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Essay

Climate Change Science and Policy—A Guided Tour across the Space of Attitudes and Outcomes

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Abstract: The ongoing debate on global climate change has polarized societies since ever. The attitude of an individual towards its anthropogenic nature as well as the need and extent to which human beings should mitigate climate warming can result from a number of factors. Also, since the consequences of such alteration in global climate have no borders and became much more severe in the last decades, it is worth it to shed some more light on a current state of an interplay between scientific findings and climate policies. In this paper, we examine a low-dimensional space of possible attitudes toward climate change, its impact, attribution, and mitigation. Insights into those attitudes and evidence-based interpretations are offered. We review a range of inconvenient truths and convenient untruths, respectively, related to fundamental climate-change issues and derive a systematic taxonomy of climate-change skepticism. In addition, the media track related to climate change is reconstructed by examining a range of cover stories of important magazines and the development of those stories with global warming. In a second major step, we span a low-dimensional space of outcomes of the combined climate science-policy system, where each of the sub-systems may either succeed or fail. We conclude that the most probable outcome from today's perspective is still the same as it was 12 years ago: a *tragic triumph*, i.e., the success of climate science and the simultaneous failure of climate policy.

Keywords: climate change; climate science; policy; society; attitudes

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1. Introduction

For many years, scientific research has been conducted to find the factors and interactions that determine how climate change is seen by the public. Most often, an interplay between education, knowledge, and political orientation is investigated (e.g., [1–3]). A while ago, citizens of two big countries, i.e., Americans and Chinese, expressed similarly low concern rates for climate warming in a survey covering 15 industrialized countries (The Pew Global Attitudes Project; [1]). Interestingly, the findings for the US as presented in Hamilton [1] suggest that in contrast to age, gender, and party affiliation, education has no significant effect on perceived global warming as a serious risk within one's lifetime. This was in clear contradiction to previous studies. In the authors' opinion, the most striking result was the conclusion that *"the probability of perceiving global warming as a threat increases with education among Democrats, but decreases with education among Republicans"*. On the other hand, similar studies on Australians found that education can play a useful role in reducing the impact of ideologies on climate-change opinions [2]. Finally, complex studies on the role of different key factors in shaping beliefs on climate change revealed—contrary to what was expected—that gender, knowledge, education, and even experience of extreme weather events provide lower predictive power than ideologies, worldviews, and again, political orientation [3].

Moreover, according to a recent study by Crandon et al. [4], the so-called "climate anxiety" is perceived by children and adolescents themselves as one of the major external stressors (next to family violence and bullying). These feelings can cause different malfunctions in their life, such as sleep deprivation or difficulties in school performance. Young people are evidently much more susceptible to climate change and its consequences than adults, thus climate-related impacts on children and adolescents are way bigger. It was assessed that more than 65% of diseases connected to changing climate will affect these age groups much more than adults [5–7]. Furthermore, additional child deaths under global warming may reach 40–250 thousand by the end of 2100 [8]. Several factors possibly related to climate anxiety in children and adolescents were discussed in the literature, not least the role of technology and social media. Two major reasons for concern as reported by Crandon et al. [4] are (i) the unrestricted access to *"sensationalist media"*, emphasizing the disastrous nature of climate change, and (ii) the risk of ending up in internet *"filter-bubbles"*, exacerbating young people's worries about the state of current and future climates. One of the most alarming findings of the same authors is that two-thirds of the global young generation feel that their governments are lying about the real climate actions or are generally letting them down. Finally, the role of education was strongly emphasized, which should aim at open discussions, encouraging action, and creating the hope that it is still possible to collectively mitigate climate change [4].

These observations reflect powerful recent trends in youth communities around the world, where several climate-protest initiatives (such as Greta Thunberg's "School Strike 4 Climate") emerged and flooded social media since 2018 [9]. This demonstrates that the climate crisis is for the younger generation what class inequality was for their parents and grandparents. The climate actions are often aimed at the traditional world order represented by governments and institutions.

A very interesting aspect is the fairly wide set of motivations for protecting nature under climate change. Gustafson et al. [10] pointed out two principal reasons for environmental protection—an anthropocentric (human-centered) one, asking to protect nature for ensuring the health and well-being of human beings, and a more eco-centric one, asking for the conservation of biodiversity for its own sake or even asking to grant nature an independent status and certain legal rights. Wolsko et al. [11] observe that this divergence in views on the climate crisis or, more broadly, nature protection, is rooted in general views on life and politics. Traditionally, liberals are more likely to accept the scientific evidence proving global warming and its causes. In recent years, however, noticeable changes in attitudes toward the climate crisis within more conservative societies are taking place. Yet this does not result from the acceptance of scientific arguments, but rather from accepting and obeying authority, from defending the purity of creation, and from demonstrating one's patriotism.

Climate change should therefore also be seen as a social problem. It is a phenomenon that will increasingly disrupt everyday routines and even pose a threat to the functioning of the community on various scales. Moreover, as a consequence of human activities, it is the human population who must make attempts to deal with this phenomenon and its impacts (e.g., extreme weather events). This fact also illustrates the interdependence of social and ecological systems [12]. Bostrom et al. [13] stated that to implement climate mitigation activities, there is a need for an actor to believe in them. A conviction that climate stabilization is possible and effective with appropriate measures is a crucial factor for any actions being implemented. Therefore, the role of effectiveness perception is emphasized, both in people's activities and in activities undertaken by decision-makers or governing bodies.

As stated before, there is no omnipresent consensus regarding various issues related to climate change, although scientists publishing in peer-reviewed journals broadly agree on the essence—namely, on the anthropogenic nature of climate change and the severity of its impacts (cf. [14,15]).

Hulme [16] even postulated that "climate change is an idea as much as a physical phenomenon" and further claimed: "climate change has moved from being predominantly a physical phenomenon to being simultaneously a social phenomenon". We do not share this interpretation, which can be misused for classifying global warming as an "intractable problem", but Hulme [16] reflects the attitudes of quite a few scholars in the field.

In this paper, we take a broad, systemic look at the space of attitudes towards the interpretation of the climate challenge and at the space of possible outcomes (success or failure) of climate science and climate-policy interactions. The two main concerns regarding these outcomes can be summarized in the following questions:

1. Is science *"successful"* in the sense that climate projections adequately represent the development of future climate reality?
2. Is policy *"successful"* in the sense that effective actions are undertaken globally to control the atmospheric concentrations of greenhouse gases and hence the ensuing warming?

2. Space of Attitudes

Let us consider a logical suite of a few fundamental questions that a layman may pose on various issues related to climate change, thus constructing a low-dimensional space of possible attitudes. The number of those basic questions is determined by only four crucial aspects, as illustrated in Figure 1.

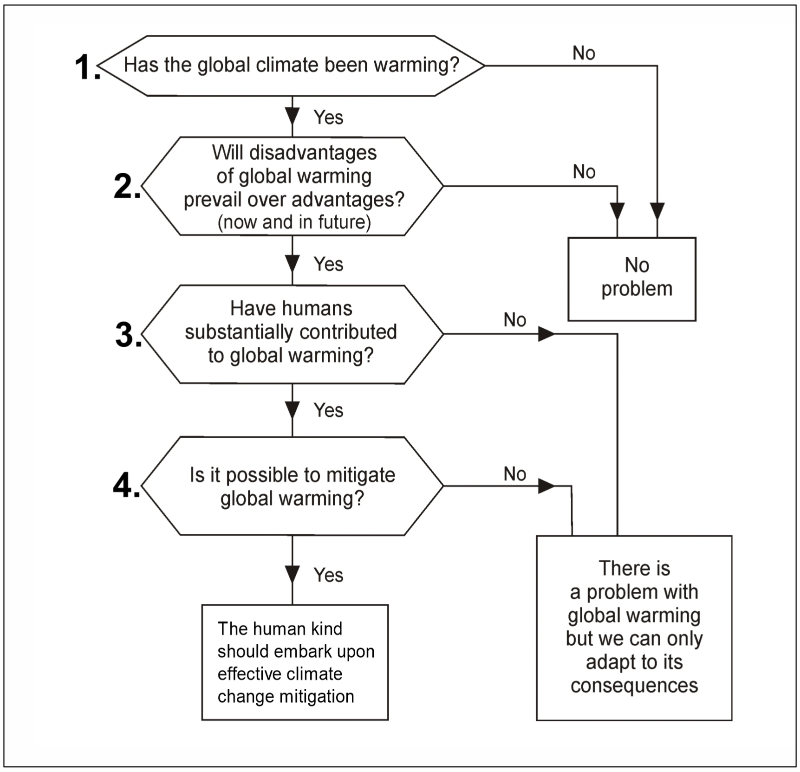

Figure 1. A short list of questions spanning a low-dimensional space of attitudes on various aspects of climate change (by modifying concepts from Kundzewicz [17] and Kundzewicz et al. [18]).

A vast body of literature exists conveying responses to each of the four questions presented in Figure 1. There are virtually thousands of relevant peer-reviewed publications providing positive ("YES") answers to each of these questions. In contrast, the number of references providing the negative ("NO") responses is very low, as indicated in Oreskes [14] and Powell [15]. Moreover, the set of references demonstrating that climate has not been warming in recent decades is empty—it does not contain any elements. In this work we subjectively identified 43 data source items (publicly available data sets, scientific journal papers, IPCC publications, other reports, and auxiliary references; see No. 19 to 61 in the References section) that convey the essential message. In the following Sections 2.1–2.4 we presented selected evidence on the responses to key questions from Figure 1 one by one. The aim was not to answer these questions directly but rather to extract a concise summary based solely on scientific findings reported in different literature items mentioned above.

2.1. Has the Global Climate Been Warming?

Many observers follow the latest worldwide temperature records regularly and especially watch announcements that several agencies release as their annual assessments of global observations, where they discuss the major climate trends (e.g., [19–21]).

According to NASA/NOAA data, the year 2021 was the 6th warmest year on record (since 1880; [22]), being 0.84 °C above the 1901–2000 baseline (Figure 2), despite the presence of La Niña (the cool phase of the ENSO cycle). The last eight consecutive years since 2014 belong to the eight warmest years in more than 140 years of history of temperature measurements. The year 2021 was the 44th consecutive year with global temperature exceeding the mean of 1951–1980. Each of the 21 years of the 21st century, i.e., 2001–2021, is among the 22 globally warmest years on record. The only pre-21st century year on that list was 1998, when a major El Niño event in the Eastern Pacific triggered a warming episode [23]. All five different long-term time series of global temperature produced by different groups (GISTEMP [19], HadCRUT [20], NOAA [21]) agree well, showing a gradually increasing trend of global temperature, with short-lived departures from this tendency, despite the differences in methodology and spatiotemporal coverage [22].

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change [24] states in its Summary for Policymakers that the average global surface temperature in 2011–2020 was higher than during the 1850–1900 period by 1.09 °C [0.95 to 1.20], with a higher rate of increase observed over land (1.59 °C) than over the ocean (0.88 °C). Moreover, it also confirms that each of the last four decades has been warmer than any decade preceding it since 1850, as illustrated in Figure 2. The qualifier "since 1850" actually means "since proper data are available". It does NOT suggest that, for instance, the 1840s could have been warmer. What it actually means is that we do not have sufficient information for allowing us to reliably reconstruct the global temperature of the 1840s and earlier.

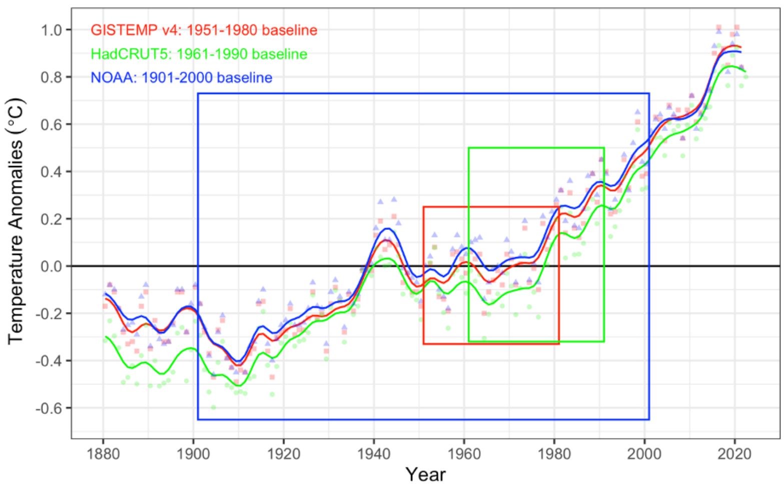

Figure 2. Global annual means of temperature anomalies (land and ocean) for 1880–2021, developed by three research teams: GISTEMP Team [19]; Lenssen et al. [25] [red], HadCRUT5 Analysis [20]; Morice et al. [26] [green] and NOAA [21] [blue]. Time series smoothed with binomial filter ([27], bandwidth = 5).

Now we better understand the stagnation or even slight decrease in global mean surface temperature after 1945, lasting till the late 1970s. It now seems that this was caused by sulfuric aerosols emitted from coal- and oil-fired power stations in the Global North:

insolation was dimmed and thereby the greenhouse effect of rising CO_2 was masked for a while. The mask was removed when appropriate filters were implemented to avoid air pollution and acid rain [28].

The warming since the 1970s has not been smooth but, to a large extent, we can interpret these irregularities—for instance, by making use of information on the natural climate variability of the ocean-atmosphere system [29]. Kundzewicz et al. [23] demonstrated that the natural variability, in particular El Niño–Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO) as well as the Atlantic Meridional Oscillation (a.k.a. Atlantic Multi-decadal Oscillation), is indeed influencing the global mean annual temperature. Correlation with ENSO, IPO, and AMO indices was shown to explain over 70% of the global temperature variability. The year 1998, in which a strong El Niño occurred, was very warm globally, thus being a large upwards excursion from the long-term tendency. In contrast, between 1998 and 2012, there were no strong El Niños. Simultanously, the La Niña phase was more common. Therefore, as stated by IPCC [30], the warming over 1998–2012 was smaller than the value resulting from a trend. Yet, the year 2010 was found to be globally the warmest year on instrumental record, despite the cold La Niña phase in the second half of that year and low sunspot numbers, corresponding to lower solar radiation, throughout the year. The new global temperature record was set in 2014 and then broken already in the next year, 2015. Even warmer was the year 2016. It can be expected that if a strong El Niño occurs any time now, the global temperature record attains new high scores [23].

In the most recent report of Working Group I of the IPCC [24], important statements were made. The global surface temperature has increased faster in the recent 50-year period (since 1970) than in any other 50-year period over the last 2000 years or more. Moreover, temperatures during the decade 2011–2020 exceeded those of the most recent warm period that lasted multiple centuries, about 6500 years ago. Before that, the next-to-last warm period was some 125,000 years ago and aggregated temperatures over that period overlap the records of 2011–2020. During this most recent decade, the late summer Arctic Sea ice area was at its lowest at least over the last 1000 years and the global, synchronous retreat of glaciers since the 1950s was unprecedented over at least the last 2000 years [24]. Furthermore, it was stated that the global mean sea level rise has been faster since 1900 than over any other century at least over the last 3000 years, and that the ocean has warmed faster over the past century than since the end of the last deglaciation, recorded some 11,000 years ago [24]. It was also made clear, that changes observed during the last few decades cannot be attributed to natural factors, like variations in solar radiation or volcanic activity. Regarding total solar irradiance (TSI), the results of the new estimates of the 20th-century course suggest that: *"TSI averaged over the solar cycle very likely increased during the first seven decades of the 20th century and decreased thereafter"* (IPCC, 2021 [24], Chapter 2, after Lean [31] and Wu et al. [32]). Similarly, it was stated, with a medium level of confidence, that the effects of volcanic eruptions (expressed as the variability of Stratospheric Aerosol Optical Depth—SAOD) were not unusual since 1900 at the background of the last 2500 years [33].

Despite this overwhelming evidence, global warming—being indeed the most conspicuous piece of the climatic puzzle—has been questioned by surprisingly many people, even if the number of such people has been decreasing as the warming gets more and more unequivocal and persuading (see Figure 2). Skeptics refer to the urban heat island effect that is real and can be very important locally, and even regionally, but it can explain only a very small portion of the observed warming at the global scale. Jacobson and Ten Houve [34] estimated that the urban heat island effect may contribute only 2–4% of gross global warming.

2.2. Will Disadvantages of Climate Change Prevail over Advantages?

Not all observed and projected climate-change impacts are or will be negative everywhere. For instance, people in boreal climates would probably greet some increase in regional temperature, despite the concomitant negative effects on unique and valuable cold-climate ecosystems [35]. The iconic example of such a phenomenon is the much-discussed threat to the existence of polar bears. Tangible agricultural advantages, such as an extension of cultivation potential and an increase in vegetation season duration, can be expected in the North (e.g., in Canada and Siberia) [35]. Yet, even if the aggregate economic impact of slight warming can be globally positive, many people will be worse off. Undoubtedly, there will be winners and losers, hence a difficult compensation issue (the winners would be supposed to compensate those less fortunate) may come about. However, since people have adapted to a stable climate over many centuries, a rapid change in adaptive behavior would generate substantial costs.

In particular, the transgression of so-called tipping points [36] would imply tremendous challenges to the affected societies: There are sub-systems of the planetary machinery ("tipping elements") that will change dramatically and possibly irreversibly if certain levels of global warming are reached. Tropical coral reefs and certain parts of the big ice sheets will probably be destroyed below the 2 °C guardrail adopted by the Paris Agreement [37]. Generally, the damages rise non-linearly with temperature, although the range of gross estimates is rather big [38].

Nevertheless, climate impact science goes now far beyond the "reasons for concern" and "burning embers" perspective as introduced in the 3rd IPCC Assessment Report [39] and offers a plethora of quantitative estimates. It is projected that, globally, the disadvantages of significant warming clearly outweigh its advantages. Damages will be particularly severe in the lower latitudes. The safety or even the existence of certain small islands, jeopardized by sea-level rise, will be at stake. The increasingly warmer and drier Mediterranean basin is another region where negative impacts are already visible and are projected to become devastating in the future [37].

A particular extreme weather event cannot be rigorously attributed to climate change but the probability of its occurrence grows with global warming. There has been a considerable increase in the frequency of record-breaking events (heat waves, heavy precipitation spells, hurricanes) in our rapidly changing world [40–42]. To put it simply, there is more room for water vapor in the warmer atmosphere, and hence the potential for intense, possibly flood-generating, precipitation increases. Also, the intensity of tropical storms potentially increases with higher sea-surface temperatures. Not surprisingly, heat waves have been getting more frequent and more intense [43]. Many extremes are becoming "even more extreme", with dramatic consequences and projections for the future, so the sentiment of "atmosfear" is spreading within societies [44]. Ban Ki-Moon, the former UN Secretary-General, aptly summarized that situation: The abnormal is the new normal [45].

Diffenbaugh et al. [46] presented a transfer function relating the reduction of emissions of greenhouse gases (GHG) (climate policy) to climate and weather extremes. They found that almost all national GHG emissions reduction commitments are insufficient: The emissions consistent with those commitments may considerably amplify the wet extremes leading to more pronounced flood risk (e.g., the number of wettest days over more than a third of Europe, North America, and East Asia may treble). In contrast, meeting the Paris Agreement target to restrict global warming to below 2 °C could reduce the area experiencing such trebling to less than 10% in the regions studied.

The hot extremes are on the rise while the cold extremes are mostly on the decline. However, even if recent cold extremes, like the Arctic storm "Elliott" over North America that raises considerable interest worldwide, are counter-intuitive, they are in line with fundamental physics. They result from changes in jet-stream behavior and polar circulation patterns [47].

2.3. Have Humans Substantially Contributed to Global Warming?

Jonathan Swift's observation *"there is nothing in this world constant but inconstancy"* clearly holds for climate [48]. Indeed, there have been many warm and cool episodes in the natural history of the Earth, even before humankind emerged on the planet. However, we are able now to interpret the warming and cooling phases of the remote past and identify the driving factors. Modern science provides strong arguments in favor of the hypothesis that the nature of the present global warming is considerably different from all the paleo-warmings.

The latter resulted entirely from natural factors, while at present, in the advanced Anthropocene [49], human beings (whose number exceeded eight billion in 2022) are powerful enough to influence the global climate. The maximum instantaneous atmospheric concentration of CO_2 recorded so far at the Mauna Loa station, the oldest measuring point of that kind, reached 422 ppm in 2022, in comparison to 318 ppm in 1958 (the beginning of CO_2-concentration measurement there), while the global level in the pre-industrial era was only 280 ppm [24,50]. Already in 2004, Meehl et al. [51] showed that without considering anthropogenic sources, especially the increasing emissions of greenhouse gases from fossil-fuels burning, it is not possible to explain the warming observed in the last decades; this interpretation has been corroborated since. Natural mechanisms (solar and volcanic activity) alone would cause even slight cooling rather than warming. Nevertheless, looking from the pure time-series-analysis perspective, [52] suggested that global temperature can be "naturally trendy", pointing at the intrinsic climate-systems variability, including the Hurst effect.

Global climate change is a result of both natural and human-caused changes. However, the essence of the most important attribution statements spelled out by the last four assessment reports of the Working Group I (WG I) of the IPCC ([24,30,53,54]) was that human activities have largely contributed to the observed global warming. The attribution statement in successive reports has actually got stronger and stronger (Table 1). There is a basic consensus as to the anthropogenic nature of the observed global warming also in the statements by major learned societies in the USA, such as the National Academy of Sciences, American Meteorological Society, American Geophysical Union, and American Association for the Advancement of Science [14].

Table 1. Evolution of essential climate change attribution [1] statements in consecutive IPCC WG I assessment reports. The interpretation of assessed likelihood terms, following the calibrated IPCC uncertainty/likelihood/probability language is: virtually certain (greater than 99% chance that a result is true); very likely (90–99% chance); likely (66–90% chance); medium likelihood (33–66% chance); unlikely (10–33% chance); very unlikely (1–10% chance); exceptionally unlikely (less than 1% chance)—TAR. Additional terms: (extremely likely: 95–100%, more likely than not >50–100%, and extremely unlikely 0–5%)—AR4.

Source [2]	Principal Message	Additional Notes
IPCC, 1990 (FAR), [55]	"We are certain of the following: emissions resulting from human activities are substantially increasing the atmospheric concentration of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs). These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface".	"(. . .) basic conclusions concerning the reality of the enhanced greenhouse effect and its potential to alter global climate are UNLIKELY to change significantly". "We are certain that the concentration of greenhouse gases in the atmosphere have changed naturally on the ice-age timescale, and have been increasing since pre-industrial times due to human activities"
IPCC, 1995 (SAR), [56]	"(. . .) the balance of evidence suggests that there is a discernible human influence on global climate."	"These trends [3] can be attributed largely to human activities, mostly fossil-fuel use, land-use change, and agriculture." "Most of [these] studies have detected a significant change and show that the observed warming trend is unlikely to be entirely natural in origin "Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors."

Table 1. *Cont.*

Source [2]	Principal Message	Additional Notes
IPCC, 2001 (TAR), [53]	"In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." "Emissions of CO_2 due to fossil fuel burning are virtually certain to be the dominant influence on the trends in atmospheric CO_2 concentration during the 21st century."	"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." "The warming over the past 100 years is very unlikely to be due to internal variability alone, as estimated by current models." "The warming over the last 50 years due to anthropogenic greenhouse gases can be identified despite uncertainties in forcing due to anthropogenic sulfate aerosol and natural factors (volcanoes and solar irradiance)." "Detection and attribution studies consistently find evidence for an anthropogenic signal in the climate record of the last 35 to 50 years."
IPCC, 2007 (AR4), [54]	"Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations"	"The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture." "The understanding of anthropogenic warming and cooling influences on climate has improved since the TAR, leading to very high confidence that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W m^{-2}" "Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes, and wind patterns"
IPCC, 2013 (AR5), [30]	"It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century" "It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together."	"Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system."
IPCC, 2021 (AR6), [24]	"It is unequivocal that human influence has warmed the atmosphere, ocean, and land." "The likely range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8 °C to 1.3 °C, with a best estimate of 1.07 °C."	

[1] "Attribution" is the process of establishing cause and effect relations, including the testing of competing hypotheses.—SAR, IPCC; [2] Acronyms used in the left column of Table 1: FAR—First Assessment Report, SAR—Second Assessment Report, TAR—Third Assessment Report, AR4—Fourth Assessment Report, AR5—Fifth Assessment Report, AR6—Sixth Assessment Report; [3] The atmospheric concentrations of greenhouse gases, inter alia, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) which have grown significantly: by about 30%, 145%, and 15%, respectively (values for 1992).

However, the issue of whether global warming is largely anthropogenic continues to divide public opinion. In contrast to consensus assessments by Oreskes [14] and Powell [15], Pielke [57] stated that out of more than 11,999 articles on climate change in the existing back then Information Systems Institute (ISI) database, there were approximately 10% somehow contradicting the IPCC consensus position. It is thus worth mentioning that in the last IPCC report [24] not only global warming itself but also the increase in the frequency of some extreme weather events were attributed to human activities with high confidence. The general statement in regard to the attribution analysis says that *"greenhouse gases and other external forcing factors have affected individual extreme weather events"*. A detailed description can be found in Table 11.1 in the latest IPCC report [24], but in brief, the human contribution to the observed trend of warmer and/or more frequent hot days and nights, warmer and/or fewer cold days and nights, increases in frequency or intensity of warm spells and heatwaves as well as decreases in frequency or intensity of cold spells and cold waves, over most land areas since 1950, were qualified as extremely likely. For the two other major extreme-event regimes, i.e., increase in the frequency, intensity, and/or amount of heavy precipitation on a global scale, as well as increases in agricultural and ecological drought events in some regions, the probability of anthropogenic causes was qualified as likely (66–90% chance) to medium (33–66%), respectively.

If climate models can mimic broad features of past climate changes, when the increased anthropogenic GHG emissions have led to the enhancement of the greenhouse effect, then there is a reasonably high chance that we can make meaningful model-based projections for the future warmer climate and estimate the impacts. However, the models are not yet able to precisely mimic some important details of the climate of the recent past, such as precipitation patterns and their impacts (for instance, river-flow processes [58]. Therefore, climate models are sometimes ridiculed for being untrustworthy, reflecting the subjective notions (and pet concepts) of individual modelers rather than reality.

Fleming et al. [59] addressed widespread causal misconceptions about climate change. They emphasized the existence of persistent beliefs about climate change causes and risks, such as the conviction that parallel environmental problems (air pollution, ozone depletion, etc.) triggered global climate change. Conservative thinking and political ideology may indeed weaken or even divert support away from effective climate-change action. But can such an action be successful at all?

2.4. Is It Possible to Mitigate Global Warming?

Concluding that human interventions have brought about the present global warming, implies, in principle at least, that changing the course of human behavior could also stop or even reverse that warming. Meinshausen et al. [60] analyzed GHG emission targets for curbing global warming to no more than 2 °C above the pre-industrial level against the time horizon of 2100, and the result of their research was found spectacular enough to be promoted to a cover story of NATURE magazine (*"The coming climate crunch"*, Nature, 30 April 2009). In spite of this, the percentage of experts and laymen alike, who feel that climate-change mitigation is all but feasible, is relatively high – actually higher than the percentage of those who give negative answers to the previous questions in the scheme depicted in Figure 1.

So far indeed, the existing international climate policy architecture has proved to be inadequate for the Gargantuan task at hand. The Kyoto Protocol was a modest, rather symbolic step in the right direction. It was arguably the maximum move that could be agreed upon back in 1997, but unsurprisingly insufficient to curb global warming. Further, despite the advanced process of high-level international negotiations and annually-held Conferences of the Parties (COP) of the UN Framework Convention on Climate Change (UNFCCC), some of which have gathered up to 50, 000 participants, the results have been rather disappointing so far. Global greenhouse gas emissions continue to grow despite the adoption of the historic Paris Agreement [61] by 196 nations at COP 21 in France. The goal of the Paris Agreement, a legally binding international treaty on climate change—adopted on 12 December 2015 and entering into force on 4 November 2016—is to limit global warming to well below 2, preferably even to 1.5 degrees Celsius.

Unfortunately, the climate mitigation pledges made so far by governments across the globe do not augur well for confining the warming to the Paris range. The outcomes of recent COPs (COP 26 in Glasgow, UK, in October and November 2021 and COP 27 in Sharm el Sheik, Egypt, November 2022) cannot be regarded as a breakthrough, but at least curbing global warming to "below 3 °C" seems to come into reach.

2.5. Inconvenient Truths and Convenient Untruths

Figure 1 assumes a simple binary format of responses, yet the two-element alphabet (either yes or no), may not be sufficient, and intermediate attitudes are thinkable—plus the humble, but honest, option *"I really don't know"*. There are four questions illustrated in Figure 1, and the three concluding boxes (*"no problem"*; *"there is a problem, but we can only adapt"* and *"humankind should embark upon effective climate change mitigation"*). They divide the public scene into camps or silos and the proportions of those populating different camps can be estimated. The situation is nonstationary, in the sense that there is some traffic between the camps and silos over time. In some nations, climate awareness has been systematically increasing, while in other places people do not wish to accept "the inconvenient truth". This can be especially observed in countries where energy stems predominantly from fossil fuel burning (cf. Gore, [62]). The distribution of responses of individuals or societies to questions in Figure 1 can change with time, possibly illustrating the success of the learning process. There may also be some opportunism in judgments by a broader audience, depending on whether there is a cold spell or a heat wave behind the window, and whether there is a kind of "climate-gate" or "glacier-gate" hype in the media.

An exemplary set of responses to essential questions posed in Figure 1 can be interpreted in the light of the existing knowledge as a suite of *"inconvenient truths"* in the sense of Gore and *"convenient untruths"*, as illustrated in Table 2.

Table 2. Basic inconvenient truths and convenient untruths. Statements on issues related to climate change (ref. Figure 1).

No.	Inconvenient Truths	Convenient Untruths
1.	The global climate has been warming.	The global climate has not been warming.
2.	Disadvantages of future climate change and its impacts are likely to be critical and to prevail over the advantages.	Disadvantages of future climate change and its impacts are likely to be marginal and advantages prevail.
3.	Humans have substantially contributed to global warming.	Humans should not be blamed for having substantially contributed to global warming. Natural factors have been primarily responsible.
4.	Counteracting dangerous climate change is possible, hence humans should embark upon effective climate change mitigation.	Counteracting dangerous climate change is not possible, hence it is naïve to believe that climate change mitigation can be successful.

One could envisage a taxonomy of various species of climate change skeptics (some say: contrarians or deniers), organized around negative responses to the questions posed in Figure 1 and discussed above.

- The first group is *"Warming skeptics"* who claim that there is no warming. This is a very problematic claim in light of a clear, observation-based trend presented in Figure 2 that is strengthening with every new warm year.
- *"Impact skeptics"* claim that climate change impacts are mostly advantageous or marginal.
- *"Attribution skeptics"* claim that the observed warming is largely natural, not anthropogenic.
- *"Mitigation skeptics"* claim that no mitigation is realistically possible, because it would consume a large portion of desired growth, or that it is simply too late for effective mitigation, as whole decades have been wasted.

In addition, subcategories of mitigation skeptics can be identified. *"Priority skeptics"* state that there are many more pending and burning issues. This has been of particular relevance during the COVID-19 pandemic and the Russian aggression on Ukraine. The *"timeliness skeptics"* follow the "better-wait-and-see" rule, while *"climate policy skeptics"* doubt that emissions can be sufficiently curbed by effective enforcement of an international regulation.

2.6. Media Track

The media tend to cover actual, short-term trends, reacting mainly to extreme weather events. Usually, extrapolations of the most recent development are taken as proxies for the future. Sometimes, however, a broad interest is attracted by provocative cover stories that have nothing to do with observed trends. The most influential and opinion-making weekly in Poland (a country virtually sitting on coal), POLITYKA, selected, rather surrealistically, the concept of a new ice age as the cover story of an issue dated 12 July 2003 (i.e., during the record-hot summer in Europe!) and of an issue dated 12 April 2008. The former cover story heralded *"The advent of a new ice age"* (*"Nowa epoka lodowa"*) on orbital grounds and stated: *"Scientists warn of a large cooling"* (*"Naukowcy ostrzegają przed wielkim ochłodzeniem"*). The latter cover story—*"It will be colder"* (*"Będzie zimniej"*)—announced a specific report and asked *"Is global warming a mere business trick?"* (*"Czy globalne ocieplenie to tylko chwyt biznesowy?"*). We can well qualify these covers as conveying fake news.

It is interesting to review "climatic" cover stories of *TIME*, one of the most influential and popular American weekly magazines for many years (Table 3). As a matter of fact, we could not find any *TIME* covers denying the existence of global warming. There were some stories relating to cold, but these referred to cold weather problems that actually occurred back then. The cover from January 1977, *"The Big Freeze"*, even has been exploited within social media as an example of a sensation-seeking new-ice-age story. Speculations about the true motifs of the authors are a natural consequence of flashy titles and the like: April 2006, *"Be worried. Be very worried"*; April 2007, *"The Global Warming Survival Guide. 51 Things You Can Do to Make a Difference"*; July 2020 *"One last chance. The defining year for the planet"*. Such headlines obviously run the risk of eventually anesthetizing the initially interested readers. Unfortunately, this is not only the case with the climate-change discourse, but a general media trend moving towards "infotainment", where the audience is attracted for a short time until another exciting news trumps the previous one.

Table 3. A compilation of *TIME* magazine cover stories relating to climate change. The publication date, cover story title, and description of the cover graphics are presented.

Date of Publication	Cover Story Title	Description of the Cover Content
31 January 1977	"The Big Freeze"	The man with the frosted balaclava on his head. The picture was taken in cold weather conditions.
19 October 1987	"The Heat Is On. How the Earth's Climate Is Changing. Why the Ozone Hole Is Growing."	Planet earth with heated-looking edges locked in a cage resembling a greenhouse.
4 September 2000	"Arctic meltdown"	A polar bear standing on the edge of an iceberg.
9 April 2001	"Global warming."	A frying pan on which an egg is fried. The yolk of the egg symbolizes the earth, the contours of the continents are outlined on it.
28 April 2008	"How to Win the War On Global Warming."	Paraphrase of a historical photograph showing American soldiers raising the flag after their victory over Japan on the island of Iwo Jima. Soldiers put a tree instead of a flag.
24 June 2019	"Our sinking planet."	U.N. Secretary-General Antonio Guterres dressed in a suit stands knee-deep in the water. The picture was taken off the coast of Tuvalu, vulnerable to sea level rise flooding.
23 September 2019	"2050: how earth survived." Special climate issue.	A two-dimensional image of the earth prepared in the sand by many people, seen from a great height.
20/27 July 2020	"One last chance. The defining year for the planet."	A combined chart of declining land ice, increasing sea level, increasing global average temperature, an increase in CO_2 emission with a projection to drop by 7% in 2020, an increase in renewable energy consumption. Every element of the chart is represented with a related graphic.
26 April/3 May 2021	"Climate is everything. How the pandemic can lead us to a better, greener world."	Map of the world made of 50,000 matchsticks set on fire in different continents.
8/15 November 2021	"Last call."	World leaders sitting on chairs with the inscription COP26. Some places are empty, there are nameplates. Extreme weather events are taking place around. Under one of the chairs there is a note "blah, blah, blah!"

People disagree about climate change also because they may have different expectations about *"what science can or should tell us"* [16]. The climate change field can be regarded as a post-normal science [63,64], with deep uncertainties (and risks that cannot be reliably quantified), high stakes (irreversible changes may adversely affect billions of people), and high urgency of decisions. Uncertainty, value loading, and the plurality of legitimate perspectives are integral to analyzing the issue. However, some scientists have doubts about the practical usefulness of the view of the climate challenge after Funtowicz and Ravetz [63,64], because *"post-normal science"* is still a nebulous concept and has produced very few tangible results so far.

Climate change, like other challenges of comparable complexity such as public-health management, requires problem-solving strategies that transcend the standard approach of mono-disciplinary sciences. Uncertainty about the things that are supposed to happen in the future, but also uncertainty about what is happening now, plays a central role. This refers to both the projected changes as well as to the expected human reactions. This is evidently a consequence of the fact that climate change concerns people in a potentially existential way. The stakes are high, many actors are involved, and different opinions are formed so that the decision-making process becomes extremely convoluted.

If effective emissions reduction starts late, it must be more radical and, simultaneously, more expensive, in order to curb the warming; hence opportunities must not be lost. Due to the complexities involved, however, the expectation that the pertinent science generates reliable, definitive, quantitative, and detailed statements about the future is largely futile—despite massive research efforts and the rapidly growing number of relevant scientific publications. Common sense rather calls for obeying the precautionary principle and trying to *avoid the unmanageable while managing the unavoidable*.

Trenberth's [65] prediction was that while knowledge increases with time, so does our understanding of factors that were previously not accounted for or not even recognized (the famous *"unknown unknowns"*). Hence, more knowledge may translate into less certainty! This does not augur well for broadening the consensus, or, at least, for a considerable reduction of the existing disagreement about climate change on the timescale of years.

On the other hand, Oppenheimer et al. [66] postulated that it is necessary to avoid premature consensus. A full exploration of uncertainty [67] may be more useful than the establishment of a premature consensus. Obviously, caveats are included in the body of IPCC reports, but they are often quite cryptic or even lost entirely in the highly influential Summaries for Policy Makers (SPMs).

The way people perceive climate change is being impacted by extreme weather and climate events. Researchers interpret weather and climate extremes and the scientific findings are available to policymakers.

3. Space of Outcomes

In the global super-system, almost everything is connected with everything. We know that even the structure of its sub-systems is very complex as a rule, with complicated interconnections, strong nonlinearities, and multiple feedbacks, both negative (yielding stability) and positive (generating instability). And there is no doubt that the climate plays an important role in many sub-systems of the global make-up.

In the following section, we look at the potential final outcomes of the development of the climate-related science-policy system, extending the ideas of Schellnhuber [68]. Bellman's *"curse of dimensionality"* can be avoided, if we concentrate, in a binary way, on the most essential factors only, ignoring all those aspects that are not absolutely crucial for the problem at hand. The *"curse of dimensionality"* notion was introduced by the mathematician Richard Bellman in his book "Dynamic Programming" back in 1957. According to him, that curse is inflicted by the exponential increase in volume associated with adding extra dimensions to Euclidean space. This basically means that the error increases dramatically with the increase in the number of features. It refers to the fact that algorithms are harder to design in high dimensions and often have a running time growing exponentially with the number of dimensions. Multi-dimensional approaches theoretically allow more information to be accounted for, but practically it rarely helps due to the higher possibility of noise and redundancy in the real-world data.

Therefore, we consider again a low-dimensional space, with four definite outcomes only. We assume that each individual venture of the *"science-policy"* couple can either succeed or fail. One can herald a *"success"* of science if the projections of climate impact adequately represent the development of future reality. The *"success"* of policy means that the global community of nations manages to undertake effective actions to control the atmospheric concentration of GHGs, and hence to confine planetary warming to a "safe" range. The quotation marks were used because some adverse effects are likely to occur already for warming levels below 2 °C.

Let us have a closer look at the four considered outcomes, labeled as proposed by Schellnhuber [68], illustrated in Figure 3, and briefly outlined in the sequel. In particular, we examine whether the situation has changed during the last 12 years or whether the considerations by Schellnhuber [68] still hold today.

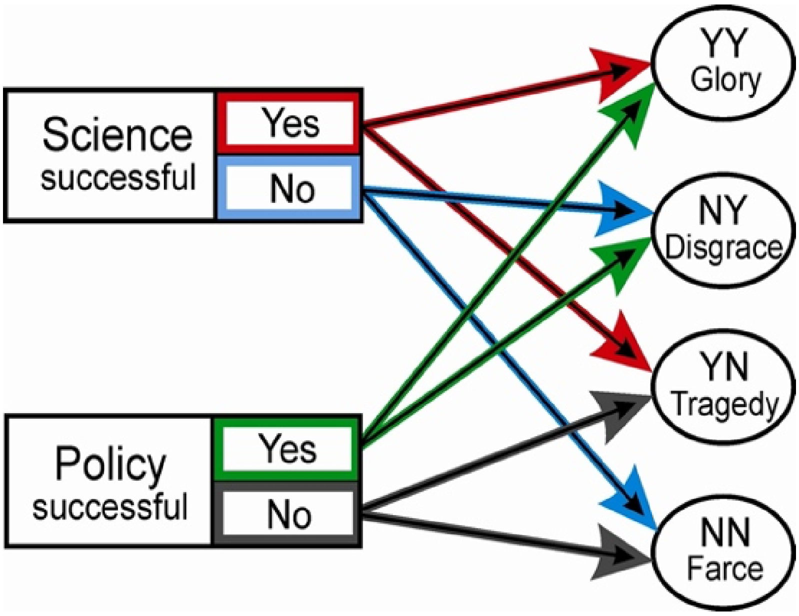

Figure 3. Combinatorics of binary outcomes of climate change science and policy. Notation: Y—yes (success), N—no (failure), YY—science successful, policy successful (glory), NY—science unsuccessful, policy successful (disgrace), YN—science successful, policy unsuccessful (tragedy), NN—science unsuccessful, policy unsuccessful (farce).

The main message of science is the projection of significant global warming in response to human interference with the atmosphere and the anticipation of large adverse impacts of that climatic change. Oreskes [14] searched for articles published in ISI journals between 1993–2003 with the keyword "global climate change" and found 928 entries, none of which, based on the abstracts, negated human-caused global warming. In his study, Powell [15] found that during 2013 and 2014, only four of 69,406 authors of peer-reviewed articles on global warming (0.0058%) rejected anthropogenic global warming (AGW). Most importantly, none of the skeptical articles presented the magic bullet that could falsify human-caused global warming.

The combinatoric representation of the four outcomes in question can be viewed in the context of the subjective probability of occurrence. It seems, at present, that the most likely outcome is still a tragic triumph, as it was put in the time of Schellnhuber's paper [68]: the success of science and failure of policy. This evidently defines a tragedy of humankind, since the voice of science, which issued well-founded regular wake-up calls and warnings, has been largely ignored by the political world. Among the reasons behind a *"tragic triumph"* are—conflicts of interests between countries and deficient communication between the scientific community and the public. The jury is still out as to how to effectively explain climate change science to the public and how to persuade people to act in sustainable ways.

The truly preferred (and still rather unlikely) outcome is glory—a conjunction of the success of science and the success of the policy. This would be a brilliant happy end indeed: climate-change science, backed by extensive observations and robust modeling results, succeeds in persuading decision-makers worldwide that rapid decarbonization across all sectors is necessary and feasible, so that adequate and timely measures are taken. In such a perfect world, the warming might even stay below 1.5 °C, thus meeting the most ambitious target of the Paris Agreement [61]. In this way, the scientific system would trigger the global transition towards sustainability, averting the unmanageable consequences of anthropogenic climate change.

However, the glorious outcome, as described above, could carry considerable risk as well [68]. Once mitigation measures have instigated the desired effects (i.e., after long-lasting and persistent decarbonization efforts), the scientific community might be accused post-factum of alarmism and gloomy exaggeration. Actually, such accusations have accompanied climate researchers ever since Arrhenius' legendary 1896 study on the enhanced greenhouse effect, but the attacks became quite nasty from the 1970s on [69]. Therefore, it is not implausible that the broad public would easily forget the fact that the worst climate change impacts were avoided due to the wake-up calls by the scientific community. What might stick instead, could be the pains and nuisances of decarbonization.

Somewhat naïve expectations of the preferred outcome were stronger in the past (e.g., before the UNFCCC COP 15 held in 2009 in Copenhagen, wishfully baptized as Hopenhagen), but have been tempered by very limited (if any) progress at and since that event, except for the Paris Agreement at COP 21 in 2015. This remark can be generalized, because it holds also for other global environmental issues beyond climate policy, such as the preservation of biodiversity [70]. The Rio+20 conference in 2012 could have been called Rio-20 as it basically meant a considerable step back in comparison to the highly promising narratives and effects of the Earth Summit held in the same place in 1992. Many observers feel that the three decades since the advent of the UNFCCC have been wasted. Also, the Aichi biodiversity targets have not been met yet. In fact, in some aspects, the situation is worse now than in 2010, when the targets were established [70].

The two remaining outcomes illustrate the (unlikely) case of failure of science. The coincidence that both science and policy failure can be labeled a farce [68]. This would be a situation where climate-change science grossly exaggerates the risks of anthropogenic global warming, but decision-makers—for whatever reasons, yet fortunately—fail to take adequate climate-policy measures. The occurrence of this scenario would shatter the public confidence in the scientific system and deal a fatal blow to the principle of evidence-based decision-making. However, the world would be safe since it was never at risk.

The least probable outcome, disgrace, represents a shameful conjunction of failure of science and success of policy where mainstream climate-science projections turn out to be incorrect, yet the scientists manage to fool the decision makers, and—more broadly—humankind, into costly mitigation measures. This outcome would be even more embarrassing for the research community worldwide, even if, as a by-product of this situation, strong mitigation action may offer co-benefits, proving to be globally advantageous in the sustainable development context.

It seems today that, despite some persistent uncertainties hampering projections of the type in question, the probability of success of science is high, and clearly growing with each additional piece of evidence (e.g., every newly recorded warm year in the time series in Figure 2). By contradistinction, the probability of success of policy does not tend to grow at present. Many decision-makers avoid publicly doubting the scientific mainstream nowadays, but they may do cherry-picking and restrict their perspective to a small subset of available information, conveniently ignoring the inconvenient part of the overall evidence.

4. Discussion

There is a growing body of scientific findings indicating that unbridled anthropogenic warming will be globally disadvantageous, if not disastrous. However, the uncertainty, which is endemic in climate (impacts) science, generates not only legitimate, and possibly constructive, expert skepticism [71–73], but also radical, destructive public criticism, sowing confusion and justifying inaction (cf. review by Pidgeon & Fischhoff [74]). Even issues perceived as virtually certain by the research community are being challenged by certain authors who try to polemicize away the reality of man-made climate change along with its likely consequences. Leaving a climate-burden legacy to future generations (against the principles of sustainability and inter-generational equity) is simply delinquent.

The "G3"—China, the USA, and India, i.e., the three countries with the largest greenhouse gas emissions – bear a critical responsibility for the high-risk development. Their controversial positions regarding climate protection remain deadlocked, however. It is certain that the slightly quixotic (in fact, this is perhaps a problematic adjective, since Don Quixote fought windmills, i.e., harbingers of renewable energy) struggle of the European Union towards decarbonization of its energy system will not be sufficient to protect the global climate. There is a hiatus between the recognized science-based aspirations and the accepted politics-driven consequences. There are obvious risks of breaching not only the 1.5 °C line, but even the 2 °C-guardrail, specified in the Paris Agreement.

It should be also emphasized that from the attitudes towards climate change and global warming presented in this work, a far more complex division than just into two basic groups (deniers of and believers in scientific insights) emerges. A black-and-white picture of reality will not suffice here. Particularly in the group of "believers", there is much variation. It includes, for instance, the tragic attitude described by Jonathan Safran Foer in his book entitled "We Are the Weather: Saving the Planet begins at Breakfast" [75]. Many people do not accept the statement in the title, although they accept the findings of (natural) climate science. As a consequence, they are unable to take real action to stop the intensification of the greenhouse effect. As a consequence, Foer has a point when he argues that it doesn't matter for the future of the Earth whether someone actively denies the science or uses far-fetched excuses for inaction like *"I can't do anything because my personal emissions are insignificant compared to those of China or the US."* The final result is exactly the same: emissions continue to rise and global warming proceeds.

This hands-off attitude deserves further investigation, since it is perhaps the most common one worldwide, judging by the lack of progress in international climate action. Its popularity comes from the convenient fact that people adopting it cannot be accused of being climate problem deniers. After all, they appear to trust the scientific logic and seem happy to confirm: *"I'm not a denialist; I'm an intelligent and rational person."* This is a fairly cheap way to raise one's self-esteem. In addition, such people are often "modernists", relying exclusively on "green" technological progress.

This may be a futile hope, however. Many of those technologies are only first attempts in the quest for zero-emission schemes. Of course, we should be glad that they are being created and developed. Yet, firstly, we do not have much time left for testing which technologies or solutions are really climate-friendly. Secondly, for many representatives of a "passive acceptance" attitude, this is just another comfortable excuse for doing nothing themselves.

In this context, one may or may not agree with Foer (2019) that buying electric cars is not an expedient individual action in the fight against global warming, despite the so-called Life Cycle Assessment (LCA) [76], which is in favor of electric cars (battery electric vehicles (BEV)) compared to internal combustion engine vehicles (ICEVs) [77]. The right move might be to give up buying cars at all and to increase political pressure towards investment in public-transport systems.

On the other hand, the debate has to transcend the narrow transport-emissions topic: The car is also a powerful symbol of wealth and a consumption-oriented lifestyle, which we may need to give up anyway. The biggest problem appears to be our strict objection to personal sacrifices, even if they would help to save the climate and the Earth's total ecosystem. This is becoming ever more evident, but the above-mentioned attitude of "passive acceptance" allows one to procrastinate real climate action, with the hope that the consequences of global change will not be so severe in one's own lifetime.

In this vein, societies and their governments conspire to represent to avoid pro-climate policies, which might harm economic growth and the current comfort of living. The alarming thought here is that with such an approach towards the climate issue, we are basically doomed as a species.

At this point, another question arises, which is also asked by the previously cited Foer [75]: *Why, in the face of arguably the greatest threat to our civilization, aren't we able and ready to undertake an effort similar to what was done by countries and societies in wartimes?* Undoubtedly, conflicts of interests of individual countries are a major obstacle to global integration and solidarity. They worry that reducing emissions will lead to the impoverishment of their country, while those maintaining emissions unchanged will gain an advantage. It is also easier to see an adversary in the form of another country or nation than immaterial global warming. Therefore, it comes with ease to compete with each other. Military conflict brings sudden death and destruction, just like hurricanes or floods. However, in case of war, we have someone to blame, and we know the enemy so that we can take revenge. But, is it possible to blame nature, let alone take revenge for the harm inflicted by the weather?

There is one more aspect that needs to be addressed here. In the face of threats as terrifying as war, societies consolidate around centers of power. Most people then instinctively look for leaders who will organize defense and attack. Patriotism helps to make personal sacrifices and self-limitations palatable. Citizens willingly save energy and resources and let other aspects of the state's functioning recede into the background, especially in the case of fighting an invasion. Nobody thinks about economic growth under such conditions; the entire economy is put into war mode. A similar attitude of authorities and people would be necessary for the fight against global warming. However, in the case of the "war on global warming", we seem to lack leaders capable of persuading societies to make a war-like effort for the climate's sake.

5. Conclusions

The space of attitudes discussed in this paper illustrates the divisions pervading public opinion. Scientists typically achieve broad consensus regarding the warming and the anthropogenic nature of climate change, with somewhat less common agreement on largely adverse impacts and the best mitigation and adaptation options. In particular, it was demonstrated by a thorough analysis of the literature based on selected keywords [14,15] that the bulk of articles in peer-reviewed scientific journals reveals no disagreement as to human-caused global warming. This is a powerful result, even if some skeptical papers may have escaped the examination due to the specific keywords sieve used. There are skeptical scientists, also among eminent pundits of academia in many countries, including Poland, but they are not publishing meaningful expert papers in peer-reviewed journals. The principal avenues of dissemination of articles of contrarians usually run through the "grey" domain. Within the peer-reviewed literature, global-warming denial has virtually no influence [15]. And yet it still exerts a surprisingly strong influence on media, politicians, and the broader public, who tend to cling to *"the impression of confusion, disagreement, or discord among climate scientists"*, even if that impression is incorrect [14].

The disappointing results of a long suite of conferences within the UN Framework Convention on Climate Change have shown that the chance for the glorious outcome, i.e., joint success of science and policy is very small, and it does not seem to grow vigorously at present. Unfortunately, the most probable outcome of the *"Great Climate Game"* is still, as it was more than a dozen years ago [68], a tragic triumph. A novel viewpoint that should be considered here stems from an important reference about the *"Climate Endgame"* [78], stating the problem of bad-to-worst-case scenarios and the possibility of their catastrophic consequences to mass extinction, human mass mortality and morbidity, as well as societal vulnerabilities to climate-triggered risk cascades.

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