emissions. Since then, the increasingly harmful impacts of global climate change and repeated scientific warnings about future risks have not been enough to change the emissions trend and enforce policy actions. This paper synthesizes the climate change challenges and the insofar insufficient mitigation responses via an integrated literature review. The fossil industry, mainstream economic thinking, national rather than international interests, and political strive for short-term interests present key barriers to climate mitigation. A continuation of such trends is reflected in the Dice model, leading to a 3.5 °C temperature increase by 2100. Despite receiving the Nobel Prize for integrating climate change into long-run macroeconomic analysis via the Dice model, increases in global mean temperatures overshooting the 1.5 °C to 2 °C Paris targets imply an intensified disruption in the human–climate system. Past and present policy delays and climate disruption pave the way for solar radiation management (SRM) geoengineering solutions with largely unknown and potentially dangerous side effects. This paper argues against SRM geoengineering and evaluates critical mitigation solutions leading to a decrease in global temperatures without overshooting the Paris targets. The essential drivers and barriers are discussed through a unified approach to tipping points in the human–climate system. The scientific literature presents many economically and technologically viable solutions and the policy and measures required to implement them. The present paper identifies the main barriers to integrating them in a globally cooperative way, presenting an efficient, long-term, and ethical policy approach to climate change.

**Keywords:** climate change theory; Paris solution; system analysis; economy; energy; fossil fuels; emissions; scenarios; adaptation; tipping points



**Citation:** Santos, F.D.; Ferreira, P.L.; Pedersen, J.S.T. The Climate Change Challenge: A Review of the Barriers and Solutions to Deliver a Paris Solution. *Climate* **2022**, *10*, 75. <https://doi.org/10.3390/cli10050075>

Academic Editors: Forrest M. Hoffman and Rajib Shaw

Received: 15 March 2022

Accepted: 12 May 2022

Published: 20 May 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

Anthropogenic emissions of greenhouse gases (GHGs), in particular CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, have significantly increased their atmospheric concentrations since the industrial revolution, causing a progressive global climate change that is provoking widespread harmful impacts across the world [1,2]. Since 1880, the average global temperature has increased by a little more than 1 °C. Almost two-thirds of the warming has happened since 1975, by about 0.15–0.2 °C per decade [3,4]. Almost half of global GHG (and CO<sub>2</sub>) emissions (1850–2020) were emitted since 1990 [5,6], mounting the mitigation challenge [7]. Since the Paris Agreement, emissions have increased annually, with a temporary drop in 2020 caused by the COVID-19 pandemic crisis [8,9], the largest annual reduction ever observed [10]. However, no significant structural changes in the global energy system have been recorded, and global fossil CO<sub>2</sub> emissions have rebounded by 6% to 36 GtCO<sub>2</sub> in 2021 [11–13]. Thus,

a rapid decrease in anthropogenic GHG (45%) by 2030 is urgently required to stay on a 1.5 °C pathway [1,14].

Since the establishment of the Intergovernmental Panel on Climate Change (IPCC), the world has not significantly changed pathways, continuing being on a middle-of-the-road pathway [15], as fossil-fuelled energy consumption has continuously increased, and the share of fossil fuel primary energy supply has remained almost unchanged at around 81% [16]. Although electric power generation from renewable energies reached 27% in 2019 and is fast increasing, there is no evidence yet of a sustained global energy transition from fossil to renewable sources [16]. A renewable transition is needed before 2050, implying global annual emissions cuts of 1–2 GtCO<sub>2</sub> annually in the coming decade [10].

Although global emissions, in general, still increase, some structural changes have begun in several OECD countries [16], related to declining renewable costs and rising climate concerns [17–19]. This created a modest shift away from fossil fuel increases in the OECD region, while fossil fuel emissions are growing in the non-OECD areas [16]. Recent UNEP estimates suggest improved policy ambitions compared to 2015 [20–22]. The world is moving towards a 2.8 °C pathway under current national policies, while (un)conditional Nationally Determined Contributions (NDC) may lead to 2.5 (2.7) °C by 2100. The present national net-zero target pledges may lead to 2.1 °C [12,23]. However, the net-zero targets are not considered robust [12,24]. They face challenges such as double counting [25,26], forest fires [27], and social challenges for indigenous and local communities in developing countries [28].

Anthropogenic climate change (ACC) has often been described as a “wicked” problem to emphasize its complexity, interconnected nature, and difficulty in finding a solution, in contrast with “tame” problems which have a clear optimum solution [29–31]. Researchers emphasize that its cumulative nature brings in more difficulties associated with a long time scale that lasts for many social generations, bringing in questions of intertemporal choices, time discount rates, and the social price of carbon [32–34]. Furthermore, continued use of fossil fuels as projected in a business-as-usual scenario is now expected to limit global economic growth instead of promoting it, because of its increasingly harmful climate impacts [32,35].

This paper questions and evaluates the possibility of delivering a Paris solution to the climate change problem, here defined as a process leading to a decrease in the GMST, without overshooting the 1.5–2 °C Paris interval target, through a mitigation process that includes various natural and technological forms of CO<sub>2</sub> sequestration but excludes stratospheric aerosol injection (SAI). To achieve this, the paper presents a system analysis of the human–climate system where the main drivers of change to reach a solution and the main impediments are identified and evaluated, including their interactions. The focus is on mitigation and the energy transition, the impacts of climate change on human society and its activities, their increasing severity, the limits to adaptation, geoengineering, climate social movements, and geostrategic policies and crises.

We discuss the challenges that result from not implementing mitigation actions in the past—human society has been unable to mitigate climate change in the past and present (the global energy transition actions today are insufficient to achieve a Paris solution in the future: we know that!). This past and present have implications for the future. It is still possible to deliver a Paris solution, but two conditions exist. First, we must fully understand what has happened in the past and present (namely insufficient mitigation of climate change) and know why it has happened to eliminate as much as possible those reasons. Second, we must adopt solutions that have been recommended by science and technology, some of them recommended for a long time in the past. These solutions are described in the paper.

To our knowledge, this is the first paper that addresses within a historical perspective the key obstacles to climate change mitigation in a concise and integrated way. It also addresses why it has been so difficult to solve the problem despite the scientific and technological breakthroughs in mitigation. Furthermore, it describes the tipping points in the human–climate system in a novel way. Human system tipping points are the most likely thresholds that can lead to a mitigation solution in compliance with the Paris Agreement.

Climate system tipping points in the various climate subsystems are also addressed, since they are critical to the incentives that may unblock urgent climate actions.

## 2. Results

### 2.1. Historical Developments

Historical developments, although mostly well-known, are important to be briefly reviewed to fully understand the origin and resilience of the pros and cons for finding a Paris solution to the climate change problem.

Already in the 19th century, several researchers, Fourier [36,37], Tyndall [38] and Arrhenius [39,40] discovered that intensive fossil fuel use has an unintentional effect on the global climate. This effect was fully described by Plass [41] and was further analysed afterwards [1,42]. The intensive use of coal at the beginning of the Industrial Revolution (1750–1850) was followed by oil from the end of the 19th century and natural gas in the 20th century. It has improved the average human economic prosperity globally, especially in the last two centuries [43], although without solving the deepening global North–South socioeconomic divide. The abundant availability of an affordable form of energy associated with socioeconomic, scientific, and technological advances contributed to rapid improvement of public health, life expectancy, and later also increased fertility. It led to a 7.8-fold increase in the global population from 1800 to 2019. Furthermore, the Industrial Revolution sustained exponential global economic growth, which allowed a 33-fold increase in global GDP per capita between 1800 and 2006 [44]. Global primary energy consumption increased from 20 EJ in 1800 to 584 EJ in 2019 [45,46]—a 3.7-fold increase in primary energy consumption per capita.

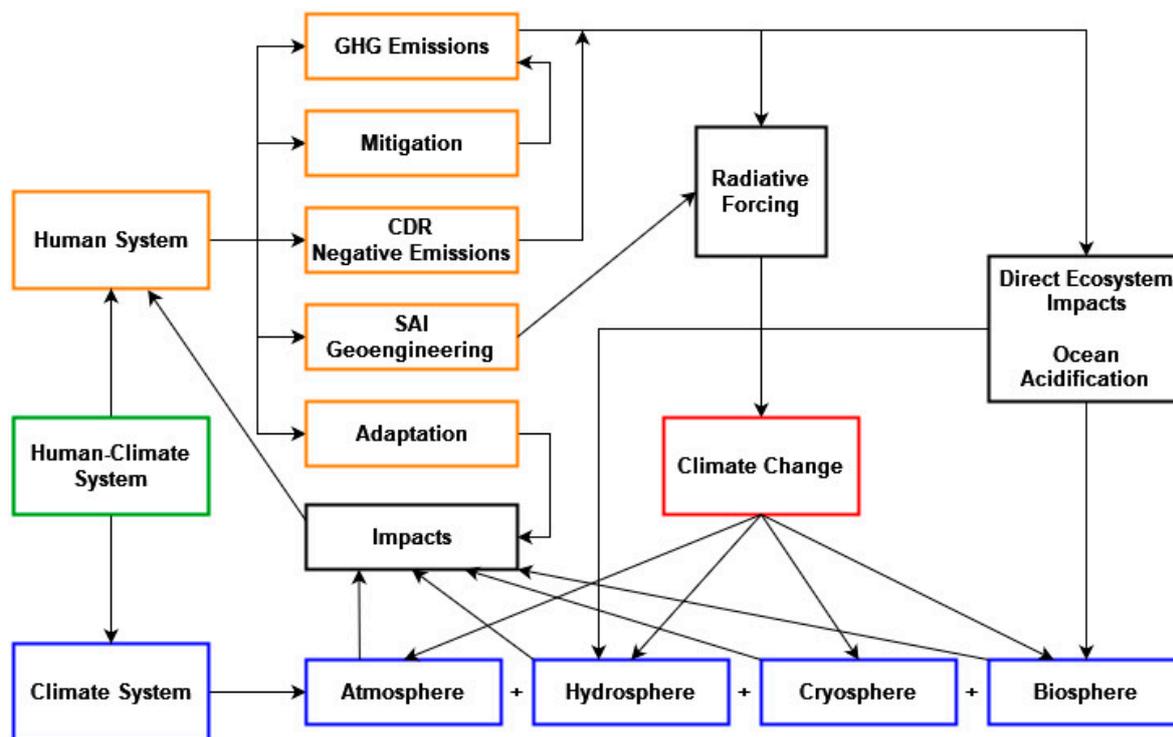
Advances in our knowledge of the interaction between GHG and infrared radiation and the use of electronic computers allowed to repeat and refine Arrhenius's calculation of climate sensitivity [39,40], arriving at 3.8 °C. This estimate implied that fossil fuel burning would add 6 GtCO<sub>2</sub> per year to the atmosphere. Plass concluded that “if no other factors change, man's activities are increasing the average temperature by 1.1 °C per century” [41]. It is close to current observations of a 1.1 °C increase by 2020 above 1850–1900 levels [47]. He also predicted a 30% increase in atmospheric CO<sub>2</sub> concentration during the 20th century. Observations show a 24% increase—from 296 pmv to 370 pmv [48]. In the following year, 1957, Revelle and Suess [49] agreed that CO<sub>2</sub> concentration would increase significantly if the use of fossil fuels continued to rise exponentially. However, data availability on the rates and mechanisms of CO<sub>2</sub> exchange between the various Earth sources and sinks was insufficient to give an accurate baseline to measure future changes in atmospheric CO<sub>2</sub> [49].

At this point, the dominant narrative to deal with the climate change problem was a need for more research and obtain better data before making any decisions. The first official response came in November 1965 via a Subpanel report from the Environmental Pollution Panel President's Science Advisory Committee to the USA President. The report on atmospheric carbon dioxide was chaired by Roger Revelle [50]. The report states that, “through his worldwide industrial civilization, Man is unwittingly conducting a vast geophysical experiment” and recognizes that climatic changes “produced by increased CO<sub>2</sub> content could be deleterious from the point of view of human beings”. However, this was without specifying why and how. The suggested response was to “bring about countervailing climatic changes. A change in the radiation balance in the opposite direction to that which might result from the increase of atmospheric CO<sub>2</sub> could be produced by raising the albedo, or reflectivity, of the earth”. The report stated as justification that global industrial civilization was so inextricably linked with fossil fuel use that mitigation and a renewable transition was impracticable and therefore not worth talking about. The report's main conclusion was that the only politically acceptable solution is SRM geoengineering [50,51].

### 2.2. A complex System Methodology for the Human–Climate System

Climate change science, including impacts and mitigation, has advanced considerably since the 1965 report. Nevertheless, the challenge is much worse today since global GHG emissions have increased steadily. To address this growing discrepancy and possible ways out,

we use a systems analysis applied to the concept of a human–climate system that incorporates the human subsystem [52] and the climate subsystem (Figure 1). The first is defined as the whole human enterprise and includes the technosphere [53], recognized as a functional system anchored and integrated into the Earth system. The second comprises five components: atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere [54]. The human–climate system can be considered as an enlarged socio-ecological system [55–57] or a socio-technical-ecological system [58], where human interference in the abiotic and biotic components of the environment plays a determinant role.



**Figure 1.** Interactions between the human (orange) and climate subsystems (blue), including processes of adaptation, mitigation, geoengineering and stratospheric aerosol injection (SAI), carbon dioxide removal (CDR), and negative emissions technologies (NETs). Notice that SAI does not prevent the direct ecosystem impacts and ocean acidification that result from CO<sub>2</sub> emissions. The climate subsystem includes only four of its subsystems, since the role played by the lithosphere in the anthropogenic climate change (ACC) time frame is likely to be relatively small.

The advantage of dealing with the more embracing and complex human–climate system is that the focus on the interaction between the two subsystems is facilitated by an equitable framework for the human and climate subsystems. This interaction is dominated by anthropogenic GHG emissions, biodiversity loss, land-use and land-cover changes, atmospheric pollution, oceans, water resources and soils, and over-exploitation of natural resources [52]. The current approach emphasizes that the observed ACC has an influence on the whole human subsystem (Figure 1) and has forced the development of ideologically divergent response narratives in a process where ethical and moral values are argued to have been transgressed [59–62]. Figure 1 describes interactions between the human and climate system and serves as the conceptual framework for the paper, and ensures that all the main drivers, challenges, and solution pathways to the climate change problem are addressed in an integrated and systematic way.

Emissions developments, the role of mitigation, and the barriers are addressed in Sections 2.3.1–2.3.4, negative emissions approaches and challenges in Section 2.3.5, barriers in Section 2.3.6 (mainstream economics), climate change impacts, adaptation, and climate justice ethics are addressed in Sections 2.3.7 and 2.3.8, while Section 2.3.9 discusses geoen-

neering, which is introduced as a mitigation option by a group of scientists, not considered by the IPCC, and in reality presents a barrier to actual mitigation. The consequences of the human–climate interactions are discussed in Section 3 (tipping points).

### 2.3. System Analysis of Climate Change Responses in the Human–Climate System

#### 2.3.1. The Role Played by the Fossil Fuel Industry since the 1970s

To fully understand the present difficulties to decarbonize the world economy, it is essential to address the erratic role played by the fossil fuel industry. Since the pre-industrial era, anthropogenic CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions represent 66%, 16%, and 7%, respectively, of the global radiative forcing increase [63]. The past decade, CO<sub>2</sub> accounts for about 82% of the increase in radiative forcing. About 85.5% of global CO<sub>2</sub> emissions came from fossil fuels and industry, and the remaining from land-use changes [7].

During the 1970s, the major US oil corporations were interested in developing research on the increasing atmospheric CO<sub>2</sub> concentration, produced by or with government support. The leading oil corporation, Exxon, funded a program to understand the potential damage caused by fossil fuels [64]. In 1977, James F. Black, a Scientific Advisor in the Products Research Division of Exxon Research & Engineering, told Exxon's Management Committee that because humankind influences the global climate through CO<sub>2</sub> released from burning fossil fuels, "man has a time window of five to ten years before the need for hard decisions regarding changes in energy strategies might become critical" [64–66].

This frankness was short-lived. In 1982, Exxon decided to terminate the research program. It issued a briefing on the "CO<sub>2</sub> 'Greenhouse' effect" [67], restricted to Exxon personnel, that would become a precursor of the fossil fuel industry's perceptions, arguments, and policies over the following decades. The first point was to argue that "there is currently no unambiguous scientific evidence that the Earth is warming". Thus, "the increased greenhouse effect is not likely to cause substantial climatic changes until the temperature rises at least 1 °C above today's levels", which "should occur in the second to the third quarter of the next century" [67]. The second point emphasized significant uncertainties in the science of climate change and, in particular, in the models projecting future climate, arguing that those uncertainties might be impossible to eliminate.

Despite mounting scientific evidence for ACC, the 1982 briefing became the model for the fossil fuel industry's communication strategy to maintain and consolidate its role as the world's dominant primary energy source. They successfully opposed mandatory national and global GHG emissions reductions via a systematic campaign built on a vast edifice of misinformation regarding climate change science [68]. American climate change deniers created an economic ideology of denial [69] centred on the economic growth imperative. It has successfully influenced (and confused) public opinion, delayed mitigation, and exerted decisive impact in Washington and international organizations, such as the United Nations.

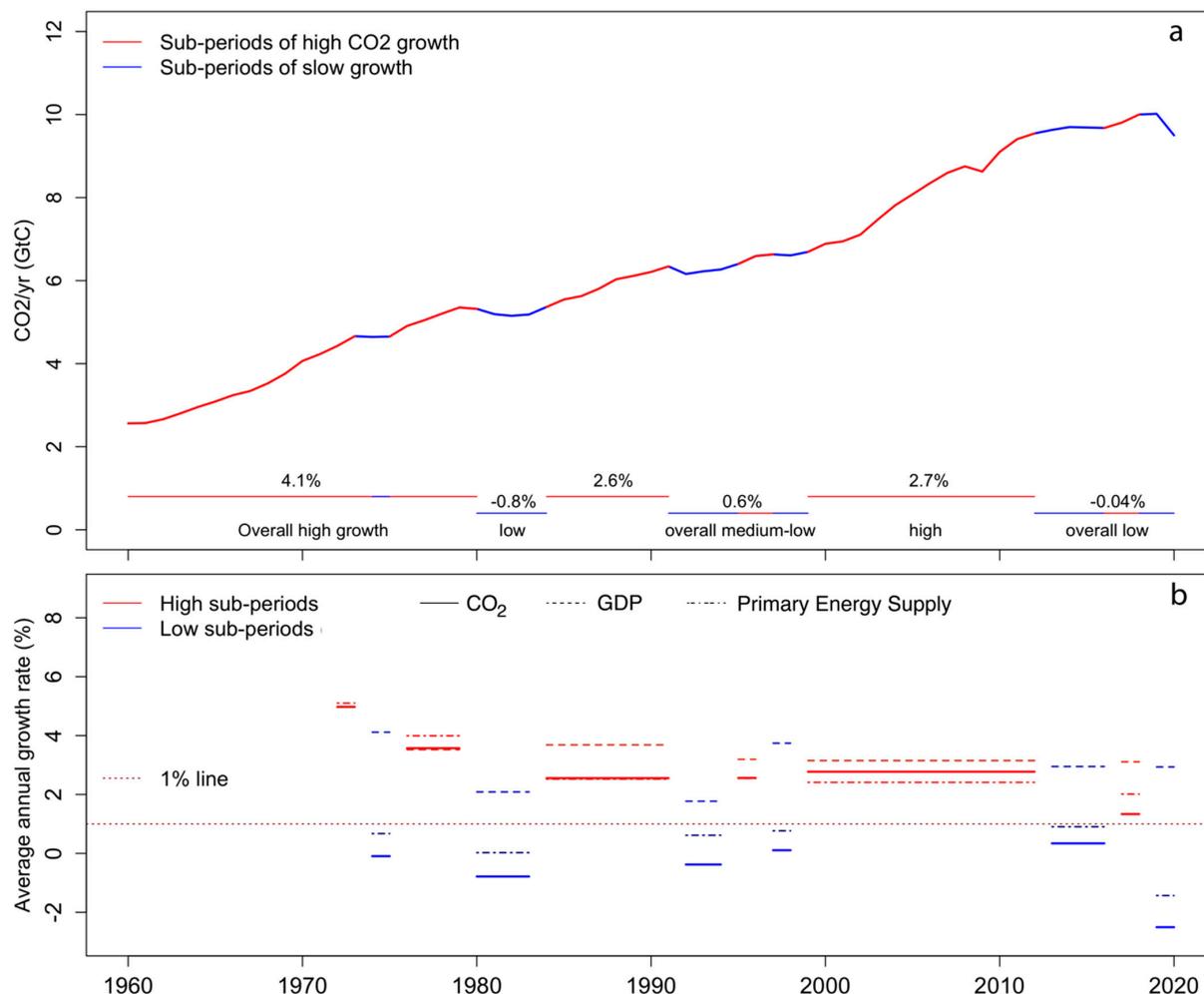
Today, oil companies have changed their discourse to face the increasing public scrutiny over their climate change policies and measures and embrace Environmental, Social, and Governance (ESG) goals. This arguably aims to attract investors, employees, and customers. Renewable energy is making inroads and becoming price competitive with fossil fuels in several regions of the world [19,70,71], with technologies maturing quickly now and ready to play a defining role in a near-term future, promoted by both climate policies and market forces. In conclusion, oil companies have adopted a different narrative towards climate change. Still, based on economic incentives, they may be eagerly waiting to find new opportunities to expand their activity, as revealed by the recent exploitations of weak governments in African countries by energy companies representing industrialized and newly industrialized countries [72–76]. This may also be supported by the Ukraine–Russian conflict, however, it is too early to conclude [77].

#### 2.3.2. Climate Change, Crises, and the Fossil Fuel Dependencies

This section briefly discusses emissions reductions in the light of economic crises, focusing on three key periods of slow emissions growth: 2013–2016, 2020–2021, and 2022.

The analysis shows that such periods are exceptional and have no significant impact on the overall emission growth trend.

We see several historical temporary drops in CO<sub>2</sub> emission growth, starting with the oil crisis in the 1970s and 1980s, and successive crises, such as the Asian financial crisis and the COVID-19 economic recession. However, financial crises did not have a lasting effect on global emissions reductions or stabilizations. Primary energy consumption growth rates follow more closely the sub-periods of higher and lower emissions growth (Figure 2b). Primary energy is a more reliant short-term indicator of emissions growth because fossil fuels have remained above 80% of total energy since 1990 [15].



**Figure 2.** Development in global CO<sub>2</sub> emissions from fossil fuels and industry, 1960–2020. (a): Emissions per year with six high-growth sub-periods (red) (years with annual growth rates >1%) and five slow-growth sub-periods (blue) (years with growth rates equal to or below 1%). (b): Average annual growth rates for high- and low-growth sub-periods of CO<sub>2</sub> compared to sub-period growth rates of GDP and primary energy supply (PES). PES 2020 is based on the IEA projection (−4%) compared to 2019 [78]. Data source: Global Carbon project [5], World Bank [79], IEA [16]. The figure is an update of Figure 1 in Pedersen et al. [15].

One low emission growth period is different from the previous. Figure 2 shows that despite low emissions growth between 2013–2016, GDP growth rates were relatively stable with low variability. Compared to previous periods, which were characterized by crises, the 2013–2016 period marks a shift from historical patterns. It shows a period of slower emissions growth that was not forced by financial crises in major world regions, like in 2008/2009, 1998/1999, and earlier. This may be a result of at least three fundamental

changes: emerging climate policies, falling prices of renewable energy technologies, and expansion of fracking [15].

Historically, CO<sub>2</sub> emissions are tightly coupled directly with primary energy use, and indirectly with GDP. Despite short-term variabilities in global CO<sub>2</sub>, emissions are mainly caused by a combination of slow changes in long-term drivers [15].

The impact of the COVID-19 pandemic provides relevant insights into the current dependency on fossil-fuel-driven global economic growth. Protection measures to slow the spread of COVID-19 in 2020 caused a 2.6 Gt CO<sub>2</sub> decrease in global fossil and industry CO<sub>2</sub> emissions, corresponding to a 5.6% reduction relative to 2019 [7,8,80], which has seldom been observed before [10]. Nevertheless, annual cuts of 1–2 GtCO<sub>2</sub> are required by 2030 to stay below the Paris Agreement 1.5 °C and 2 °C warming targets [10].

Primary energy is a direct driver of fossil fuel CO<sub>2</sub> [15]. In 2020, global coal, oil, and natural gas consumption decreased by 4%, 9%, and 1.9%, respectively, relative to 2019 [11,13]. The coal decline was the largest annual drop since World War II. While the USA, EU, and other regions decreased, China consumed more than half of global coal, leading to rapid economic recovery by the second semester of 2020. No further decreases in global coal consumption are expected between 2021–2025, while decreases in the USA, EU, and some other countries will offset increases in China and India [81]. Despite the uncertainty, future global oil demand is projected to increase during the 2020s, peaking around 2030 [82]. An average annual growth rate of 1.5% in global gas is projected between 2019–2025, while the pre-COVID-19 projection was 1.8%. The largest part of the projected growth in demand in 2021–2025 comes from Asia, particularly China and India, where political support for gas is strong [83]. Before the Ukraine–Russian war, political support for gas was also high in the OECD. This may change in the EU with an increasing focus on national security and seeking independence from Russian gas [84].

The “Stated Policies Scenarios” developed by the International Energy Agency (IEA) focusing on fossil fuel demand in the post-COVID period broadly agree with the NDC submissions under the Paris Agreement by December 2020. During 2021 more countries updated their NDCs, putting the world on a pathway where global GHGs will increase about 16% by 2030 relative to 2010 [21]. A pathway with no or limited overshoot of the 1.5 °C Paris goal requires global GHG emissions to be reduced by 45% between 2010–2030 and reaching net-zero around 2050 [14]. Limiting the temperature rise to below 2 °C requires a 25% decrease between 2010–2030 and reaching net-zero around 2070 [14,21]. Rapid global decarbonization between 2022 and 2030 is mandatory to achieve the Paris goals. The NDC completion depends on financial support from industrialized countries to developing countries [21,85].

Recently, the energy transition has become a security issue. The current Russia–Ukraine war imposes a security risk, which involves EU and US dependencies on import of Russian natural gas and oil. Thus, we shortly discuss climate change security risks, geostrategic implications, and interaction with various types of crises. The objective is two-fold: first to briefly review the security concerns related with climate change, and second the impacts that world crises have on climate change, with particular attention to the Russia–Ukraine war crisis.

Global climate is likely to create critical challenges to global security, through localized disruption that may scale-up into regional and international security scenarios leading to crises [86]. The most vulnerable countries and regions to ACC, namely those that have extensive arid lands with water scarcity problems, countries with economies that are highly dependent on agriculture and with low socioeconomic development, fragile states, small island states, and the Arctic polar region, are also areas of significant military engagement [87]. However, the causal relation between climate change and conflict is difficult to establish [88,89]. During the Holocene, there is evidence that the consequences of natural climate change in conjunction with other stresses have led to armed conflicts and the disintegration of societies, and in some cases contributed to societal collapse [90–93]. In the period 1980–2010, about 23% of conflict outbreaks in ethnically fractionalized countries

coincided with extreme climate events [94]. These results point to an increased risk of armed-conflict outbreaks in drought-prone regions of fragile states [94]. Climate change impacts constitute an additional stressor for social destabilization and may contribute to triggering migratory flows in various regions, such as Sub-Saharan Africa and the Middle East, affecting geostrategic equilibrium. This also implies increased technological competition between the major powers, and cybersecurity concerns [95,96]. Some of these geopolitical problems have been downplayed relative to fossil fuels because renewable energy sources are more abundant and evenly distributed around the world [97]. The rapid global implementation of the new renewable energy paradigm depends crucially on technology, innovation, investment and the availability of critical minerals, areas that would benefit from a closer collaboration between the US, EU, China, and other powerful economies. The way the energy transition affects each country depends on its energy resources, circumstances, and capabilities. Fossil-fuel-dependent countries constitute a big challenge for these processes, since they represent almost one-third of the global population and are responsible for about 20% of global GHG emissions [98]. There is a risk that in a fast transition to renewables some of the less resilient fossil-fuel-dependent countries, especially those whose economies depend more on oil and gas revenues, may begin to decline and destabilize, with potential security implications.

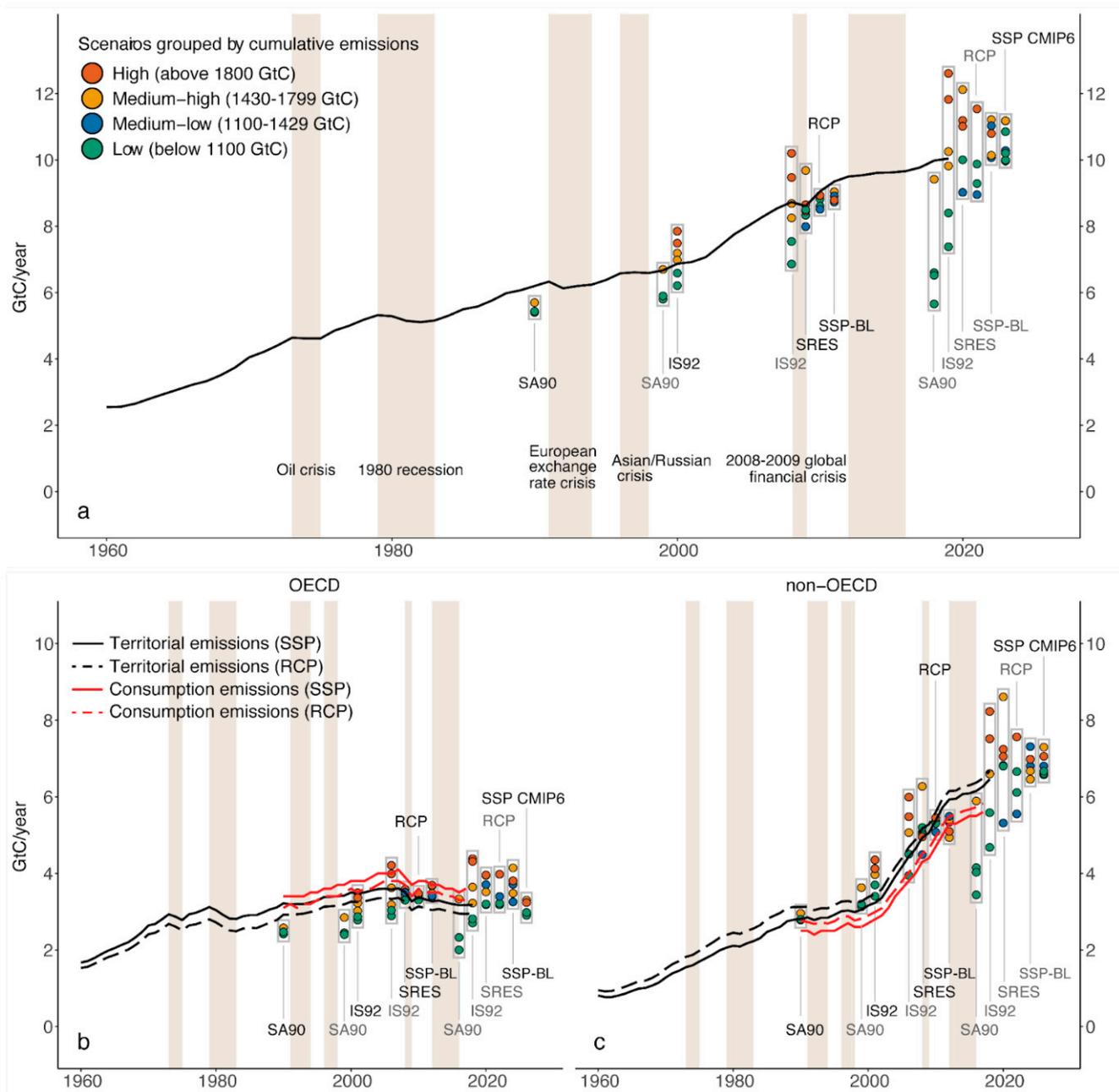
Most global crises are likely to have an impact on the climate change crisis as exemplified by the COVID-19 pandemic and the Russia–Ukraine war. The first did not result from voluntary mitigation measures or long-lasting structural energy system changes. The second is very likely to be a protracted crisis lasting many years and with major implications as regards fossil fuel use and the climate crisis. It is still too early to foresee the full implications of the war on climate change. However, the war has made the EU ramp up renewable energy transitions and energy efficiency via behaviour changes in EU, which may speed up EU mitigation and global energy transitions, e.g., for nations to become independent of fossil import or to avoid reliance on non-democratic petro-states. Moreover, a perturbing impact of the war crisis stems from the higher cost of commodities, which may also lead to changes in the mobility sectors.

### 2.3.3. Structural Differences I: GHG Emissions Grow at Different Regional Rates

The purpose of this subsection is to argue that delivering a Paris solution to the climate change problem depends critically on OECD countries assuming a leading role in the mitigation process both in their countries and in the non-OECD countries. Furthermore, it points out that changing the emission inventories to consumption-based (rather than territorial) emissions would contribute favourably to global mitigation.

Most national climate targets rely on reporting the emissions that are created inside their national borders (the country's territory). When imported goods originate from emissions-intensive manufacturing, a country's consumption emissions easily exceed their territorial emissions. Thus, emissions inventories including consumption is a more reliable indicator of a country's mitigation responsibility. In April 2022, Sweden was the first country to include consumption-based emissions in its climate targets and include overseas emissions reporting [99], setting a new standard for Annex-I parties (the industrialized countries under the UNFCCC often opposed to the non-Annex-I developing or least, semi, and newly industrializing countries).

Furthermore, climate financing of mitigation actions within the UNFCCC and the Paris Agreement [85] in non-OECD countries is crucial if we are to follow a 1.5 °C pathway. The historical reality is that CO<sub>2</sub> emissions tend to stabilize in OECD regions while growing rapidly in non-OECD regions (Figure 3), mainly in Asia [15,80]. This trend is very likely to persist, since global primary energy demand is projected to increase by 50% up to 2050, led by growth in non-OECD countries [11].



**Figure 3.** Global and regional developments in fossil fuel CO<sub>2</sub> emissions 1990–2019. From Pedersen et al. [80] Global emissions (a), Regional non-OECD (b) and OECD emissions (c).

The rapid growth of emissions in non-OECD countries and in countries with economies in transition is partly caused by the objective of equity and economic development leading to higher levels of GDP per capita, comparable with those of OECD countries. “Sustainable economic growth and development in all Parties, particularly developing country Parties,” is a principle recognized in Article 3 of the UNFCCC. In line with this principle, the Kyoto Protocol only sets binding emission reduction targets for the Annex A countries—37 industrialized countries and economies in transition and the European Union [100].

Emissions growth in non-Annex-1 countries is partly caused by material consumption in Annex-1 countries. Reduced consumption of material goods, particularly in Annex-1 countries, is not considered in UNFCCC negotiations but appears to be a relevant issue to deliver a Paris solution to the climate change problem. This concern could be the basis for changing the emission inventories to consumption-based emissions rather than including

only territorial emissions [80]. Solving this issue would give a clearer picture of relative responsibilities for national emission reductions on a global scale.

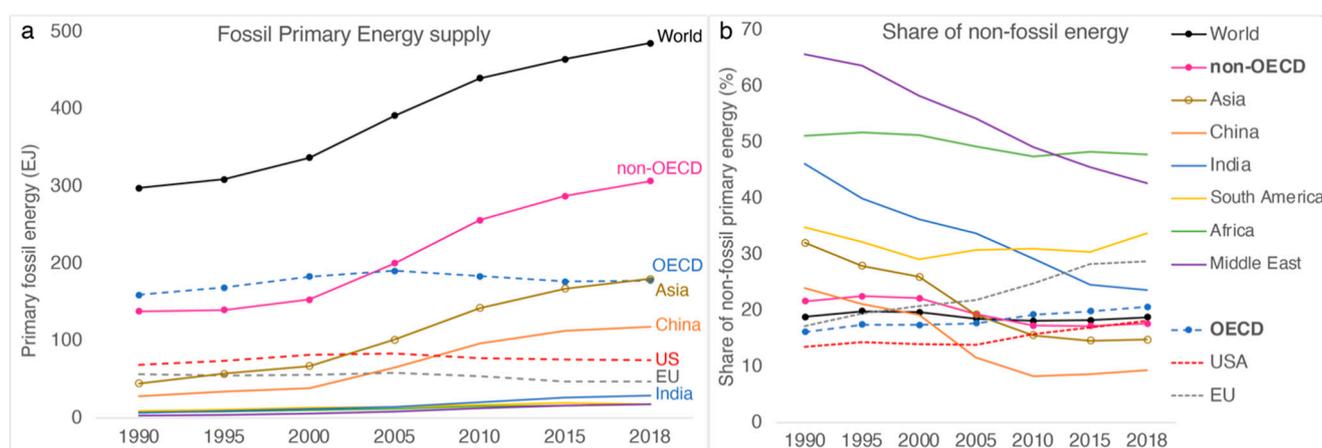
In conclusion, there is an urgent need to support mitigation actions and an energy transition in developing semi-industrialized regions. Climate financing from rich countries to non-OECD countries to help them accelerate their energy transitions, as laid down in the Paris Agreement [85], is essential to revert growing global emissions.

#### 2.3.4. Structural Differences II: The Energy Transition Occurs at Different Rates

This subsection is complementary with the previous one, briefly analysing the different challenges various types of countries face in the energy transition process.

Since the signing of the Paris Agreement, global primary energy has grown 1.6% annually (2015–2019), almost unchanged, compared to the past three decades (1.8%). The growth in primary fossil energy has been slightly slower since the Paris Agreement (1.2% annually) compared to 1990–2019 (1.7%) [15,16]. Although emissions growth is directly related to fossil primary energy consumption [15], the policy strategies of the four major emitters—China, US, EU, and India, which historically have contributed to 57% of GHG emissions from 1850–2019 [5,6]—focus on increasing renewables. However, the substitution of fossil fuels with renewable sources has had limited success [101–107]. Since the Paris Agreement, fossil energy consumption decreased in South America and OECD, while it increased in other regions and fastest in Asia. Since 1990 Asia and the Middle East contributed most to global growth.

Despite increasing shares of non-biomass renewables, the global share of fossil energy has remained almost unchanged since 1990 (~82%), with a slight decline to 81.5% between 2015 and 2019 [16]. OECD countries display increasing shares of non-fossil energy, while non-OECD declined (Figure 4 right). Africa has a low fossil fuel primary energy consumption, comprising less than 4% of global consumption, and the world's highest non-fossil share (48%). This is significantly above South America (34%) and EU (30%) levels in 2019. The US (18%) and Chinese (9%) levels are below the world average (19%). Around 2000, India exceeded Africa in fossil energy consumption with a fast-decreasing non-fossil share of the total energy supply.



**Figure 4.** Fossil fuel primary supply (a) and share of non-fossil primary energy (b) 1990–2018, globally and for selected non-OECD and OECD countries. Based on data source from IEA [16].

High fossil energy consumption and low shares of renewable energy make China's and India's energy futures critical for global climate mitigation [108–110]. On the one hand, the non-fossil energy shares are increasing in China (Asia and non-OECD). On the other hand, global fossil energy consumption has increased significantly since 2015 and almost simultaneously at the same rate as Asia's (China and India's) energy consumption.

Globally, increasing oil and gas consumption between 2015 and 2020 outbalanced a slightly decreasing trend in coal since the ratification of the Paris Agreement [16].

China, India, and the US are among the world's largest coal consumers, while the EU has been phasing out coal and substituting it partly with biomass [16]. India and China rely heavily on coal production and consumption, with large coal reserves. At the same time, renewable energy has grown impressively in both countries, setting them to a leading global role in areas such as solar power and batteries [111,112]. Coal comprises 70% and 56% of the fossil fuel consumption in China and India, respectively. In 2020, China increased its coal power plant capacity above 2018 and 2019, reaching roughly half of the world's coal power capacity and half of the coal-fired power plants in development [109]. India has ambitious renewable energy policies, but their implementation has been slower than expected, making it unlikely to reach its 2022 renewable targets [110].

History showed slow transitions in socioeconomic and energy systems, with policy regulation proposals opposed by industry [113–115], in politics, the public debate [68,116], and by some scientific experts [117–119]. However, in recent years, public and scientific consensus on ACC seems to be increasing. Youth movements and public awareness have created a new political operating space (see Section 2.3.8). This is reflected in recent European elections e.g., [120] and an associated development policy agenda regarding increasing emissions reductions e.g., [121,122]. Environmental policy stringency has increased gradually in the EU in the past decades and rapidly in China and India since 2009 [123,124]. Moreover, the fossil energy industry, which organized several anti-climate policy campaigns [114,125] (Section 2.3.1), is now gradually reselling itself as climate 'responsible', with ExxonMobil as one of the last [126,127]. In conclusion, the OECD fossil fuel economies have a higher resilience and are better prepared for the energy transition, while most non-OECD economies require support from richer countries to decarbonize their economies.

### 2.3.5. Negative Emissions to Reach the New Net-Zero Targets

This subsection analyses ways to solve challenges created by long delays in implementing solid global mitigation policies—the feasibility and side effects of implementing negative emissions to compensate for the time lost.

The Paris Agreement encourages that all GHG emissions not eliminated be balanced by removing an equivalent amount of CO<sub>2</sub> from the atmosphere [85]. Aligned with the Paris Agreement, carbon neutrality is central to several national policies. However, the net-zero definitions and monitoring are uncertain [28]. Net-zero is a formal or informal stated policy target of the four major global emitters, covering about 60% of global emissions. The EU and US have committed to net-zero by 2050 [122,128]. The EU includes all GHG, while the US is unspecified. China aims to be CO<sub>2</sub> neutral in 2060 [104], and India [129] recently announced a net-zero carbon emissions target by 2070 [130]. Achieving net-zero means that a country can still produce emissions if negative emissions technologies (NETs) (NETs comprise afforestation and reforestation; land management to increase carbon in soils; bioenergy with carbon capture and storage (BECCS); carbon capture, use, and storage (CCUS), a process of capturing CO<sub>2</sub> emissions from fossil power generation and industrial processes for storage deep underground or for re-use; direct capture of CO<sub>2</sub> from ambient air with storage or re-use; and other methods e.g., [107,131]) are used. Forest land is the leading NET and net sink strategy [103,132,133]. This creates challenges for national carbon neutrality and the 2030 net emission targets.

In general, reforestation policies face challenges. These comprise, e.g., double counting [25,26], forest fires [27], and social constraints for indigenous and local communities in developing countries [28]. The anticipated role of CO<sub>2</sub> removals also needs more clarity, since strategies for removal or offsetting often have uncertain effectiveness and may comprise various risks, e.g., impacts on biodiversity, food security, and water supplies. Implementation of NETs may cause trade-offs with the UN Sustainable Development Goals (SDGs) [134,135], e.g., human rights trade-offs. Indigenous people movements have con-

tested REDD+ projects and the inclusion of REDD+ in the Paris Agreement [136] because of land grabbing practices that have denied access to forest resources by the local communities [137]. As future climate impacts (Section 2.3.7) may cause more severe wildfires, preserving natural forests may imply a sustainable and resilient strategy. Unmanaged historical forests show higher energy efficiency than human-managed forests [138], suggesting higher climate change resilience and may strengthen forest management efforts [139]. Primary forests accumulate about 35% more carbon than younger trees planted between now and 2050 and thus will accumulate less carbon as historical forests during that same growth time [140].

As discussed previously, fossil fuel industries resell themselves as climate responsible (Section 2.3.4), and present mitigation strategies including unrealistic emissions offsetting, thereby legitimizing continued pollution. For example, four fossil fuel companies, Shell, BP, TotalEnergies, and ENI, require emissions offsetting equal to a land area twice the size of the UK [28], which indicates apparent contradictions between optimistic strategy aims and actual implementation [141]. To be effective, a net-zero target must be complemented by detailed and sectoral mitigation policies and measures and by intermediate commitments. The EU 2030 targets put them on an almost linear path to net-zero, while China and India have not yet peaked their emissions, which makes their net-zero targets by 2060 and 2070 more challenging. The US Forest policy is not specific about reaching their negative net emissions [142–144], while India's policy is also overly optimistic [110].

The main conclusion is that negative emission policies are presently a necessary condition to comply with the Paris agreement temperature interval goal, but attention must be given to assure that their implementation is realistic and compatible with human rights and the SDGs.

### 2.3.6. How Compatible Is Mainstream Economics with Rapid Global Decarbonization?

This subsection addresses an overarching issue in the pathway to deliver a Paris solution. The question is to what extent the global usage of mainstream economics (ME) may accommodate a solution. Rapid global mitigation is disruptive for many economic activities, with some industries and businesses gaining value and flourishing. In contrast, others shrink and disappear, which generates social and economic costs and losses to groups of people and countries with the potential to slow down GDP growth. Thus, a just and equitable transition to a global low-carbon economy faces difficulties [145]. No transition is not just, e.g., since impacts are already damaging vulnerable countries (see next Section 2.3.7). Thus far, a transition was partly constrained by an underlying global role of ME.

The mainstream economic theory acknowledges market failures or negative externalities. Over-exploitation of natural resources, pollution, GHG, waste, and environmental degradation can be corrected by cost internalization of negative externalities through market correction measures. For climate change, the market correction implies establishing a price attached to GHGs, making emitters bear the cost of emissions. All countries, or initially a climate club of countries [146], should use a carbon tax or a cap-and-trade mechanism or both methods to put a carbon price in all economic sectors. Despite implementation of national carbon taxes (e.g., in Europe) and various emissions trading schemes (e.g., in China and EU), the global economy is still far from correctly pricing the cost of externalities. Economic cost-benefit optimization models that use mitigation as a market correction based on a carbon price were developed about 30 years ago and continuously updated [34,146–148]. However, their practical application in global climate governance [149,150] and national policymaking [101,128] to mitigate and 'control' climate change has had limited success.

It is tough to address climate change challenges from a mainstream economics' perspective. First, solving climate change requires intertemporal decisions involving periods much longer than two social generations (40 to 60 years). However, the main objective of the economic growth theory of R. M. Solow and T. W. Swan [151,152] is to maximize

GDP over periods of 50–60 years or shorter [153] with no further attention to the medium and long term. The optimized economic activities in the human subsystem for a period of 50–60 years interfere with the Earth system for many centuries and may generate negative feedbacks on the human subsystem [2]. For instance, the adverse impacts of anthropogenic GHG emissions during the last 200 years will be felt for centuries and millennia. These periods for human hyperbolic time discounting are nearly irrelevant [154]. The point is that mainstream economics assumes that human time discounting is exponential. However psychological experiments show that it is hyperbolic, which is quite different. In the intertemporal decisions recommended by the cost–benefit optimization models [34,155], the critical point is to assume that the future is a series of successive intermediate runs of 50-to 60 years of economic growth. The reason for favouring the intermediate run rather than the long term is that the operative social time of this generation is strongly focused on its own gains and sacrifices (i.e., its own element of operative time). The spaces of experience and horizons of expectation of future generations are barely relevant, because they go beyond the operative time of this social generation [52] (Santos, 2021).

Second, ME face another difficulty in dealing with long-term intertemporal decisions. Climate change market-based mitigation policies are sensitive to the value chosen for the social time discount rate used for mitigation investments, a choice generating well-known debates [32,33]. Social discount rates are used to put a present value on social costs and benefits that will occur later. In climate change policy they are critical because they are used to determine how much should be spent in mitigation now to limit the impact of climate change in the future. High discount rates put less weight on the future, weaken mitigation efforts and work against regulations to reduce GHG emissions. Low discount rates imply that we should act now to protect future generations from the impacts that would result from unmitigated climate change. Mainstream economists, such as Nordhaus, advocate for a high discount rate essentially because in mainstream economics, the social discount rate should reflect the opportunity cost of capital and point out that rapid mitigation would slow global GDP growth. It is therefore better to wait until technology advances have lowered the mitigation costs. Contrarily, other economists focus on ethical considerations of intergenerational justice to advocate for a low social discount rate to avoid future impacts of unmitigated climate change, favouring the most vulnerable countries.

Third, the way ME are dealing with the differentiated climate change impacts in populations with different socioeconomic development levels puts human rights at risk for poor and vulnerable people [156]. Negative climate change impacts are on average more severe in lower- and middle-income countries than in higher-income countries. Thus, loss of lives and livelihoods in lower- and middle-income countries highly affect poor people's rights to life, development, food, health, water, sanitation, and housing. This disparity is not captured by mitigation models based on a cost–benefit economic optimum. The economic losses in a poor and vulnerable population, measured in terms of GDP, can be low, but the loss of human rights and environmental degradation can be high. Using the Global Progress Indicator (GPI) [157] of ecological economics, which considers both environmental and social factors, instead of GDP, would provide different results.

According to ME, nations have adopted minimal mitigation policies. Only alternative climate policies based on optimized growth theory models can successfully address the problem [155]. Reaching the Paris targets with current policies is infeasible with reasonably accessible technologies, even with very ambitious mitigation strategies [155]. The cost–benefit economic optimum (DICE model), which optimizes climate policy, projects that the average global temperature increase will reach about 3.5 °C in 2100 and keep increasing in the 22nd century [155,158].

Knowledge of the beneficial long-term effects of mitigation has been insufficient to move the electorates in the OECD towards rapid decarbonization policies. In addition, global mitigation has not yet been sufficiently supported by the developed Annex-1 countries [149,159], as inscribed in the Paris Agreement [85]. Recently, the damage caused by climate impacts has caught the attention of OECD society and governments, emphasizing

the need for rapid adaptation and mitigation action. The UNFCCC and the Paris Agreement allow fossil-fuel-driven socioeconomic development in countries with emerging and developing economies [85,160]. Rapid mitigation is more difficult in such countries, including China and India, because their priority is to complete their development agenda and reach the same GDP, economic prosperity, and well-being as the OECD countries [104,161,162].

In the ME model, all countries are committed to the same global GDP growth, believed to necessarily lead to increased future global economic prosperity and well-being. Carbon pricing is likely to slow down the country's GDP growth and its competitiveness in the global economy in the short term. However, each country is a particular case as regards the energy transition, so the effect of putting a price on carbon depends on the endogenous energy sources, the energy system, the rate of growth of energy demand, and the transition process. Governments, especially in OECD countries, frequently prefer to use regulation and administrative measures to decarbonize the economy instead of a carbon tax because the cost of such measures is less transparent to society. Therefore, it becomes unclear which voters will be more affected by the process [161]. The introduction of a uniform CO<sub>2</sub> price on all emissions in a world economy based on intensive energy use, where about 81.5% of the primary energy sources in 2019 were fossil fuels [16], would necessarily reduce its GDP. In any case, rapid decarbonization requires increasing state intervention in macroeconomics. However, for ME, this is not an option.

In conclusion, world climate policies are far from following the optimal global mitigation pathway advocated by the recent ME mitigation model [158]. According to this point of view, if governments would decide to follow the optimal pathway today, it is already too late to reach the Paris targets. Nevertheless, world climate change policies continue to be strongly influenced by sub-optimal ME applications.

### 2.3.7. Limits to Climate Change Adaptation and Loss and Damage

The present paper focuses on finding a Paris solution to climate change, i.e., mitigation. So why discuss adaptation? The reason is that, following a rational perspective, the evolving scientific knowledge about increasingly harmful climate change impacts [2] may enhance the likelihood of accelerating the global mitigation process. Moreover, further knowledge about limits to adaptation and loss and damage is likely to become a determinant to reach a deliverable solution to climate change. In the recent public presentation of the IPCC Working Group II 6th Assessment Report [2,14], it was stated that "Human-induced climate change is causing dangerous and widespread disruption in nature and affecting the lives of billions of people worldwide, despite efforts to reduce the risks. People and ecosystems least able to cope are being hardest hit". In the 50 years from 1970–2019, there were more than 11,000 reported disasters attributed to weather, climate, and water extremes globally, with just over 2 million deaths and USD 3.64 trillion in losses [163,164].

Already in 2007, the IPCC acknowledged "substantial limits and barriers to adaptation (very high confidence)" [165]. In 2018, the 1.5 °C report concluded that climate-related risks to food security will rise from moderate to high between 1.5 °C and 2 °C, respectively. Above 1.5 °C, available adaptation options will be less effective, with limits to adaptation for vulnerable regions and sectors. Limiting warming to 1.5 °C may result in smaller net reductions in yields of major crops, affecting food availability and nutrition, and also adversely affecting livestock via changes in feed quality, fertility, production, the spread of diseases, and water availability [14].

An adaptation limit can be defined as "a point at which an actor can no longer secure valued objectives from intolerable risk through adaptive action" [166]. The notion of limits implies the absence of adaptation options over a given time horizon [167], including both social systems and the inability of natural systems to adapt to climate change [165,168]. Risks can be grouped as acceptable, tolerable, or intolerable risks. Intolerable risks are related to threats to core social objectives, such as public health and safety, welfare, continuity of traditions, security, and legal standards [166,167,169]. With escalating climate change risks, the human and natural system capacities to effectively adapt through incremental

adjustments are increasingly impaired. Breaching adaptation limits may result in escalating losses. The most vulnerable countries are increasingly calling the attention of the rest of the world to the impacts that occur beyond adaptation limits, i.e., the residual effects that occur after those limits have been reached [170], referred to as loss and damage (L&D) [149]. The intensity of L&D depends critically on the degree of global mitigation efforts and nature of future climate tipping points (see Section 3). L&D was framed within the context of the UNFCCC in 2013 [171,172] and contemplated in the Paris Agreement (Article 8) [85]. However, L&D discussions have been contentious at the UN climate talks because the high-income countries, in particular the USA, have so far discarded the legal possibility of being declared co-responsible for the losses and damages resulting from climate change in the low-income countries. Despite fearing a third climate financing pillar, the EU approached the L&D discussions at the Glasgow climate summit in 2021 [159,173].

Furthermore, non-economic loss and damage (NELD), developed within the UNFCCC, represents climate-change-related losses of values (both tangible and intangible) not typically traded in markets. They are context dependent and incommensurable, such as loss of biodiversity, cultural identity, cultural heritage, human health, or even loss of life triggered by climate change. They are mediated by social factors that determine vulnerability and cultural factors, shaping the context in which those losses are experienced [174]. The effects of NELD on human well-being are rarely included in observed and projected climate impacts estimates. This reveals additional shortcomings of cost-benefit economic optimum models for mitigation, as previously discussed in Section 2.3.6.

In conclusion, if it turns out to be impossible to deliver a Paris solution to the climate change problem, science projects that humankind likely moves in the direction of a dystopic world where countries are increasingly affected by climate change impacts. Limits to adaptation and L&D will become more frequent and damaging in vulnerable regions, governments, and sectors as the GMST increases. From a rational viewpoint, this scientific knowledge should be a solid driver to accelerate the global mitigation process.

### 2.3.8. Climate Change Ethics, Climate Justice, and Anti-Fossil Fuel Moral Norms

This subsection addresses the ethical aspects of climate change. Climate change ethics have been the subject of extensive research since the 1990s [59,60,62,162,175,176], debated to trigger the acceleration of the global mitigation required to meet Paris targets. There are clear links between research and grassroots climate justice and action movements in democratic countries. These movements tend to stimulate public debate and reaction, plausibly contributing to speed up global mitigation. Faced with the increasing evidence that climate politics is “difficult, problematic, or perhaps wicked” [177], climate ethicists have tried to be more practical and seek pragmatic ways to bring individual people and eventually society closer to the normative ethical ideals. This emergent approach, called non-ideal theory, specifically addresses the question of realism, which implies starting from an accurate description of people, politics and policies, transitional processes, concerns, and ways to deal with non-compliers [178].

A critical aspect of the non-ideal theoretical approach of leading individuals and society closer to normative ethical ideals is identifying agents of change willing to pursue changes that would reduce the injustices resulting from climate change [179]. An agent of change is ready or potentially willing to pursue actions to address and help resolve relevant injustices. A crucial theoretical question is to what extent the agents of change are free to move successfully towards the normative ethical ideals or are constrained by the overarching mainstream economics implied in the world economic system (Section 2.3.6) that empowers the agents [180]. “Even non-ideal climate justice may be too disconnected from the fast-moving and messy climate circus” [177]. Recently, “engaged methods” to activate climate action that involve substantial interaction between the theorist and potential agents of change have been proposed [181].

Climate justice comes mainly in three forms: an academic discourse, a motivational ideal of nongovernmental organizations (NGOs), and social and political grassroots move-

ments concerned with questions of human rights, social, distributive, and intergenerational justice related to climate change. Grassroots climate justice and action movements are forms of climate activism with their origin in the 1990s [182]. Non-ideal ethical theories and climate justice grassroots movements represent complementary approaches to address ethical climate change challenges [182]. A great diversity of climate justice and climate action movements and individual climate change activists have been able to develop and establish what has been called anti-fossil-fuel norms [96,181]. Examples are discontinuing fossil fuel subsidies, promoting fossil fuel divestments, phasing out coal power stations and coal mining investments, discontinuing oil and gas fracking, and phasing out fossil fuel use. Anti-fossil-fuel norms have been advocated in explicit ways by individuals and organizations in civil society, as well as international organizations such as the IMF [183], the World Bank [184], the OECD [185] and state leaders [181].

Recently, a growing number of young climate activists are expressing their dissent about current climate change global policies and business-as-usual economic and social policies, including their undisputable emphasis on economic growth [186,187]. Youth concerns [171] imply at least three types of dissent: dutiful, disruptive, and dangerous [188]. This heterogeneous global climate movement has captured the world's attention, becoming more powerful and potentially influencing the future course of events. Part of its strength results from the fact that the young activists do not represent someone else's agenda. Furthermore, the young protesters do not yet have vested interests, except their existential interest in protecting their future lives and well-being. Furthermore, the risks of overshooting the Paris temperature goals are disproportionately higher for the young and following generations [189].

In conclusion, from an ethical perspective it is worthwhile to pay more attention to the concerns of the younger generations as regards delivering a Paris solution to the climate change problem.

### 2.3.9. SAI Geoengineering

This subsection plays a central role, arguing that SAI geoengineering should not be part of the solution to climate change. There are fundamentally three types of climate geoengineering or climate intervention actions to partially counteract ACC. Carbon dioxide removal (CDR) or negative emissions aims at removing CO<sub>2</sub> directly from the atmosphere using natural sinks or chemical engineering processes [51,190], as already mentioned in Section 2.3.4. Other methods are solar radiation management (SRM) or albedo modification and infrared radiation management (IRM), which aims at increasing the outgoing infrared radiation emitted by the Earth and atmosphere into outer space [191,192]. The last two methods consist of purposely modifying the energy balance in the atmosphere to reduce or cancel out part of the climatic consequences of the current ACC according to a specific metric such as the surface air temperature, precipitation, or others [51,190,193]. The mitigation urgency to reach the 1.5 °C goal of the Paris Agreement requires the implementation of a variety of negative emission processes [194]. However, the extraction of sufficient amounts of CO<sub>2</sub> from the atmosphere to halt climate change would be by itself economically unfeasible [195]. In that respect, SRM geoengineering is more promising and may potentially reduce some of the ACC impacts if deployed globally [196]. However, it faces social, political, ethical, and technical challenges [197]. IRM geoengineering is still in its early stages but is less likely to be as competitive as SRM. Here, we will only consider SAI SRM geoengineering, which has the potential to be more cost effective and is attracting more research and investment [198,199].

SAI geoengineering would control GMST rise without needing to reduce the amplification of the greenhouse effect produced by anthropogenic GHG emissions, and therefore without needing rapid mitigation through phasing out fossil fuels. SAI consists of launching large amounts of sulphate aerosols into the stratosphere by injecting precursors, such as sulphur dioxide (SO<sub>2</sub>), hydrogen sulphide (H<sub>2</sub>S), and sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) containing aerosols, delivered by plane, balloon, or artillery [200,201]. The aerosols cool the climate

system by increasing the Earth's albedo, a well-known effect that happens in a powerful volcanic eruption where large quantities of ash and aerosols are launched into the stratosphere, reflect more solar radiation, cause global dimming, and temporarily lower the GMST [202]. Humankind would therefore have a climate system in which the atmospheric greenhouse effect could continue to intensify but would absorb less energy from the Sun. This is essentially the same idea that was suggested to the President of the USA in 1965 [50] (mentioned in Section 2.1).

The deployment of SAI [198,199] could be implemented relatively quickly and produce a fall in the GMST within a few years. Another important feature of SAI is that it is relatively inexpensive compared to other geoengineering processes. Cooling the lower atmosphere by 1 °C would require delivering about five million tons of aerosols annually to an altitude of 20 km, with an annual cost on the order of USD 18 billion in 2020 USD [203].

The global, regional, and local consequences of this dual interference in the climate system are naturally more difficult to model and project into the future. However, SAI geoengineering does not compensate for all the effects that arise directly from the increase in atmospheric GHG concentration. Ocean acidification and the serious impacts that it has on marine and coastal ecosystems and fishing [204] is an example (see Figure 1). Another direct consequence of the higher atmospheric CO<sub>2</sub> concentration is that it causes a faster growth rate in crops, and this in turn favours the production of carbohydrates rather than the production of nutrients that are especially important for human health [205]. As regards mean global sea level rise, SAI is likely to fail to preserve the West Antarctic ice sheet [206].

The uncertainties regarding the magnitude, severity, and regional distribution of SAI side effects are unlikely to be fully resolved before studying the effects of a full-scale implementation of the technology [207]. Limited local experiments cannot fully test SAI [207]. It is widely recognized that SAI has a termination problem. If it is fully implemented, and if GHG emissions continue to grow, which is very likely in view of the increasing global energy demand and the historically stable high percentage of fossil fuels in the world's primary energy mix, SAI's temporary or definitive termination would lead to a rapid increase in GMST, increasing the risks of ACC [208]. Ross and Matthews [209] conclude that "climate engineering in the absence of deep emissions cuts could arguably constitute increased risk of dangerous anthropogenic interference in the climate system under the criteria laid out in the UNFCCC". Climate modelling shows that SAI would alter the global hydrological cycle and fundamentally affect global circulation patterns such as monsoons, leading to significant reductions in monsoon precipitation in Africa and Asia [210–213] which are essential to sustain the lives of billions of people.

According to current projections it will not be possible, at either the global or regional level, to restore the GMST and the precipitation conditions that prevailed in the pre-industrial period using SAI to counteract ACC in an incomplete and distorted way. In theory, geopolitical agreements would need to be reached on optimizing temperature and precipitation at regional levels [214]. The question then arises of which is the relevant metric: temperature or precipitation? There is evidence that developing countries are particularly vulnerable to drought because of their geography and strong dependence on subsistence agriculture [215] but it has been suggested that reduced precipitation has a more limited impact on GDP growth at the global level than the increase in GMST, leading to the conclusion that SAI would reduce inter-country GDP-based economic inequality [216]. Reaching agreement on a specific intervention in the climate system using SAI geoengineering that would be acceptable for most countries will be difficult. The reason is that there are significant differences in projections regarding the nature and intensity of the adverse side effects at regional levels worldwide [207,214,217–221]. Just as in the case of ACC impacts, medium- and low-income countries are likely to be more negatively affected by SAI side effects than high-income countries. Models have been developed to optimize the levels of SAI geoengineering against climate change and economic conditions projected for 2050 using the SSP baseline scenarios [222]. Despite these developments, the IPCC did not include SAI geoengineering as a possible policy measure to reach the 1.5 °C

Paris Agreement target [14], a position that has been harshly criticized [193]. Horton [223] considers that SAI geoengineering has been hampered by the fear of unilateralism in its implementation and presents various mechanisms that encourage collaboration between states. More recently, Heyen and Lehtomaa [196] advocate the formation of stable coalitions under various international arrangements to implement SAI geoengineering.

There exist at least two current scientific opinions. The first one defends the need to start SAI experiments to test the technology and better understand its potential benefits and side effects. The main justification is that full SAI deployment is increasingly likely. This is because “the political will needed to effectively mitigate climate change might not emerge in time to avoid serious, potentially catastrophic damage to future populations around the world” [224]. The other current opinion, shared by the authors of this paper, considers that SAI experiments are unnecessary given all the well-known and well-proven technologies available to decarbonize the world economy. It emphasizes the potential dangers and the uncertainties involved in deliberately changing the global climate to countervail ACC in a distorted and incomplete way and considers that geoengineering involves unnecessary risks for humankind and conflicts with the Sustainable Development Goals [207,214,217–221]. Furthermore, it defends that SAI is not ethically sound, because current research indicates that the side effects of its deployment are likely to be more harmful to people in some regions than in others. In other words, it disregards the need to safeguard the fundamental question of justice [225].

Recently, the US National Academies of Sciences, Engineering, and Medicine urged the US government to spend at least USD 100 million to fund SAI geoengineering experiments in the atmosphere [197]. The critical objective is to involve the USA government and governments of other countries in openly funding SAI experimental field research. The justification is that the accumulated scientific knowledge on the subject is manifestly insufficient to decide about future implementation. Governmental decisions to start funding are likely to act as a political tipping point initiative that will generate its own irreversible social and economic dynamics. The main reason for irreversibility has also been called a “slippery slope” [193,226]. It results from the fact that “there is obvious commercial potential in the developing, construction and operation of the technologies required for geoengineering the climate” [227]. Once SAI experiments start, they are likely to be perceived as pioneering a potentially important future economic activity that contributes to global GDP growth, because it countervails some (but not all) of the harmful ACC impacts without impairing the lucrative fossil fuel industry.

In conclusion, SAI geoengineering countervails only some aspects of ACC, increases the uncertainty about the future global climate, and is likely to aggravate its impacts on the world’s most vulnerable populations.

### 3. Tipping Points in the Human–Climate System

This section identifies several tipping points that may lead to a solution to the climate change problem as defined in this paper. The concept of tipping points has been increasingly used in climate change science to identify points of abrupt transition in the nonlinear dynamics of the human–climate system, its subsystems, and their interactions. They occur when sudden shifts towards a contrasting dynamical regime take place [228]. It is argued that identifying these critical points from early warning signs is essential to project the future evolution of the human–climate system. Tipping points have also been increasingly used in climate change communication to elucidate the dangerousness of its impacts [229].

Tipping points in the climate system occur in tipping elements, which are subsystems of the Earth system of at least subcontinental scale [230]. These elements can reach a threshold where they switch into a qualitatively different dynamical state in a process that is irreversible on human time scales. Policy-relevant tipping points are those expected to cause significant damage to the human subsystem and have been identified in four of the five subsystems of the climate system: the atmosphere, hydrosphere, cryosphere, and biosphere [54]. These subsystems and their interactions change via interference of

the human system, and such changes could become abrupt and/or irreversible after a tipping point has been reached [231]. Examples of these policy-relevant tipping points include the irreversible meltdown of the Greenland ice sheet, the irreversible grounding line retreat of the West Antarctica ice sheet, the severe slowdown or even shutdown of the oceanic Atlantic Meridional Overturning Circulation (AMOC), disruption of the West African and South Asia monsoons, the large-scale dieback of the Amazonian rainforest and boreal forests, the collapse of the permafrost in the Northern Hemisphere, and the abrupt decline of tropical coral reefs [231].

IPCC models project a significant number of near-term policy-relevant tipping points between a 1.5 °C and a 2 °C GMST increase, and these have been used to justify the need not to go over 1.5 °C [14]. Several tipping points that are dangerously close in terms of GMST rise occur in the cryosphere, such as the irreversible melting of the Greenland ice sheet [232]. The time required for complete melting decreases rapidly due to the GMST maximum increase above pre-industrial times. The relevance of climate system tipping points to the human–climate system depends on the severity of their associated impacts [233], the adaptation challenges, and L&D. Reducing the physical and biological uncertainties justifies the Paris solution, focusing on policy-relevant tipping points and their impacts on the human system [234–236].

Another type of tipping point in the climate system, especially relevant for the interaction between the human and climate subsystems, is when the atmosphere's GMST starts to decrease after reaching a maximum, here called the point of global warming decrease. This climate transition is critical for the success of worldwide mitigation efforts, since it marks the starting point for reducing the severity of climate change impacts. The time when it occurs will be viewed as a crucial outcome of a successful global mitigation process. The global warming decline is estimated to emerge only about 25 to 30 years after reaching a pathway compatible with the heavily mitigated emission scenario RCP2.6 because of the inertia and internal variability of the climate system [237]. More recent calculations, using the MAGICC6 model forced to follow the RCP4.5 and RCP2.6 scenarios, show that the difference in the GMST between them for 66% of ensemble members can only be expected to be visible after 2046 [238]. If rapid mitigation succeeds in following the RCP2.6 scenario, global warming decline is unlikely to be observed before 2100. This delay, after persistent mitigation efforts when the climate system is more disruptive, has significant psychological consequences worldwide and may discredit the global decarbonization process. SAI geoengineering would become more favourable for science–policy interactions and communication since the tipping point of global warming decrease would be reached a few years after the full deployment.

Global warming decrease was not a priority in the first three IPCC reports. The main mitigation objective was to stabilize GHG atmospheric concentrations [239]. The founding and ultimate objective of the UNFCCC (Article 2) “is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”, an objective that would only lead to GMST stabilization after more than 1000 years [160]. Twenty years later, Matsuno et al. [240] proposed the concept of zero-emissions stabilization as an alternative to CO<sub>2</sub> concentration stabilization, which would decrease GMST and would make it possible to postpone rapid mitigation. In 2007, it was clear that NET would have to be implemented to keep the temperature below 2 °C. The IPCC AR4, when considering emission scenarios where the GMST increase above pre-industrial at equilibrium is between 2 °C and 2.8 °C, recognized the need for negative net emissions towards the end of the century [241].

Human system tipping points are usually called social tipping points. Those that explicitly involve the interaction between the human and climate systems are tipping points in the mitigation and adaptation processes. Two types of social tipping points were presented independently by Otto et al. [56] and van Ginkel et al. [242]. The first approach focuses on the most promising dynamics in the human system to stabilize the Earth's

climate. It is built as an extension of the methodology used for the climate system [230]. It defines social tipping domains in the human system where disruptive changes leading to rapid mitigation, named social tipping point interventions, are more likely to occur. These are tipping points leading to a successful mitigation process and include removing fossil fuel subsidies, building carbon-neutral cities, divesting from fossil fuel assets, and revealing the moral implications of fossil fuels, among others [56]. The second approach addresses climate-change-induced socioeconomic tipping points and identifies 22 examples with policy relevance for Europe, where adaptation strategies and plans have been widely adopted [242]. In some cases, the adaptation measures are so transformative that they lead to socioeconomic tipping points. In the case of emergent and developing economies, this type of tipping point, such as farmland abandonment and global mean sea level rise induced migration, tends to be a more direct consequence of climate change impacts without the buffer of planned adaptation.

The concept of tipping point is also used to describe points in an adaptation process [243]. The magnitude of the climate change impacts is such that it becomes necessary to adopt an alternative adaptive strategy [244,245]. Identifying tipping points in adaptation pathways is essential to gain insight into the most appropriate policy responses as a function of time, for extended time horizons, and to postpone or antedate a given response because of changing conditions and/or the availability of new technologies [246].

Imminent changes in the abiotic subsystems of the climate system, not belonging to the typology of climate system tipping points, may have profound impacts on some critical biosphere ecosystem goods and services and hence on the human subsystem, such as changes in the general circulation of the atmosphere, the hydrosphere, and the cryosphere [245]. These impacts may eventually lead to socioeconomic tipping points [242]. A crucial example is changes in precipitation patterns related to the atmosphere's general circulation and more frequent and intense droughts. These are projected to increase water stress in many world regions during the 21st century if rapid mitigation to reach the temperature goals of the Paris Agreement fails [1]. Freshwater availability, a critical resource for human development, is under increased pressure because of climate change coupled with human and naturally induced stressors. In the past 20 years, terrestrial water storage has been reduced by 1 cm per year [164]. It is estimated that about 2.3 billion people have inadequate access to fresh water at least one month per year, and this number is likely to increase to 5 billion in 2050 [164]. Climate change is also warming the ocean, increasing its acidity and contributing to hypoxia, with potentially severe consequences for the goods and services provided by marine ecosystems [245].

#### 4. Discussion

An integrated review of climate change challenges, primary responses, and difficulties in the mitigation and adaptation processes is presented. The system analysis of the main drivers and responses to ACC concludes that despite the scientific evidence, the world is still far from a pathway that can deliver a Paris solution to climate change. The brief historical perspective in Section 2.1 shows how climate change is inextricably linked with the intensive and increasing use of fossil fuels over the past 200 years.

There are essentially two economically competitive pathways to solve the problem. The politically more accepted pathway at the international level is rapid mitigation, which requires an energy transition away from fossil fuels, which is already started, especially in some OECD countries, but still unable to decrease the global annual rate of GHG emissions. A clear example of the difficulties associated with this pathway at the international level is that only after 25 UNFCCC COPs was it possible to approve at COP26 the "phasing down of coal". However, there was no consensus on "phasing out". The second pathway is SAI geoengineering, which is not a Paris solution and is presently viewed internationally as politically unacceptable, despite ongoing efforts to obtain public funding for local field experiments. The implementation of SAI would allow the continued use of fossil fuels and would lead to a fast decrease in GMST within a few years. However, continuous SAI

would be required for an extended period until significant reductions in GHG emissions are achieved. Before achieving such deep emissions cuts, SAI termination would rapidly increase GMST to pre-SAI levels. SAI geoengineering has the additional problem of side effects that are likely to boost climate risk in some of the world's most vulnerable regions. The IPCC found SRM untested [14] with side effects and ethical implications [247].

Rapid mitigation involves less climate risk but has specific problems. The most important positive and negative determinants and the critical tipping points in the human–climate system are presented and discussed. The main conclusions are the following: the leading positive determinant to accelerate mitigation is the increasing evidence of the negative impacts of climate change, especially disasters related to extreme weather, climate, or water hazards [164]. However, vulnerability to climate change is highly unequal between high-, medium-, and low-income countries, and the capacity for planned adaptation is considerably higher in high-income countries than in other countries.

A second emerging positive determinant for rapid mitigation is the appearance of social anti-fossil-fuel movements created by young climate activists, mainly in democratic countries. The capacity of this global and diversified social movement to advance rapid mitigation is limited. A third positive determinant related to the first one is an increasing perception in high-income countries that unabated climate change is starting to negatively impact global GDP growth and disrupt the world's long-term security. However, this concern is frequently devalued in the face of the perceived short-term negative impact on global GDP growth caused by the economic energy disruption that could result from a disorderly mitigation process, as documented during the inflation surge in the second half of 2021 [248]. A fourth positive determinant is that technological advances have promoted the development of low-cost renewable energy sources that, through adequate investment, can provide an affordable, efficient, sustainable, and secure energy future at the global level [249].

The leading negative determinant is the very stable and high global dependence on fossil fuels that has supported about 80% of the global primary energy demand in the last half century. There are signs that the fossil fuel industry is beginning to accept the need to decrease fossil fuels (i.e., coal and oil). Still, the pace of change is incompatible with the temperature goals of the Paris Agreement. The coal divestment campaign is currently leading to more coal being produced for a longer time, pushed by growing global energy demand, as in the case of the Glencore mining company spinning off its coal assets into the newly listed company Thungela Resources [250]. With current national mitigation policies, the average temperatures in 2100 will likely be 2.7 °C higher [12,23]. The most optimistic scenario, which assumes full implementation of all the announced long-term pledges for decarbonization and net-zero targets (with the support of negative emissions), is that global temperature increases may be limited to 2.1 °C [23] or 1.8 °C by 2100 [24]. Without significant new national mitigation policy developments, uncertainty about negative emissions, and adequate climate financing from high-income countries to help low-income countries decarbonize, the probability of reaching the 2 °C goal is still low. Furthermore, the deployment of large-scale NETs carries the risk of overshooting the Paris temperature goals [251,252].

A second negative determinant, related to the previous one, is the geopolitical tensions and conflicts at the global scale between the major economies and the determination of the large oil-producing and natural-gas-producing countries to defend their economic interests. Phasing out fossil fuels is likely to face increasing resistance from countries with economies more dependent on fossil fuel exploitation. This resistance can cause disruption and price instability in the energy markets, as recently observed in some advanced and emergent economies in the 2021 post-COVID-19 economic recovery. Finally, the third major negative determinant is the slow investment in technological innovation and development to decarbonize critical sectors of the world energy system, including aviation, shipping, and large energy-consuming industries such as steel, cement, and chemicals. This difficulty is compounded by the low level of investment in CCUS technologies, which are essential to achieve net-zero emissions by mid-century. Nuclear fusion is unlikely to play a determi-

nant role in the rapid global mitigation process because advances in research have been slow [253]. However, investments in small and medium nuclear fission and fusion reactors are increasing.

Seven years after the Paris Agreement, the future of the mitigation process remains highly uncertain. Unquestionably, humankind has interfered deeply with the climate system. This interference is already negatively affecting human well-being and economic prosperity, especially in the most vulnerable countries. However, what percentage of people in OECD countries care about this problem and are available to spend time and money contributing to its solution? The number appears to be increasing in both the US and EU, leading to increased support for policy regulations [120,254]. It is still possible to deliver a Paris solution, but time is rapidly running short. If temperatures pass 1.5 °C, climate change's harmful medium and long-term impacts will be aggravated and affect an increasing fraction of the human population. Furthermore, the time needed to reach the tipping point of global warming decrease will expand markedly, favouring the dangerous solution of SAI implementation.

While the COVID-19 pandemic did not provide a structural change in energy systems, the Russia–Ukraine war may ramp up (EU) energy transitions. It is too early to foresee the impact of the war, despite distracting the world from the climate change emergency. Escalating oil and natural gas prices may cause consumer behaviour and energy investments to accelerate the electrification of the economy. Higher commodity costs resulting from the war, sanctions, and higher fossil fuel prices are likely to have dramatic effects on the most vulnerable countries, some of which are already at the hedge of their resilience to climate change impacts. Furthermore, the higher living costs in OECD countries and higher military expenditure may affect international climate financing.

To deliver a Paris solution, it is necessary to integrate all the well-known mitigation technologies, policies, and measures cooperatively and construct an efficient, long-term, and ethical global policy approach. The critical aspects of this program have been presented and discussed. We conclude that the constraints imposed by ME must be superseded by an approach based on ethical grounds that addresses the issues of climate justice and human rights. This approach requires phasing out fossil fuel subsidies and faster divesting from fossil fuels. It also requires the technological support and investment of OECD countries to decarbonize the non-OECD countries and help them adapt to the increasingly adverse climate change impacts. These objectives are hardly compatible with the present tension and distrust between the major powers, especially between the USA and China and the ongoing Russia–Ukraine war. It is likely, but not inevitable, that climate change continues to be addressed without following the pathway to deliver a Paris solution.

## 5. Conclusions

This paper synthesizes the climate change challenges and the insofar insufficient mitigation responses via an integrated literature review. Many solutions have been investigated in the climate change science–policy interface but have been blocked by our dependency on fossil fuels and the fossil fuel industry's lobbying power. The paper recaps how scientists identified anthropogenic climate change in the 19th century and have been scrutinized since the 1980s. Humanity has sufficient evidence of the consequences of unabated climate change and how to respond to and mitigate climate change. However, global emissions have increased, and OECD countries export the problem to non-OECD countries rather than focusing on a worldwide solution.

William Nordhaus's Dice model is an iconic reference to the present global deadlock on climate change. It assumes, as a priority, rapid and sustained global economic growth and a carbon tax system for all countries and economic sectors with a focus on GDP that favours the interests of countries with more advanced economies. This approach does not address the implications of climate change on human rights in the more vulnerable countries. Furthermore, Nordhaus's complete application of his optimized carbon tax system leads to a 3.4 °C temperature increase. This scenario is well outside the Paris Agreement

and will lead to severe climate impacts, unequally distributed among countries. Past and present policy delays and climate disruption pave the way for solar radiation management (SRM) geoengineering solutions with largely unknown and potentially dangerous side effects. A solution aligned with mainstream economics strives for short-term interests but implies increasing annual aerosol injections into the atmosphere. On the contrary, long-term mitigation solutions are available to stay below the Paris targets, e.g., via renewable transition combined with CO<sub>2</sub> sequestration from the atmosphere. It implies international cooperation and increased responsibility of the rich countries to support mitigation inside and outside their territory.

There are six key specific contributions to be addressed in the UNFCCC and implemented by governments to strengthen their national targets and NDCs to achieving the Paris targets:

1. Include consumption emissions in the National Paris Agreement targets and additionally in the UNFCCC inventories. This may strengthen and increase the national mitigation approach in OECD countries and support global mitigation, instead of OECD exporting emissions to the non-OECD regions.
2. Creation of incentives and information opportunities to start reversing the current increase in beef consumption globally (e.g., by including it in UNFCCC negotiations). Cows are less efficient than other farm animals in meat production, requiring relatively more water resources and grazing areas, besides being a methane source.
3. Initiate a political process to stop natural gas fracking because it produces additional methane emissions (this can be implemented in the UNFCCC to support reaching the Paris Agreement).
4. Initiate a global political and economic process to use CCS in coal power plants and other carbon-intensive energy and industrial infrastructures. It generally makes electricity and consumer goods more expensive, but it is a form of mitigation, and therefore it reduces the economic losses from present and future climate change impacts. The capture and liquefying process increases electricity generation costs in a CCS coal power plant by about 30%. It implies a voter challenge but could be financed by a carbon tax.
5. Stop subsidizing fossil fuels, encourage green technology advances and implementation, and reduce incentives for fossil fuel extraction.
6. UNFCCC negotiations leading to the phasing out of Annex-I energy companies' fossil exploration in non-Annex-I countries.

**Author Contributions:** Conceptualization, F.D.S., J.S.T.P.; methodology, F.D.S., J.S.T.P., P.L.F.; software, J.S.T.P., P.L.F.; validation, F.D.S., J.S.T.P., P.L.F.; formal analysis, F.D.S., J.S.T.P., P.L.F.; investigation, F.D.S., J.S.T.P., P.L.F.; resources, F.D.S., J.S.T.P., P.L.F.; data curation, F.D.S., J.S.T.P., P.L.F.; writing—original draft preparation, F.D.S., J.S.T.P.; writing—review and editing, F.D.S., J.S.T.P., P.L.F.; visualization, J.S.T.P., P.L.F.; supervision, F.D.S., J.S.T.P.; project administration, F.D.S., J.S.T.P.; funding acquisition, none. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** We obtained the historical emissions data from the following sources: **GHG emissions:** We obtained the historical emissions data from the following sources: **GHG emissions:** The PRIMAP-hist national historical emissions time series (1750–2019) v2.3.1 [6] (Gütschow et al., 2021): <https://dx.doi.org/10.5194/essd-8-571-2016>. (accessed on 25 November 2021) UNFCCC inventories [255] (UNFCCC, 2021c): [https://di.unfccc.int/detailed\\_data\\_by\\_party](https://di.unfccc.int/detailed_data_by_party) (accessed on 25 November 2021). CO<sub>2</sub> emission: Global Carbon Project (2021). Supplemental data of Global Carbon Budget 2021 [256] (GCP, 2020): <https://doi.org/10.18160/gcp-2021>. (accessed on 25 November 2021) Global: 2021 Global Budget v1.0 (metadata). Carbon dioxide (CO<sub>2</sub>) emissions from fossil fuel

combustion, cement production, and gas flaring. Regional: 2021 National Emissions v1.0 (meta-data). Production-based CO<sub>2</sub> emissions (Sheet: “Fossil fuels and cement production emissions by country (territorial, GCB)”); Consumption-based CO<sub>2</sub> emissions (Sheet: “Consumption emissions (GCB)”). We obtained the historical emissions driver databases: **Primary energy**: IEA primary energy supply: <https://www.iea.org/statistics> (accessed on 25 November 2021). **GDP**: World Bank (PPP, constant 2017 international USD): <https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD> (accessed on 25 November 2021). World Bank (Marked Exchange Rates, constant 2015 USD): <https://data.worldbank.org/indicator/NY.GDP.MKTP.KD> (accessed on 25 November 2021). **Population**: World Bank population data: <https://data.worldbank.org/indicator/SP.POP.TOTL> (accessed on 25 November 2021). Based on United Nations Statistic Division: <http://data.un.org/Default.aspx> (accessed on 25 November 2021).

**Acknowledgments**: Not applicable.

**Conflicts of Interest**: The authors declare no conflict of interest.

## References

1. IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M.K., Eds.; Cambridge University Press: Cambridge, UK, 2021.
2. IPCC. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; in press; Cambridge University Press: Cambridge, UK, 2022.
3. NASA. NASA Earth Observatory: Global Temperatures. Earth Observatory. 2020. Available online: <https://earthobservatory.nasa.gov/world-of-change/decadaltemp.php> (accessed on 25 November 2021).
4. Hansen, J.; Ruedy, R.; Sato, M.; Lo, K. Global Surface Temperature Change. *Rev. Geophys.* **2020**, *48*, RG4004. [CrossRef]
5. GCP. *Supplemental Data of Global Carbon Budget, Version 1.0*; Global Carbon Project: Canberra, Australia, 2021.
6. Gütschow, J.; Günther, A.; Pflüger, M. The PRIMAP-hist national historical emissions time series (1750–2019) v2.3.1. *Zenodo* **2021**, *8*, 571–603. [CrossRef]
7. Peters, G.P.; Andrew, R.M.; Canadell, J.G.; Friedlingstein, P.; Jackson, R.B.; Korsbakken, J.I.; Quéré, C.L.; Peregón, A. Carbon dioxide emissions continue to grow amidst slowly emerging climate policies. *Nat. Clim. Chang.* **2020**, *10*, 3–6. [CrossRef]
8. le Quéré, C.; Jackson, R.B.; Jones, M.W.; Matthe, W.J.; Smith, A.J.P.; Abernethy, S.; Andrew, R.M.; De-Gol, A.J.; Willis, D.R.; Shan, Y.; et al. Temporary reduction in daily global CO<sub>2</sub> emissions during the COVID-19 forced confinement. *Nat. Clim. Chang.* **2020**, *10*, 647–653. [CrossRef]
9. Becker, S.; Bouzdine-Chameeva, T.; Jaegler, A. The carbon neutrality principle: A case study in the French spirits sector. *J. Clean. Prod.* **2020**, *274*, 122739. [CrossRef] [PubMed]
10. le Quéré, C.; Peters, G.P.; Friedlingstein, P.; Andrew, R.M.; Canadell, J.G.; Davis, S.J.; Jackson, R.B.; Jones, M.W. Fossil CO<sub>2</sub> emissions in the post-COVID-19 era. *Nat. Clim. Chang.* **2021**, *11*, 197–199. [CrossRef]
11. IEA. *Global Energy Review 2021*; IEA: Paris, France, 2021.
12. UNEP. *Emissions Gap Report 2021*; UNEP: Nairobi, Kenya, 2021.
13. IEA. *Gas Market Report, Q2-2021*; IEA: Paris, France, 2021.
14. IPCC. *Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*; IPCC: Geneva, Switzerland, 2018.
15. Pedersen, J.S.T.; Duarte Santos, F.; van Vuuren, D.; Gupta, J.; Coelho, R.E.; Aparício, B.A.; Swart, R. An assessment of the performance of scenarios against historical global emissions for IPCC reports. *Glob. Environ. Chang.* **2021**, *66*, 102199. [CrossRef]
16. IEA. Total Primary Energy Supply (TPES) by Source, World 1990–2019. World Energy Balances 2020. 2021. Available online: <https://www.iea.org/statistics> (accessed on 2 February 2022).
17. Ambrose, J.; Henley, J. European Investment Bank to Phase Out Fossil Fuel Financing. 2019. Available online: <https://www.theguardian.com/environment/2019/nov/15/european-investment-bank-to-phase-out-fossil-fuels-financing> (accessed on 2 February 2022).
18. IRENA. *Renewable Power Generation Costs in 2019*; IRENA: Abu Dhabi, United Arab Emirates, 2020.
19. Observ’ER The State of Renewable Energies in Europe. Edition 2018. 18th EurObserv’ER Report. 2019. Available online: <https://www.eurobserv-er.org/category/2018/> (accessed on 5 January 2022).
20. UNEP. *The Emissions Gap Report 2016*; UNEP: Nairobi, Kenya, 2016.
21. UNFCCC. *Nationally Determined Contributions under the Paris Agreement: Synthesis Report by the Secretariat. 2021* UNFCCC/PA/CMA/2021/8; UN: New York, NY, USA, 2021.
22. UNFCCC. *Synthesis Report on the Aggregate Effect of the Intended Nationally Determined Contributions*; UN: New York, NY, USA, 2015.
23. UNFCCC/UNEP. UNFCCC, UNEP, Ambition: The Emissions Gap Report 2021. In Proceedings of the COP-26, Glasgow, Scotland, 1–12 November 2021.

24. CAT. Countries. Climate Action Tracker. 2021. Available online: <https://climateactiontracker.org/countries> (accessed on 22 April 2020).
25. Schneider, L.; Kollmuss, A.; Lazarus, M. Addressing the risk of double counting emission reductions under the UNFCCC. *Clim. Chang.* **2015**, *131*, 473–486. [[CrossRef](#)]
26. Rogelj, J.; Geden, O.; Cowie, A.; Reisinger, A. Net-zero emissions targets are vague: Three ways to fix. *Nature* **2021**, *591*, 365–368. [[CrossRef](#)]
27. Costa, H.; de Rigo, D.; Libertà, G.; Durrant, T.; San-Miguel-Ayanz, J. *European Wildfire Danger and Vulnerability in a Changing Climate: Towards Integrating Risk Dimensions*; Publications Office of the European Union: Luxemburg, 2020.
28. Hite, K.; Lawson, M.; Gore, T.; Hoglund, R.; Zagem, B.; Herman, M.; Comte, A.L.; Pérez Terán, A.S.; Codispoti, B.; Burgos, S.; et al. *Tightening the Net: Net Zero Climate Targets—Implications for Land and Food Equity*; Oxfam: Oxford, UK, 2021. [[CrossRef](#)]
29. Rittel, H.W.J.; Webber, M.M. Dilemmas in a general theory of planning. *Policy Sci.* **1973**, *4*, 155–169. [[CrossRef](#)]
30. Incropera, F.P. *Climate Change: A Wicked Problem*; Cambridge University Press: New York, NY, USA, 2015.
31. Sun, J.; Yang, K. The Wicked Problem of Climate Change: A New Approach Based on Social Mess and Fragmentation. *Sustainability* **2016**, *8*, 1312. [[CrossRef](#)]
32. Stern, N. *The Economics of Climate Change: The Stern Review*; Cambridge University Press: New York, NY, USA, 2007.
33. Nordhaus, W.D. A Review of the Stern Review on the Economics of Climate Change. *J. Econ. Lit.* **2007**, *45*, 686–702. [[CrossRef](#)]
34. Nordhaus, W.D. Revisiting the social cost of carbon. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 1518–1523. [[CrossRef](#)] [[PubMed](#)]
35. Kiley, M.T. Growth at Risk from Climate Change. *Financ. Econ. Discuss. Ser.* **2021**, *2021*, 1–19. [[CrossRef](#)]
36. Fourier, J. Memoire sur les températures du globe terrestre et des espaces planétaires. *Mém. L'acad. R. Sci. L'inst. Fr.* **1827**, *7*, 569–604.
37. Fourier, J. Résumé theorique des propriétés de la chaleur rayonnante. *Ann. Chim. Phys.* **1824**, *27*, 236–281.
38. Tyndall, J., XXVII. On radiation through the earth's atmosphere. *Lond. Edinb. Dublin Philos. Mag. J. Sci.* **1863**, *25*, 200–206. [[CrossRef](#)]
39. Arrhenius, S., XXXI. On the influence of carbonic acid in the air upon the temperature of the ground. *Lond. Edinb. Dublin Philos. Mag. J. Sci.* **1896**, *41*, 237–276. [[CrossRef](#)]
40. Arrhenius, S. *Worlds in the Making: The Evolution of the Universe (Translation)*; Harper & Bros: New York, NY, USA, 1908.
41. Plass, G.N. The Carbon Dioxide Theory of Climatic Change. *Tellus* **1956**, *8*, 140–154. [[CrossRef](#)]
42. IPCC. *Climate Change: The IPCC Response Strategies, Working Group III*; IPCC: Geneva, Switzerland, 1990.
43. Santos, F.D. *Humans on Earth: From Origins to Possible Futures*; Springer: Berlin/Heidelberg, Germany, 2012.
44. Jones, C.I. The Facts of Economic Growth. *Handb. Macroecon.* **2016**, *2*, 3–69. [[CrossRef](#)]
45. BP. *BP Statistical Review of World Energy 2020*, 69th ed.; BP: London, UK, 2020.
46. Smil, V. *Energy Transitions: Global and National Perspectives*, 2nd ed.; Praeger: Westport, CT, USA, 2016.
47. ESOTC. Surface Temperature | Copernicus. 2019. Available online: <https://climate.copernicus.eu/ESOTC/2019/surface-temperature> (accessed on 21 November 2021).
48. NASA. Atmospheric Carbon Dioxide (CO<sub>2</sub>) and Methane (CH<sub>4</sub>) levels, 1800–Present. 2021. Available online: [www.sealevel.info/co2\\_and\\_ch4.html](http://www.sealevel.info/co2_and_ch4.html) (accessed on 2 February 2022).
49. Revelle, R.; Suess, H.E. Carbon Dioxide Exchange between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO<sub>2</sub> during the Past Decades. *Tellus* **1957**, *9*, 18–27. [[CrossRef](#)]
50. PSAC. *1965 PSAC: Restoring the Quality of Our Environment*; PSAC: Washington, DC, USA, 1965.
51. IPCC. *Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Geoengineering*; IPCC: Geneva, Switzerland, 2012.
52. Santos, F.D. *Time, Progress, Growth and Technology: How Humans and the Earth are Responding*; Springer: Berlin/Heidelberg, Germany, 2021.
53. Haff, P.K. Technology as a geological phenomenon: Implications for human well-being. *Geol. Soc.* **2014**, *395*, 301–309. [[CrossRef](#)]
54. Peixoto, J.P.; Oort, A.H. *Physics of Climate*; American Institute of Physics: College Park, MI, USA, 1992.
55. Folke, C.; Hahn, T.; Olsson, P.; Norberg, J. Adaptive governance of social-ecological systems. *Annu. Rev. Environ. Resour.* **2005**, *30*, 441–473. [[CrossRef](#)]
56. Otto, I.M.; Donges, J.F.; Cremades, R.; Bhowmik, A.; Hewitt, R.J.; Lucht, W.; Rockstrom, J.; Allerberger, F.; McCaffrey, M.; Doe, S.S.P.; et al. Social tipping dynamics for stabilizing Earth's climate by 2050. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 2354–2365. [[CrossRef](#)] [[PubMed](#)]
57. Walker, B.; Gunderson, L.; Kinzig, A.; Folke, C.; Carpenter, S.; Schultz, L. A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-Ecological Systems. *Ecol. Soc.* **2006**, *11*, 13. [[CrossRef](#)]
58. Ahlborg, H.; Ruiz-Mercado, I.; Molander, S.; Masera, O. Bringing Technology into Social-Ecological Systems Research—Motivations for a Socio-Technical-Ecological Systems Approach. *Sustainability* **2019**, *11*, 2009. [[CrossRef](#)]
59. Gardiner, S.M. *A Perfect Moral Storm: The Ethical Tragedy of Climate Change*; Oxford University Press: Oxford, UK, 2011.
60. Caney, S. Two Kinds of Climate Justice: Avoiding Harm and Sharing Burdens. *J. Political Philos.* **2014**, *22*, 125–149. [[CrossRef](#)]
61. Lavik, T. Climate change denial, freedom of speech and global justice. *Nord. J. Appl. Ethics* **2015**, *10*, 75–90. [[CrossRef](#)]
62. Gardiner, S.M. A Perfect Moral Storm: Climate Change, Intergenerational Ethics and the Problem of Moral Corruption on JSTOR. *Environ. Values* **2006**, *15*, 397–413. [[CrossRef](#)]

63. WMO. *Greenhouse Gas Bulletin*; WMO: Geneva, Switzerland, 2020.
64. Banerjee, N.; Cushman, J.H., Jr.; Hasemyer, D.; Song, L. *Exxon: The Road Not Taken*; Inside Climate News: Brooklyn, NY, USA, 2015.
65. Supran, G.; Oreskes, N. Assessing ExxonMobil's climate change communications (1977–2014). *Environ. Res. Lett.* **2017**, *12*, 084019. [[CrossRef](#)]
66. Santos, F.D. Climate Change in the XXIst and Following Centuries: A Risk or a Threat? In *Societies under Threat a Pluri-Disciplinary Approach*; Jodelet, D., Vala, J., Drozda-Senkowska, E., Eds.; Springer: Berlin/Heidelberg, Germany, 2020; pp. 143–155.
67. Glaser, M.B. CO2 'Greenhouse' Effect. 1982.
68. Oreskes, N.; Conway, E.M. *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*; Bloomsbury Press: London, UK, 2010.
69. Collomb, J.-D. The Ideology of Climate Change Denial in the United States. *Eur. J. Am. Stud.* **2014**, *9*, 10305. [[CrossRef](#)]
70. Metayer, M.; Breyer, C.; Fell, H. The projections for the future and quality in the past of the World Energy Outlook for solar PV and other renewable energy technologies. In Proceedings of the 31st EU PVSEC, Hamburg, Germany, 14–18 September 2015.
71. IRENA. Renewable Power Generation Costs in 2018. International Renewable Energy Agency. 2019. Available online: <https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018> (accessed on 25 November 2021).
72. FOTE. UK Government Investment in Overseas Oil Ends, but Mozambique Gas Project Continues. Friends of the Earth. 2020. Available online: <https://friendsoftheearth.uk/climate/uk-government-investment-overseas-oil-ends-mozambique-gas-project-continues> (accessed on 23 February 2021).
73. Crooks, E. Mozambique to Become a Gas Supplier to World. Financial Times. 2018. Available online: <https://www.ft.com/content/d34685b2-7995-11e8-bc55-50daf11b720d> (accessed on 4 March 2022).
74. Rawoot, I. Gas-rich Mozambique May Be Headed for a Disaster. 2020. Available online: <https://www.aljazeera.com/indepth/opinion/gas-rich-mozambique-headed-disaster-200223112556449.html?fbclid=IwAR24wdzuzb8WPPiXQPDDP7Rj4-LBi6Q6-aNWwRGzQsbowu6yUJGz0utxtII> (accessed on 12 March 2022).
75. Boele, R.; Fabig, H.; Wheeler, D. Shell, Nigeria and the Ogoni. A study in unsustainable development: I. The story of Shell, Nigeria and the Ogoni people—Environment, economy, relationships: Conflict and prospects for resolution1. *Sustain. Dev.* **2001**, *9*, 74–86. [[CrossRef](#)]
76. Wheeler, D.; Rechtman, R.; Fabig, H.; Boele, R. Shell, Nigeria and the Ogoni. A study in unsustainable development: III. Analysis and implications of royal dutch/shell group strategy. *Sustain. Dev.* **2001**, *9*, 177–196. [[CrossRef](#)]
77. Harvey, F. Is Putin's Ukraine Invasion About Fossil Fuels? Available online: <https://www.theguardian.com/world/2022/feb/24/qa-could-putin-use-russian-gas-supplies-to-hurt-europe> (accessed on 12 March 2022).
78. IEA. Global Energy Review 2021: Economic impacts of COVID-19. International Energy Agency. 2021. Available online: <https://www.iea.org/reports/global-energy-review-2021/economic-impacts-of-covid-19> (accessed on 14 March 2022).
79. WB. DataBank: World Development Indicators. The World Bank Group Database. 2021. Available online: <http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators&Type=TABLE&preview=on#>. (accessed on 11 May 2018).
80. Pedersen, J.S.T.; van Vuuren, D.P.; Aparicio, B.A.; Swart, R.; Gupta, J.; Santos, F.D. Variability in historical emissions trends suggests a need for a wide range of global scenarios and regional analyses. *Commun. Earth Environ.* **2020**, *1*, 41. [[CrossRef](#)]
81. IEA. *Coal 2020. Analysis and Forecasts to 2025*; IEA: Paris, France, 2020.
82. IEA. World Energy Outlook 2021. International Energy Agency. 2021. Available online: <https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf> (accessed on 14 January 2022).
83. IEA. *Gas 2020. Analysing the Impact of the COVID-19 Pandemic on Global Natural Gas Markets*; IEA: Paris, France, 2020.
84. Krukowska, E.; Nardelli, A. EU Aims to Cut Dependence on Russian Gas by Almost 80% This Year. *Environ. Energy* **2022**, *42*.
85. UNFCCC/COP. *Paris Agreement*; UNFCCC: Paris, France, 2015.
86. Werrell, C.E.; Femia, F. *Picenters of Climate and Security: The New Geostrategic Landscape of the Anthropocene*; Center for Climate and Security: Washington, DC, USA, 2017.
87. Guy, K. *A Security Threat Assessment of Global Climate Change: How Likely Warming Scenarios Indicate a Catastrophic Security Future*; Center for Climate and Security: Washington, DC, USA, 2020.
88. Hsiang, S.M.; Burke, M. Climate, conflict, and social stability: What does the evidence say? *Clim. Chang.* **2014**, *123*, 39–55. [[CrossRef](#)]
89. Mach, K.J.; Kraan, C.M.; Adger, W.N.; Buhaug, H.; Burke, M.; Fearon, J.D.; Field, C.B.; Hendrix, C.S.; Maystadt, J.-F.; Loughlin, J.O.; et al. Climate as a risk factor for armed conflict. *Nature* **2019**, *571*, 193–197. [[CrossRef](#)]
90. Kennett, D.J.; Breitenbach, S.F.M.; Aquino, V.V.; Asmerom, Y.; Awe, J.; Baldini, J.U.L.; Bartlein, P.; Culleton, B.J.; Ebert, C.; Jazwa, C.; et al. Development and Disintegration of Maya Political Systems in Response to Climate Change. *Science* **2012**, *338*, 788–791. [[CrossRef](#)]
91. Cullen, H.M.; de Menocal, P.B.; Hemming, S.; Hemming, G.; Brown, F.H.; Guilderson, T.; Sirocko, F. Climate change and the collapse of the Akkadian empire: Evidence from the deep sea. *Geology* **2000**, *28*, 379. [[CrossRef](#)]
92. Drysdale, R.; Zanchetta, G.; Hellstrom, J.; Maas, R.; Fallick, A.; Pickett, M.; Cartwright, I.; Piccini, L.; Holocene, L. drought responsible for the collapse of Old World civilizations is recorded in an Italian cave flowstone. *Geology* **2006**, *34*, 101. [[CrossRef](#)]

93. Büntgen, U.; Tegel, W.; Nicolussi, K.; McCormick, M.; Frank, D.; Trouet, V.; Kaplan, J.O.; Herzig, F.; Heussner, K.U.; Wanner, H.; et al. 2500 Years of European Climate Variability and Human Susceptibility. *Science* **2011**, *331*, 578–582. [CrossRef] [PubMed]
94. Schleussner, C.-F.; Rogelj, J.; Schaeffer, M.; Lissner, T.; Licker, R.; Fischer, E.M.; Knutti, R.; Levermann, A.; Frieler, A.; Hare, W.; et al. Science and policy characteristics of the Paris Agreement temperature goal. *Nat. Clim. Chang.* **2016**, *6*, 827–835. [CrossRef]
95. Vakulchuk, R.; Overland, I.; Scholten, D. Renewable energy and geopolitics: A review. *Renew. Sustain. Energy Rev.* **2020**, *122*, 109547. [CrossRef]
96. Blondeel, M.; Bradshaw, M.J.; Bridge, G.; Kuzemko, C. The geopolitics of energy system transformation: A review. *Geogr. Compass* **2021**, *15*, e12580. [CrossRef]
97. Overland, I. The geopolitics of renewable energy: Debunking four emerging myths. *Energy Res. Soc. Sci.* **2019**, *49*, 36–40. [CrossRef]
98. Peszko, G.; van der Mensbrugghe, D.; Golub, A. *Diversification and Cooperation in a Decarbonizing World: Climate Strategies for Fossil Fuel-Dependent Countries*; World Bank Publications: Herndon, VA, USA, 2020.
99. Morgan, S. Sweden Set to Be World's First Country to Target Consumption-Based Emission Cuts. Climate Home News. 2022. Available online: <https://www.climatechangenews.com/2022/04/08/sweden-set-to-be-worlds-first-country-to-target-consumption-based-emission-cuts/> (accessed on 22 April 2022).
100. UNFCCC/COP. Kyoto Protocol to the United Nations Framework Convention on Climate Change. In Proceedings of the Conference of the Parties, Third Session, Kyoto, Japan, 1–10 December 1997.
101. EC. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Stepping up Europe's 2030 Climate Ambition. Investing in a Climate-Neutral Future for the Benefit of Our People*; EUR-Lex—52020DC0562; EU: Brussels, Belgium, 2020.
102. Government of India. *India's Intended Nationally Determined Contribution: Working Towards Climate Justice*; Government of India: New Delhi, India, 2015.
103. Government of China/UNFCCC. *China First NDC (Updated Submission): China's Achievements, New Goals and New Measures for Nationally Determined Contributions*; UN: New York, NY, USA, 2021.
104. Xi, J.P. Xi Jinping's Speech at the Climate Ambition Summit (Full Text)-Xinhuanet (Google Translate). Speech of Xi Jinping, President of the People's Republic of China. 2021. Available online: [http://www.xinhuanet.com/politics/leaders/2020-12/12/c\\_1126853600.htm](http://www.xinhuanet.com/politics/leaders/2020-12/12/c_1126853600.htm) (accessed on 30 June 2021).
105. Pandve, H.T. India's National Action Plan on Climate Change. *Indian J. Occup. Environ. Med.* **2009**, *13*, 17. [CrossRef]
106. Yatsui, T. *China's Energy Policy and Related Issues Towards 2020*; Mitsui Global Strategic Studies Institute: Tokyo, Japan, 2017.
107. US Government. *The United States of America Nationally Determined Contribution Reducing Greenhouse Gases in the United States: A 2030 Emissions Target The United States' Nationally Determined Contribution Reducing Greenhouse Gases in the United States: A 2030 Emissions*; US Government: Washington, DC, USA, 2021.
108. Dubash, N.K.; Khosla, R.; Kelkar, U.; Lele, S. India and Climate Change: Evolving Ideas and Increasing Policy Engagement. *Annu. Rev. Environ. Resour.* **2018**, *43*, 395–424. [CrossRef]
109. CAT. China. Climate Action Tracker. 2021. Available online: <https://climateactiontracker.org/countries/china/net-zero-targets/> (accessed on 23 November 2021).
110. CAT. India. Climate Action Tracker. 2021. Available online: <https://climateactiontracker.org/countries/india/targets/> (accessed on 4 November 2021).
111. IEA. *India Energy Outlook 2021. World Energy Outlook Special Report*; IEA: Paris, France, 2021.
112. Zhou, N.; Lu, H.; Khanna, N.; Liu, X.; Fridley, D.; Price, L.K.; Feng, W.; Lin, J.; Szum, C.; Din, C. *China Energy Outlook: Understanding China's Energy and Emissions Trends*; China Energy Group: Beijing, China, 2020.
113. Flannery, B.P. CO<sub>2</sub> Greenhouse Update 1985. Available online: <http://www.climatefiles.com/exxonmobil/co2-research-program/1985-exxon-greenhouse-research-budget/> (accessed on 2 January 2022).
114. Reheis-Boyd, C. *WSPA Priority Issues*; Western States Petroleum Association: Sacramento, CA, USA, 2014.
115. McKie, R. Merchants of Doubt by Naomi Oreskes and Erik M Conway. *The Guardian*, 7 August 2010.
116. McCright, A.M.; Charters, M.; Dentzman, K.; Dietz, T. Examining the Effectiveness of Climate Change Frames in the Face of a Climate Change Denial Counter-Frame. *Top. Cogn. Sci.* **2016**, *8*, 76–97. [CrossRef]
117. Castles, I.; Henderson, D. The IPCC Emission Scenarios: An Economic-Statistical Critique. *Energy Environ.* **2003**, *14*, 159–185. [CrossRef]
118. Cook, J. The role of misinformation in undermining IPCC science and how to neutralize it. In Proceedings of the IPCC Expert Meeting on Communication, Oslo, Norway, 9–10 February 2016.
119. Oreskes, N. Beyond the ivory tower. The scientific consensus on climate change. *Science* **2004**, *306*, 1686. [CrossRef]
120. Henley, J. European Elections: Triumphant Greens Demand More Radical Climate Action. Available online: <https://www.theguardian.com/environment/2019/may/28/greens-eu-election-mandate-leverage-climate-policy> (accessed on 2 January 2022).
121. Farand, C. Denmark's New Government Raises Climate Change to Highest Priority. Climate Home News. 2019. Available online: <https://www.climatechangenews.com/2019/06/26/denmarks-new-government-raises-climate-change-highest-priority/> (accessed on 12 January 2022).
122. EC. *The European Green Deal*; European Commission: Brussels, Belgium, 2019.

123. Botta, E.; Kozluk, T. Measuring Environmental Policy Stringency in OECD Countries—A Composite Index Approach. OECD Environmental Directorate Working Paper. 2014. Available online: <https://econpapers.repec.org/paper/oecocaaa/1177-en.htm> (accessed on 2 February 2022).
124. OECD. Environmental Policy Stringency Index. 2019. Available online: <https://stats.oecd.org/Index.aspx?DataSetCode=EPS> (accessed on 10 February 2022).
125. Borger, J. US and Oil Lobby Oust Climate Change Scientist. Available online: <https://www.theguardian.com/world/2002/apr/20/internationaleducationnews.climatechange> (accessed on 2 February 2022).
126. Clinton, N.J. ExxonMobil and Renewable Energy Group Report Progress in Cellulosic Biodiesel Research | ExxonMobil. Exxon-Mobile Newsroom. 2017. Available online: [https://corporate.exxonmobil.com/en/News/Newsroom/News-releases/2017/1101\\_ExxonMobil-and-renewable-energy-group-report-progress-in-cellulosic-biodiesel-research](https://corporate.exxonmobil.com/en/News/Newsroom/News-releases/2017/1101_ExxonMobil-and-renewable-energy-group-report-progress-in-cellulosic-biodiesel-research) (accessed on 15 May 2019).
127. ExxonMobil. Mitigating Emissions in Our Operations. 2018. Available online: <https://corporate.exxonmobil.com/Community-engagement/Sustainability-Report/Managing-risks-of-climate-change/Mitigating-emissions-in-our-operations> (accessed on 28 February 2022).
128. The White House. Fact Sheet: President Biden’s Leaders Summit on Climate. The White House Statements and Releases. 2021. Available online: <https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/23/fact-sheet-president-bidens-leaders-summit-on-climate/> (accessed on 30 June 2021).
129. Miglani, S. Exclusive: India Baulks at Carbon Neutral Target as Pressure Grows. Reuters. 2021. Available online: <https://www.reuters.com/article/us-climate-change-india-exclusive-idUSKBN2BM1AA> (accessed on 5 November 2021).
130. NDTV. India’s Pledge To Go Carbon Neutral by 2070 Is Real Climate Action: Experts. NDTV. 2021. Available online: <https://www.ndtv.com/india-news/indias-pledge-to-go-carbon-neutral-by-2070-is-real-climate-action-experts-2597009> (accessed on 5 November 2021).
131. Government of China. *China’s Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy*; UNFCCC: Bonn, Germany, 2021.
132. Grassi, G.; Fiorese, G.; Pilli, R.; Jonsson, K.; Blujdea, V.; Korosuo, A.; Jasinevicius, G.; Avraamides, M. *Brief on the Role of the Forest-Based Bioeconomy in Mitigating Climate Change through Carbon Storage and Material Substitution*; European Commission: Brussels, Belgium, 2021; p. 16.
133. FISE, LULUCF. FISE—Forest Information System for Europe. 2020. Available online: <https://forest.eea.europa.eu/topics/forest-and-climate/lulucf>. (accessed on 25 February 2022).
134. UNGA. *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations General Assembly: New York, NY, USA, 2015.
135. Fuhrman, J.; McJeon, H.; Doney, S.C.; Shobe, W.; Clarens, A.F. From Zero to Hero?: Why Integrated Assessment Modeling of Negative Emissions Technologies Is Hard and How We Can Do Better. *Front. Clim.* **2019**, *1*, 11. [CrossRef]
136. Paquette, M. Some Indigenous groups wary of REDD+ following Paris Climate Agreement. Mongabay. 2016. Available online: <https://news.mongabay.com/2016/02/some-indigenous-groups-wary-of-redd-following-paris-climate-agreement/> (accessed on 13 November 2021).
137. Corbera, E.; Hunsberger, C.; Vaddhanaphuti, C. Climate change policies, land grabbing and conflict: Perspectives from Southeast Asia. *Can. J. Dev. Stud.* **2017**, *38*, 297–304. [CrossRef]
138. Norris, C.; Hobson, P.; Ibisch, P.L. Microclimate and vegetation function as indicators of forest thermodynamic efficiency. *J. Appl. Ecol.* **2011**, *49*, 562–570. [CrossRef]
139. Moomaw, W.R.; Masino, S.A.; Faison, E.K. Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good. *Front. For. Glob. Chang.* **2019**, *2*, 27. [CrossRef]
140. Mackey, B.; Kormos, C.F.; Keith, H.; Moomaw, R.W.; Houghton, R.A.; Mittermeier, R.A.; Hole, D.; Hugh, S. Understanding the importance of primary tropical forest protection as a mitigation strategy. *Mitig. Adapt. Strateg. Glob. Chang.* **2020**, *25*, 763–787. [CrossRef]
141. Stabinsky, D.; Dooley, K. Forests Can’t Handle All the Net-Zero Emissions Plans—Companies and Countries Expect Nature to Offset Too Much Carbon. Available online: <https://theconversation.com/forests-cant-handle-all-the-net-zero-emissions-plans-companies-and-countries-expect-nature-to-offset-too-much-carbon-170336> (accessed on 25 February 2022).
142. CAT. USA. Climate Action Tracker. 2021. Available online: <https://climateactiontracker.org/countries/usa/> (accessed on 28 October 2021).
143. D’Angelo, C. Experts Bemoan Biden’s Mixed Messages on Old-Growth Forests. HuffPost. 2021. Available online: [https://www.huffpost.com/entry/biden-deforestation-old-growth-forests-cop26\\_n\\_61841ea9e4b06de3eb726e8a](https://www.huffpost.com/entry/biden-deforestation-old-growth-forests-cop26_n_61841ea9e4b06de3eb726e8a) (accessed on 25 November 2021).
144. GFW. United States Deforestation Rates & Statistics. Global Forest Watch. 2021. Available online: <https://www.globalforestwatch.org/dashboards/country/USA/> (accessed on 25 November 2021).
145. Green, F.; Brandstedt, E. Engaged Climate Ethics\*. *J. Political Philos.* **2021**, *29*, 539–563. [CrossRef]
146. Nordhaus, W.D. An Optimal Transition Path for Controlling Greenhouse Gases. *Science* **1992**, *258*, 1315–1319. [CrossRef]
147. Nordhaus, W. *The Climate Casino: Risk, Uncertainty, and Economics for a Warming World*; Yale University Press: New Haven, CT, USA; London, UK, 2013.

148. Nordhaus, W.D. Rolling the ‘DICE’: An optimal transition path for controlling greenhouse gases. *Resour. Energy Econ.* **1993**, *15*, 27–50. [CrossRef]
149. COP/UNFCCC. *Decision-/CP.26 Glasgow Climate Pact*; UN: New York, NY, USA, 2021.
150. UNFCCC. *Nationally Determined Contributions under the Paris Agreement Synthesis Report by the Secretariat*; UNFCCC: Glasgow, Ireland, 2021.
151. Solow, R.M. A Contribution to the Theory of Economic Growth. *Q. J. Econ.* **1956**, *70*, 65. [CrossRef]
152. Swan, T.W. Economic Growth and Capital Accumulation. *Econ. Rec.* **1956**, *32*, 334–361. [CrossRef]
153. Stiglitz, J.E. Georgescu-Roegen versus Solow/Stiglitz. *Ecol. Econ.* **1997**, *22*, 269–270. [CrossRef]
154. Ainslie, G. *Breakdown of Will*; Cambridge University Press: Cambridge, UK, 2001.
155. Nordhaus, T. The Two-Degree Delusion: The Dangers of an Unrealistic Climate Change Target. *Foreign Aff.* **2018**. Available online: <https://www.foreignaffairs.com/articles/world/2018-02-08/two-degree-delusion> (accessed on 22 November 2021).
156. Olawuyi, D.S. Advancing Climate Justice in International Law: An Evaluation of the United Nations Human Rights-Based Approach. *Fla. A M Univ. Law Rev.* **2015**, *11*, 103.
157. Kubiszewski, I.; Costanza, R.; Franco, C.; Lawn, P.; Talberth, J.; Jackson, T.; Aylmer, C. Beyond GDP: Measuring and achieving global genuine progress. *Ecol. Econ.* **2013**, *93*, 57–68. [CrossRef]
158. Nordhaus, W. Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies. *Am. Econ. J. Econ. Policy* **2018**, *10*, 333–360. [CrossRef]
159. Pedersen, J. Is Glasgow COP26 a New Copenhagen, Overlooking the Countries in Most Need? Blogue SHIFT—Grupo de investigação Ambiente, Território e Sociedade do ICS-ULisboa. 2021. Available online: <https://ambienteterritoriosociedade-ics.org/> (accessed on 22 November 2021).
160. UNFCCC. *United Nations Framework Convention on Climate Change*; Parties of the Convention: New York, NY, USA, 1992.
161. Luciani, G. The impacts of the energy transition on growth and income distribution. In *Lecture Notes in Energy*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 305–318.
162. Jamieson, D. Ethics, Public Policy, and Global Warming. *Sci. Technol. Hum. Values* **1992**, *17*, 139–153. [CrossRef]
163. WMO. *2021 State of Climate Services (WMO-No. 1278)*; World Meteorological Organization: Geneva, Switzerland, 2021.
164. WMO. *State of the Global Climate 2020 (WMO-No. 1264)*; World Meteorological Organization: Geneva, Switzerland, 2021.
165. Berrang-Ford, L.; Siders, A.R.; Lesnikowski, A.; Fischer, A.P.; Callaghan, M.W.; Haddaway, N.R.; Mach, K.J.; Araos, M.; Rahman Shah, M.A.; Wannowitz, M.; et al. A systematic global stocktake of evidence on human adaptation to climate change. *Nat. Clim. Chang.* **2021**, *11*, 989–1000. [CrossRef]
166. Dow, K.; Berkhout, F.; Preston, B.L.; Klein, R.J.T.; Midgley, G.; Shaw, M.R. Limits to adaptation. *Nat. Clim. Chang.* **2013**, *3*, 305–307. [CrossRef]
167. Klein, R.J.T.; Midgley, G.F.; Preston, B.L.; Alam, M.; Berkhout, F.; Dow, K.; Shaw, M.R. Adaptation Opportunities, Constraints, and Limits. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 899–943.
168. Adger, W.N.; Agrawala, S.; Mirza, M.M.Q.; Conde, C.; O’Brien, K.; Pulhin, J.; Pulwarty, R.; Smit, B.; Takahashi, K.; Enright, B.; et al. Assessment of adaptation practices, options, constraints and capacity. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 717–743.
169. Klinkle, A.; Renn, O. A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies. *Risk Anal.* **2002**, *22*, 1071–1094. [CrossRef]
170. McNamara, K.E.; Jackson, G. Loss and damage: A review of the literature and directions for future research. *Wiley Interdiscip. Rev. Clim. Chang.* **2019**, *10*, e564. [CrossRef]
171. UNFCCC. *Report of the Conference of the Parties on Its Nineteenth Session, Held in Warsaw from 11 to 23 November 2013. Conference of the Parties, United Nations Framework Convention on Climate Change 43*; UN: Geneva, Switzerland, 2014.
172. UNFCCC/COP. *FCCC/CP/2013/10/Add.1*; COP: Warsaw, Poland, 2013.
173. Evans, S.; Gabbatiss, J.; McSweeney, R.; Chandrasekhar, A.; Tandon, A.; Viglione, G.; Hausfather, Z.; You, X.; Goodman, J.; Hayes, S. COP26: Key Outcomes Agreed at the UN Climate Talks in Glasgow. *Carbon Brief.* **2021**. Available online: <https://www.carbonbrief.org/cop26-key-outcomes-agreed-at-the-un-climate-talks-in-glasgow> (accessed on 2 December 2021).
174. Serdeczny, O. Non-economic Loss and Damage and the Warsaw International Mechanism. In *Loss and Damage from Climate Change*; Mechler, R., Bouwer, L.M., Schinko, T., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2019.
175. Arnold, D.G. *Ethics of Climate Change*; Cambridge University Press: Cambridge, UK, 2010.
176. Caney, S. Climate Change and Non-Ideal Theory: Six Ways of Responding to Non-Compliance. In *Climate Justice in a Non-Ideal World*; Heyward, C., Roser, D., Eds.; Oxford University Press: Oxford, UK, 2016; pp. 21–42.
177. Brandstedt, E. The savings problem in the original position: Assessing and revising a model. *Can. J. Philos.* **2017**, *47*, 269–289. [CrossRef]
178. Heyward, C.; Roser, D. *Climate Justice in a Non-Ideal World*; Oxford University Press: Oxford, UK, 2016.
179. Laurence, B. The Question of the Agent of Change\*. *J. Political Philos.* **2020**, *28*, 355–377. [CrossRef]

180. Somerville, P. A Critique of Climate Change Mitigation Policy. *Policy Politics* **2020**, *48*, 355–378. [CrossRef]
181. Green, F. Anti-fossil fuel norms. *Clim. Chang.* **2018**, *150*, 103–116. [CrossRef]
182. Schlosberg, D. Ecological Justice for the Anthropocene. In *Political Animals and Animal Politics*; Palgrave Macmillan: London, UK, 2014; pp. 75–89.
183. Herbst-Bayliss, S. IMF's Lagarde Eyes Subsidies, Simple Things to Tackle Climate Change. Available online: <https://www.reuters.com/article/us-imf-lagarde-idUSKCN0W62OI> (accessed on 22 November 2021).
184. King, E. World Bank Chief Backs Fossil Fuel Divestment Drive. Climate Home News. 2014. Available online: <https://www.climatechangenews.com/2014/01/27/world-bank-chief-backs-fossil-fuel-divestment-drive/> (accessed on 17 September 2018).
185. Gurría, A. *Overcoming Climate Change and Unleashing a Dynamic, Zero-Carbon Economy*; Organisation for Economic Cooperation and Development: Paris, France, 2015; pp. 2–3.
186. Marris, E. Why young climate activists have captured the world's attention. *Nature* **2019**, *573*, 471–472. [CrossRef]
187. Escobar, A. Degrowth, postdevelopment, and transitions: A preliminary conversation. *Sustain. Sci.* **2015**, *10*, 451–462. [CrossRef]
188. O'Brien, K.; Selboe, E.; Hayward, B.M. Exploring Youth Activism on Climate Change: Dutiful, Disruptive, and Dangerous Dissent. *Ecol. Soc.* **2018**, *23*, 42. [CrossRef]
189. Thiery, W.; Lange, S.; Rogelj, J.; Schleussner, C.F.; Gudmundsson, L.; Seneviratne, S.I.; Andrijevic, M.; Frieler, K.; Emanuel, K.; Geiger, T.; et al. Intergenerational inequities in exposure to climate extremes. *Science* **2021**, *374*, 158–160. [CrossRef]
190. NRC. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*; National Academies Press: Washington, DC, USA, 2015.
191. Mitchell, D.L.; Finnegan, W. Modification of cirrus clouds to reduce global warming. *Environ. Res. Lett.* **2009**, *4*, 045102. [CrossRef]
192. Gasparini, B.; McGraw, Z.; Storelvmo, T.; Lohmann, U. To what extent can cirrus cloud seeding counteract global warming? *Environ. Res. Lett.* **2020**, *15*, 054002. [CrossRef]
193. Reynolds, J.L. Is solar geoengineering ungovernable? A critical assessment of governance challenges identified by the Intergovernmental Panel on Climate Change. *WIREs Clim. Chang.* **2021**, *12*, e690. [CrossRef]
194. Honegger, M.; Reiner, D. The political economy of negative emissions technologies: Consequences for international policy design. *Clim. Policy* **2018**, *18*, 306–321. [CrossRef]
195. EASAC. *Science Advice for the Benefit of Europe Negative Emission Technologies: What Role in Meeting Paris Agreement Targets?* EASAC: Halle, Germany, 2018.
196. Heyen, D.; Lehtomaa, J. Solar geoengineering governance: A dynamic framework of farsighted coalition formation. *Oxf. Open Clim. Chang.* **2021**, *1*, kgab010. [CrossRef]
197. NASEM. *Reflecting Sunlight: Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance*; National Academies Press: Washington, DC, USA, 2021.
198. Keith, D. Engineering the Planet. In *Climate Change Science and Policy*; Schneider, S., Mastrandrea, M., Eds.; Island Press: Washington, DC, USA, 2010; pp. 493–501.
199. Keith, D.W. Toward a Responsible Solar Geoengineering Research Program. *Sci. Technol.* **2017**, *33*, 71–77.
200. Rasch, P.J.; Tilmes, S.; Turco, R.P.; Robock, A.; Oman, L.; Chen, C.C.; Stenchikov, G.L.; Garcia, R.R. An overview of geoengineering of climate using stratospheric sulphate aerosols. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2008**, *366*, 4007–4037. [CrossRef]
201. Robock, A.; Marquardt, A.; Kravitz, B.; Stenchikov, G. Benefits, risks, and costs of stratospheric geoengineering. *Geophys. Res. Lett.* **2009**, *36*, L19703. [CrossRef]
202. Parker, D.E.; Wilson, H.; Jones, P.D.; Jones, J.; Christy, R.; Folland, C.K. The impact of Mount Pinatubo on world-wide temperatures. *Int. J. Climatol.* **1996**, *16*, 487–497. [CrossRef]
203. Smith, W. The cost of stratospheric aerosol injection through 2100. *Environ. Res. Lett.* **2020**, *15*, 114004. [CrossRef]
204. Mora, C.; Wei, C.-L.; Rollo, A.; Amaro, T.; Baco, A.R.; Billett, D.; Bopp, L.; Chen, Q.; Collier, M.; Danovaro, R. Biotic and Human Vulnerability to Projected Changes in Ocean Biogeochemistry over the 21st Century. *PLoS Biol.* **2013**, *11*, e1001682. [CrossRef]
205. Smith, M.R.; Myers, S.S. Impact of anthropogenic CO<sub>2</sub> emissions on global human nutrition. *Nat. Clim. Chang.* **2018**, *8*, 834–839. [CrossRef]
206. McCusker, K.E.; Battisti, D.S.; Bitz, C.M. Inability of stratospheric sulfate aerosol injections to preserve the West Antarctic Ice Sheet. *Geophys. Res. Lett.* **2015**, *42*, 4989–4997. [CrossRef]
207. Robock, A.; Bunzl, M.; Kravitz, B.; Stenchikov, G.L. A Test for Geoengineering? *Science* **2010**, *327*, 530–531. [CrossRef] [PubMed]
208. Jones, A.; Haywood, J.; Boucher, O.; Kravitz, B. Geoengineering by stratospheric SO<sub>2</sub> injection: Results from the Met Office HadGEM2 climate model and comparison with the Goddard Institute for Space Studies ModelE. *Atmos. Chem. Phys.* **2010**, *10*, 5999–6006. [CrossRef]
209. Ross, A.; Damon Matthews, H. Climate engineering and the risk of rapid climate change. *Environ. Res. Lett.* **2009**, *4*, 045103. [CrossRef]
210. Bala, G.; Duffy, P.B.; Taylor, K.E. Impact of geoengineering schemes on the global hydrological cycle. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 7664–7669. [CrossRef]
211. Tilmes, S.; Fasullo, J.; Lamarque, J.F.; Marsh, D.R.; Mills, M.; Alterskjær, K.; Muri, H.; Kristjánsson, J.E.; Boucher, O.; Schulz, M.; et al. The hydrological impact of geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP). *J. Geophys. Res. Atmos.* **2013**, *118*, 11036–11058. [CrossRef]

212. Keller, D.P.; Feng, E.Y.; Oschlies, A. Potential climate engineering effectiveness and side effects during a high carbon dioxide-emission scenario. *Nat. Commun.* **2014**, *5*, 3304. [[CrossRef](#)]
213. ETC. *Solar Radiation Management Geoengineering and Climate Change: Implications for Africa*; ETC: Val David, QC, Canada, 2018.
214. Ricke, K.L.; Morgan, M.G.; Allen, M.R. Regional climate response to solar-radiation management. *Nat. Geosci.* **2010**, *3*, 537–541. [[CrossRef](#)]
215. IPCC. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.
216. Harding, A.R.; Ricke, K.; Heyen, D. Climate econometric models indicate solar geoengineering would reduce inter-country income inequality. *Nat. Commun.* **2020**, *11*, 227. [[CrossRef](#)]
217. Schellnhuber, H.J. Geoengineering: The good, the MAD, and the sensible. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 20277–20278. [[CrossRef](#)] [[PubMed](#)]
218. Hamilton, C. *Earthmasters: The Dawn of the Age of Climate Engineering*; Yale University Press: New Haven, CT, USA, 2013.
219. Hulme, M. *Can Science Fix Climate Change?: A Case Against Climate Engineering*; Polity Press: Cambridge, UK, 2014.
220. Schneider, L. Fixing the Climate? How Geoengineering Threatens to Undermine the SDGs and Climate Justice. *Development* **2019**, *62*, 29–36. [[CrossRef](#)]
221. Kreuter, J. *Technofix, Plan B or Ultima Ratio? A Review of the Social Science Literature on Climate Engineering Technologies*; Oxford University Press: Oxford, UK, 2015.
222. Rickels, W.; Quaas, M.F.; Ricke, K.; Quaas, J.; Moreno-Cruz, J.; Smulders, S. Who turns the global thermostat and by how much? *Energy Econ.* **2020**, *91*, 104852. [[CrossRef](#)]
223. Horton, J.B. Geoengineering and the Myth of Unilateralism. In *Climate Change Geoengineering*; Burns, W.C.G., Strauss, A.L., Eds.; Cambridge University Press: Cambridge, UK, 2017; pp. 168–181.
224. Blackstock, J.J.; Low, S. *Geoengineering Our Climate? Ethics, Politics and Governance*; Routledge: London, UK, 2019.
225. Hourdequin, M. Geoengineering Justice: The Role of Recognition. *Sci. Technol. Hum. Values* **2019**, *44*, 448–477. [[CrossRef](#)]
226. Reynolds, J.L. *The Governance of Solar Geoengineering: Managing Climate Change in the Anthropocene*; Cambridge University Press: Cambridge, UK, 2019.
227. Rayner, S.; Heyward, C.; Kruger, T.; Pidgeon, N.; Redgwell, C.; Savulescu, J. The Oxford Principles. *Clim. Chang.* **2013**, *121*, 499–512. [[CrossRef](#)]
228. Scheffer, M. *Critical Transitions in Nature and Society*; Princeton University Press: Princeton, NJ, USA, 2009.
229. Russill, C.; Nyssa, Z. The tipping point trend in climate change communication. *Glob. Environ. Chang.* **2009**, *19*, 336–344. [[CrossRef](#)]
230. Lenton, T.M.; Held, H.; Kriegler, E.; Hall, J.W.; Lucht, W.; Rahmstorf, S.; Schellnhuber, H.J. Tipping elements in the Earth's climate system. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 1786–1793. [[CrossRef](#)]
231. Lenton, T.M.; Kohler, T.A.; Marquet, P.A.; Boyle, R.A.; Crucifix, M.; Wilkinson, D.M.; Scheffer, M. Survival of the Systems. *Trends Ecol. Evol.* **2021**, *36*, 333–344. [[CrossRef](#)]
232. IPCC. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*; IPCC: Geneva, Switzerland, 2019.
233. Dietz, S.; Rising, J.; Stoerk, T.; Wagner, G. Economic impacts of tipping points in the climate system. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2103081118. [[CrossRef](#)]
234. Kriegler, E.; Hall, J.W.; Held, H.; Dawson, R.; Schellnhuber, H.J. Imprecise probability assessment of tipping points in the climate system. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 5041–5046. [[CrossRef](#)]
235. Barrett, S.; Dannenberg, A. Sensitivity of collective action to uncertainty about climate tipping points. *Nat. Clim. Chang.* **2014**, *4*, 36–39. [[CrossRef](#)]
236. Lontzek, T.S.; Cai, Y.; Judd, K.L.; Lenton, T.M. Stochastic integrated assessment of climate tipping points indicates the need for strict climate policy. *Nat. Clim. Chang.* **2015**, *5*, 441–444. [[CrossRef](#)]
237. Tebaldi, C.; Friedlingstein, P. Delayed detection of climate mitigation benefits due to climate inertia and variability. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 17229–17234. [[CrossRef](#)] [[PubMed](#)]
238. Samset, B.H.; Fuglestad, J.S.; Lund, M.T. Delayed emergence of a global temperature response after emission mitigation. *Nat. Commun.* **2020**, *11*, 3261. [[CrossRef](#)]
239. IPCC. *Climate Change 2001: Mitigation*; IPCC: Geneva, Switzerland, 2001.
240. Matsuno, T.; Maruyama, K.; Tsutsui, J. Stabilization of atmospheric carbon dioxide via zero emissions—An alternative way to a stable global environment. Part 2: A practical zero-emissions scenario. *Proc. Jpn. Acad. Ser. B* **2012**, *88*, 385–395. [[CrossRef](#)]
241. IPCC. *AR4 Climate Change 2007: Mitigation of Climate Change*; IPCC: Geneva, Switzerland, 2007.
242. van Ginkel, K.C.H.; Botzen, W.J.W.; Haasnoot, M.; Bachner, G.; Steininger, K.W.; Hinkel, J.; Watkiss, P.; Boere, E.; Jeuken, A.; Murieta, E.S.; et al. Climate change induced socio-economic tipping points: Review and stakeholder consultation for policy relevant research. *Environ. Res. Lett.* **2020**, *15*, 023001. [[CrossRef](#)]
243. Haasnoot, M.; Middelkoop, H.; Offermans, A.; van Beek, E.; van Deursen Willem, P.A. Exploring pathways for sustainable water management in river deltas in a changing environment. *Clim. Chang.* **2012**, *115*, 795–819. [[CrossRef](#)]
244. Heinze, A.; Bongers, F.; Ramírez, M.N.; Barrios, L.G.; Kuyper, T.W. The montane multifunctional landscape: How stakeholders in a biosphere reserve derive benefits and address trade-offs in ecosystem service supply. *Ecos. Serv.* **2020**, *44*, 101134. [[CrossRef](#)]

245. Heinze, C.; Blenckner, T.; Martins, H.; Rusiecka, D.; Döscher, R.; Gehlen, M.; Gruber, N.; EHolland, E.; Hov, Ø.; Joos, F.; et al. The quiet crossing of ocean tipping points. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2008478118. [[CrossRef](#)]
246. van der Vlist, M.J.; Ligthart, S.S.H.; Zandvoort, M. The replacement of hydraulic structures in light of tipping points. *J. Water Clim. Chang.* **2015**, *6*, 683–694. [[CrossRef](#)]
247. IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2014.
248. Cranston, M. Green energy transition will further fuel inflation: Bank of America. *Financ. Rev.* **2021**.
249. Bogdanov, D.; Ram, M.; Aghahosseini, A.; Gulagi, A.; Oyewo, A.S.; Child, M.; Caldera, U.; Sadovskaia, K.; Farfan, J.; Rogelj, J.; et al. Low-cost renewable electricity as the key driver of the global energy transition towards sustainability. *Energy* **2021**, *227*, 120467. [[CrossRef](#)]
250. Economist. Glencore’s message to the planet. *The Economist*, 1 January 2022.
251. Anderson, K.; Peters, G. The trouble with negative emissions. *Science* **2016**, *354*, 182–183. [[CrossRef](#)] [[PubMed](#)]
252. Riahi, K.; Bertram, C.; Huppmann, D.; Rogel, J.; Bosetti, V.; Cabardos, A.-M.; Deppermann, A.; Drouet, L.; Frank, S.; Fricko, O.; et al. Cost and attainability of meeting stringent climate targets without overshoot. *Nat. Clim. Chang.* **2021**, *11*, 1063–1069. [[CrossRef](#)]
253. Gi, K.; Sano, F.; Akimoto, K.; Hiwatari, R.; Tobita, K. Potential contribution of fusion power generation to low-carbon development under the Paris Agreement and associated uncertainties. *Energy Strategy Rev.* **2020**, *27*, 100432. [[CrossRef](#)]
254. Bloomberg. Delivering on America’s Pledge | Americas Pledge On Climate. Bloomberg IP Holdings LLC. 2021. Available online: <https://www.americaspledgeonclimate.com/report-delivering-on-americas-pledge/> (accessed on 29 November 2021).
255. UNFCCC. Greenhouse Gas Inventory Data. 2021. Available online: [https://di.unfccc.int/detailed\\_data\\_by\\_party](https://di.unfccc.int/detailed_data_by_party) (accessed on 21 October 2021).
256. GCP. *Data Supplement to the Global Carbon Budget 2020*, version 1.0; GCP: Los Angeles, CA, USA, 2020.