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Review

Perception of Climate Change Effects over Time and the Contribution of Different Areas of Knowledge to Its Understanding and Mitigation

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Abstract: Climate change is a current subject that is attracting more and more attention, whether from academics or the public. This public attention is mainly due to the frequently published news in the media, reporting consequences caused by extreme weather events. On the other hand, scientists are looking into the origins of the phenomenon, seeking answers that will somehow help to mitigate the effects of climate change. This article presents a review of some of the different possible approaches taken on climate change, to demonstrate the need to build a multidisciplinary perspective of the problem. It is understood that only the integration of different perspectives, presented by different areas of knowledge, such as natural sciences, social and economic sciences and human sciences, will make it possible to build modeling and predictive scenarios, which realistically may represent the development of the earth system under the influence of climate change. In this way, with the support of all areas of knowledge, the creation of forecast models where all possible changes to the different variables of the earth system may be simulated will allow for the mitigation measures presented to be analyzed in advance and, thus, prioritized. This review shows that a multi and interdisciplinary approach, based on the knowledge acquired from different knowledge and science fields, presents itself as the way to solve this global and complex problem caused by climate change.

Keywords: climate change; natural sciences; economic sciences; social sciences; human sciences

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1. Introduction

On 9 May 2013, the concentration of CO_2 in the atmosphere exceeded 400 ppm, according to information available on the NASA Global Climate Change website (https://climate.nasa.gov/climate_resources/7/graphic-carbon-dioxide-hits-new-high/, accessed on 20 November 2021). This mark had only been reached in the Pliocene, that is, before man evolved on earth, in a period when the sea level was about 40 m above the present, with a much warmer and wetter climate than it is now verified (Figure 1) [1–3]. Climate change is a phenomenon, or rather a set of phenomena, which currently has almost unanimously been recognized as being practical and affecting the environment and populations globally in all aspects [4]. However, recently, several and numerous factions have arisen, consisting of groups dispersed all over the world, defending the non-existence of any changes and instead proposing theories claiming that everything is a natural process as proof of the dynamism of the planet, this dynamism being a constant proof of the search for a balance between the different subsystems that make up the more extensive system, the earth [5]. When analyzing the events throughout the history of the planet, whether based on the fossil record, sedimentological analyses, or historical records, there is a sequence of occurrences that demonstrate a succession of evidence, with warmer periods alternating with cooler ones [6]. These facts, which are well documented, mainly indirectly through reports that describe, for example, periods of great agricultural abundance, are also counterbalanced by documents describing periods of significant food shortage, which may indicate successive years of bad harvests, from which a succession of climatic periods less favorable to crops may also be inferred [7–9]. This succession of events may suggest to less attentive observers that the earth system is in constant change and in a continuous search to reach a balance between the different subsystems [10,11]. However, the expression "less attentive observers" was used because, from the analysis of this evidence, it may also be seen that the so-called hot periods are associated with extreme natural phenomena, such as the occurrence of significant volcanic episodes [12,13]. These led to the emission of large amounts of greenhouse gases into the atmosphere, similar to what is happening today, causing the system to rebalance. During this readaptation period, there was a succession of warmer periods caused by the greenhouse effect, followed by a cooling period caused by the masking from clouds of dust, similar to what Carl Sagan described as the Nuclear Winter [14–16].

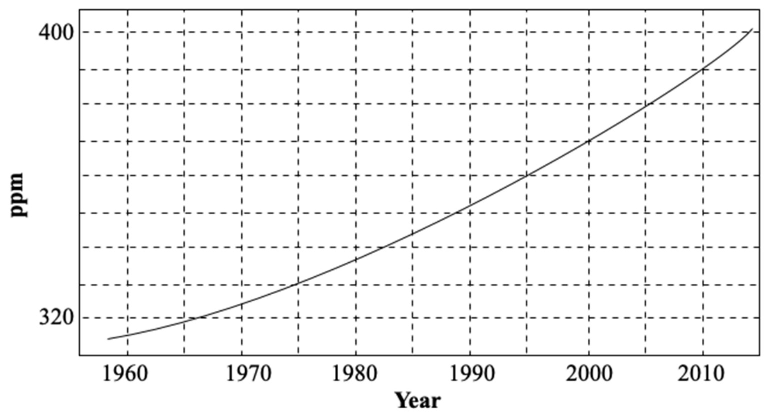

Figure 1. Carbon dioxide concentration (adapted from https://climate.nasa.gov/climate_resources/7/graphic-carbon-dioxide-hits-new-high/, accessed on 20 November 2021).

When analyzing the current period, it appears that similar episodes continue to occur [17]. In other words, volcanic events continue to occur, with the emission of large amounts of greenhouse gases into the atmosphere and naturally caused forest fires, which sometimes reach epic proportions and are also responsible for the emission of gigantic amounts of CO_2 into the atmosphere. Then, as happened throughout the entire existence of the planet, natural processes, such as chemical carbonation processes, dissolution in ocean water, or plant photosynthesis, will return to balance the system, recapturing and storing this carbon [18].

So why is it that such a balance cannot currently be achieved, and why are we witnessing a sequence of events of such an extreme type? Is this the question that enables climate deniers to have some followers, as the answers claim that the system needs more time to stabilize and reach balance again? However, the deniers forgot to add a crucial factor to the balance equation that acquires great importance. The equation does not include the anthropogenic fraction of greenhouse gases, which adds a lot to the natural fraction, making natural processes unable to neutralize the sum of natural and anthropogenic emissions caused by using fossil fuels or cement production.

An argument also widely used by defenders of climate denial is the fact that in periods of the remote past of the history of the earth, such as the Carboniferous (now

Mississippian-Pennsylvanian) [19] and the Permian periods, there were much higher CO_2 levels in the atmosphere than those found today, even with all the emissions from the post-industrial revolution period, which were responsible for the development of endless forests, and which covered the entire emerging landmass of Pangea [20,21]. The main masses of coal that are currently exploited are from these periods [22]. The same happened during the Jurassic and Cretaceous periods, which led to the formation of the main limestone masses found today, which currently serve as raw materials, namely for the cement industry, but which also resulted in oil and natural gas traps [23,24]. Now, the question that arises is the following: "Will life as we know it be able to adapt to the new conditions?" Most likely not. This is a big question because, since these changes in the composition of the atmosphere and extreme climatic changes took place, the climate shifted from tropical conditions during the Carboniferous and Permian periods, when forests were dense, to a desert-like period in the Triassic period, while in the Jurassic and Cretaceous periods it led to the growth of dense forests and an explosion of life [25–28]. The problem is that these passages from one period to another were also marked by the occurrence of mass extinctions, with the disappearance of most species, allowing the evolution of others that survived but which previously played minor roles on the socio-ecological scale [29–31]. Is mankind prepared to face a new passage era of this order of magnitude? It is precisely here that the problem arises, as nobody can find an answer. However, apart from better judgment, the negative option seems to be the best path, as it will launch the search for solutions to solve the problem, or at least for the mitigation of the problem (Figure 2).

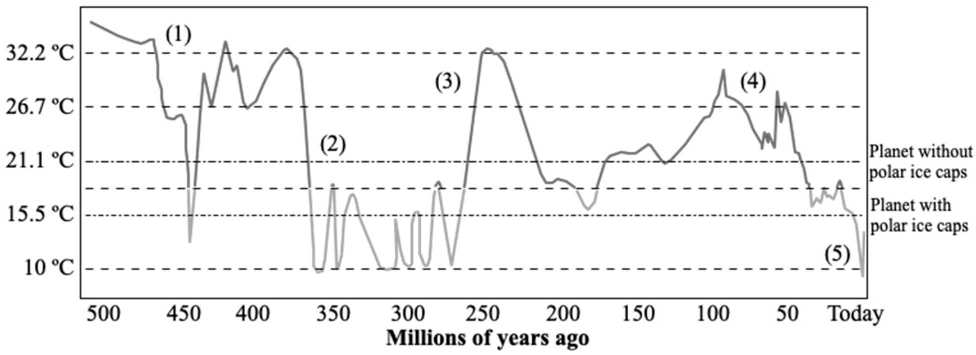

Figure 2. Preliminary results from a Smithsonian Institution project led by Scott Wing and Paul Huber, showing the earth's average surface temperature over the past 500 million years. For most of the time, global temperatures appear to have been too warm (red portions of line) for persistent polar ice caps. The most recent 50 million years are an exception. (1) Marine life diversified in extreme heat; (2) Period before land-based plants absorbed CO_2 and polar ice caps formed; (3) Volcanic activity oscillated CO_2 levels; (4) Mammals evolved in a warmer period; and (5) Humans are warming the climate (adapted from https://www.climate.gov/media/11332, accessed on 20 November 2021).

Being such a difficult problem to solve, a multidisciplinary approach seems to be the option capable of presenting an integrated perspective that, even if several paths can be followed depending on the point of view, will be able to give a more global analysis of the set of phenomena that result from climate change. Figure 3 shows the most significant impacts related to climate change and its relationship with human societies.

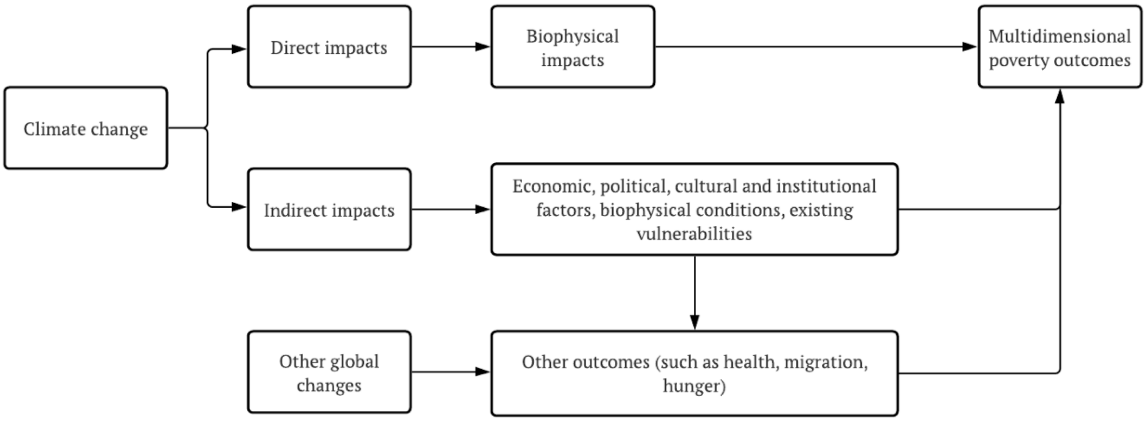

Figure 3. Climate change impacts on societies (adapted from [32]).

Thus, this work intends to present the possible perspectives studied by different areas of knowledge, starting from the quantitative analysis carried out within the scope of natural sciences, to the more qualitative and behavioral analysis presented by social, economic, and human sciences, and to present the evolution of the perception of the effects of climate change over time. The article is sequentially organized after the introductory section with a historical overview of how the phenomenon of climate change was understood and addressed, divided into the following historical periods, namely: the pre-Second World War period, the Second World War period, the post-war period, the late 20th century, and the 21st century. After this historical perspective, a review of how each area of knowledge sees and understands climate change is presented, and finally, the lack of connection between the different fields of knowledge is discussed, concluding with the need for an interconnection between the different fields of knowledge as a solution to find measures to face the problem, and above all, for a global and integrated understanding of climate change.

2. The Perception of Climate Change over Time

2.1. The Pre-Second World War Period (<1939)

The use of the expression "climate change" dates back to the beginning of the 20th century [33]. However, these references are usually associated not with changes of a global nature, as they are currently felt, but rather with particular related situations, for example, with agricultural issues or with studies relating large-scale historical events with climatic phenomena [34]. An example can be found in the work presented by Olmstead (1912), where the author related agricultural productivity and weather conditions and the impacts of these occurrences on the development of societies, while Huntington (1913) addressed the implications of climate change throughout history, highlighting the importance that climatic and meteorological phenomena had for different societies [35,36]. The author began by stating that the universal subject of conversation is the weather, presenting as examples the importance that the first monsoon rains would have had for the inhabitants of southeast Asia, or the beginning of the Nile floods in ancient Egypt, which would undoubtedly also have served as a theme of conversation among the inhabitants of those regions, given the importance of the topic. However, the theme always ends up shifting toward the impact of the climate on relevant activities, such as agriculture, livestock creation, or fisheries.

One of the several examples portraying agricultural activity is presented by Bhavan and Ambience (1914), where the authors address the effects of climate change on coffee cultivation and the importance of thinking about the problem from a systemic perspective [37].

In other words, this would be from a more global and comprehensive perspective that is not restricted to the local or merely regional scope. The authors stated that several studies in different parts of the world showed that climate change would have a massive negative impact on coffee production and that east Africa would not be an exception. However, the prominent landmark left by these two authors is precisely the integrated approach and the demonstration of how a systemic approach in agricultural research is necessary to coffee culture but which started being applied to other cultures.

Another perspective that acquired great relevance at the time was the assessment of the impacts of climate change on the health of the populations. It became relatively frequent for medical studies from the beginning of the 20th century to include chapters dedicated to the characterization of the climate of the region, especially when the focus was on, for example, pulmonary diseases, such as pneumonia or tuberculosis. Semple (1915) presented a pioneering work on the use of climate models to obtain climate projections as a way of anticipating potential health problems in populations [38]. Alperovitz et al. (1917) also presented a collection of technical documentation on exposure response to climate-sensitive health outcomes, where they related the energy of the atmosphere and humidity to the impacts on the health of populations [39].

During this period, some authors raised the question "Is the climate changing?", which is the title of the work presented by Stupart (1917). In this work, the author stated, in a skeptical way, that there have been many widespread climatic changes in late geologic times, while in historical times, there have been no worldwide changes in the climate [40]. With a very similar title, in his work entitled "Is Our Climate Changing?", Kincer (1933) conducted a study of long-term temperature trends, where highlighted the importance of studies covering extensive periods where variations and trends can be detected [41]. This new line of thought led to regional scope works, such as that presented by Raup (1933), where the author presented a study on climate change and its impact on vegetation in southern New England and adjacent New York [42].

In this study, botanical data in the Hudson Highlands of southern New York State suggested that there may have been changes in the vegetation caused by climate change during the past two thousand years.

It is worth remembering that during this period, the authors never mentioned CO_2 or greenhouse gases as being responsible for climate change. Indeed, several authors who were deeply in line with what was already happening during the 19th century tried to find causes, for example, associated with the effects of interstellar matter on climate variations, as suggested by Hoyle et al. (1939), or the influence of earth movements on climate, as presented by Lewis (1935), or even the solar hypothesis of climatic changes, presented by Huntington (1914) [43–45]. This skeptical trend regarding the existence, or not, of climate change continued, for example with Kincer (1939) stating that the examination of longer weather records of countries, going back one hundred years or more, indicated that this did not represent a permanent change in the climate, but rather a warmer phase of the average climate to be followed, doubtless, by a cooler and wetter period [46].

2.2. The Period of Second World War (1939–1945)

During the period in which the world plunged into the Second World War, all the efforts, even at an academic level, were devoted to the war effort and to themes that could somehow contribute to the resolution of problems associated with war activities. Work on the climate and the preparedness of the military to face the adversities of different types of climates and theatres of operations where armies struggled were common during this period [47–49]. In these works, despite the attention being paid to the climate issue, the focus was always given to the issue of health, as in Singer (1940), which stated that abrupt climatic change might bring to the fore latent diseases, such as tuberculosis, arthritis, or heart disease [50]. Simpson (1940) related the distribution of water and dry landmasses, concluding that the mean temperature and mean rainfall of zones was unaffected by the distribution of land and water, as it turned out, showing a tendency to maintain the theories that attributed the occurrence of climate change to more diverse factors, as seen during the previous period [51]. However, the first references to greenhouse gases began to appear, but this time without the naturalistic approach, since the effect of gases such as CO_2 in maintaining the temperature of the planet was already known at the time. This perception may have arisen due to the comparison with the increase in CO_2 contents in the atmosphere during the Second World War, which may have been the basis for a new line of thinking about the causes behind climate change. Zain (1940), already within this line of thought, related the change in food habits and rapid global environmental changes [52].

In this study, the author demonstrated that the environmental changes coincided with increasing biotic and abiotic threats, such as the atmospheric concentration of CO_2, which was continuously rising with global climate change.

Concerns about the climate were also attracting the attention of academics from places other than Europe. Indeed, the United States, despite its intense participation in the conflict, maintained a regular parallel activity, given its distance from the war scenarios. For example, Fukui (1943) analyzed the secular changes of climate in the great cities in Japan, demonstrating that despite the conflict, science continued trying to find answers to emerging problems, and the first studies relating to climate and energy production of nations emerged, of which the work published by Markham (1942) is an example [53,54].

2.3. The Post-War and Global Reconstruction Period

This period was characterized as one of intense industrial activity, mainly due to the efforts to rebuild the territories that served as the stage for the conflict, but also by the change in consumption habits, which also led to profound changes in production processes [55]. This era saw an evolution in terms of productivity, inheriting many of the lessons learned during the war [56]. After an initial period of a few years in which there were no significant developments, Plass (1959) presented a study in which related CO_2 and climate [57]. In this work, the author removed causes that were at the time generally known as being responsible for climate change, which were designated as "Olympian forces", ranging from geological upheavals and dust-belching volcanoes to long-term variations in the radiation of the sun, to refer to the increase in concentration of CO_2 as the cause of climate change.

Works addressing the occurrence of climate change through more and more evidence began to emerge, although very tenuously, and in need of permanent proof and discussion. Mitchell (1961) presented a review of recent secular changes in global temperatures, pointing to a path that had been followed by many other academics who used the study of temperatures as the primary supporting evidence of climate change [58]. An example can be found in the works by Vowinckel and Orvig (1967) and Vowinckel and Orvig (1969) who studied the impact of climate change on the polar oceans, or the work of Hepting (1963), where the author related climate to the occurrence of diseases in forest species, since climate change alters tree species distribution, and the next question would be how these weather changes influence the resilience of trees when exposed to new biotic factors [59–61].

2.4. The Late 20th Century Period (1970–2000)

In the final 30 years of the 20th century, there was an increase in the number of publications and studies dealing with climate change and its causes, but studies on its consequences emerged as a novelty. In fact, for the first time, the focus was no longer on the cause, once the CO_2 hypothesis was assumed to have been validated, and studies on the development of forecast scenarios began to emerge. These studies started, at the initial stage, from simple models, which were improved with new variables and from the capacity for data processing, which increased as the data collection procedures were structured. Other aspects of an environmental nature were also associated with a direct impact on the lives and survival of populations worldwide during this time.

Early during the period, Benton (1970) wrote about the role of CO_2 in climate evolution, basing the research on historical data [62]. On the other hand, Cess (1975) addressed the climate change theme, but from a global perspective, abandoning the regional perspective that was still primarily used [63]. During this time, comparative studies on different periods of the past also continued, with many trying to make this comparison based on fossil and sedimentological records. Kent et al. (1971) studied climate change in the north Pacific using ice-rafted detritus as a climate indicator, while Verguand-Grazzini et al. (1977) analyzed the stable isotopic fractionation, climate change, and episodic stagnation in the eastern Mediterranean during the Late Quaternary period [64,65].

Finally, works appeared relating the consumption of fossil fuels and the release of CO_2. However, this issue was still presented as a possibility, as referred in the work by Baes et al. (1977), where the authors stated that the possibility of severe consequences from the growing CO_2 release from fossil fuels required a much better understanding of the carbon cycle [66]. At the same time, studies were also initiated on the impacts that the increase in the concentrations of CO_2 in the atmosphere may have on other cycles, namely the hydrological cycle, as revealed in the study by Lettenmaier and Burges (1978) [67]. The relationship between different variables of an environmental nature and climate change became the focus of the work carried out, especially regarding the evolution of these variables and their adaptation to the new reality. For example, Gleick (1989) stated that growing atmospheric concentrations of CO_2 and other trace gases were leading to climate changes with important implications for the hydrologic balance and water resources [68]. In an attempt to elaborate a forecast model, Mitchell et al. (1990) studied the equilibrium climate change and its implications for the future [69]. Finally, the regions that could be most affected by a climate change scenario on a global scale were also beginning to be identified by Watson et al. (1998) to assert that vulnerability to climate change varies significantly from sector to sector [70].

2.5. The 21st Century

The early 21st century brought new trends to the research lines that began during this period. Concretely, a new era in the study of climate change began, in which some authors, such as Karl and Trenberth (2003), designated the topic as modern global climate change [71]. Work on future climate change projections has also intensified more recently with the study of Cubasch et al. (2001), for example, which was based on simulations made with global climate models applied to spatial scales of hundreds of kilometers and more [72]. Countries are creating research programs to quantify the problem, often solely, but also with a broader scope, sometimes covering wider geographical areas, other times focusing on specific themes associated, for example, with impacts on global food security. For instance, Wheeler and Von Braun (2013) analyzed the impact that climate change can have on the progress toward a world without hunger, as the impacts on crop productivity can have consequences on food availability [73].

Notwithstanding the large number of works that emerged from the beginning of this century, the disruptive moment occurred when works that addressed the problem not only from the perspective of its identification and even quantification, but rather from the perspective of its resolution, began to emerge. Indeed, numerous works with reference to the mitigation of climate change on the environment have emerged. Examples include works by Guero et al. (2010), Kovacevic et al. (2012), Pendley et al. (2016), Gaglio et al. (2019), or Indira and Srinagesh (2021) [74–78].

This period has also been witnessing the rise of interest on the part of researchers from other areas of knowledge, outside the scope of natural sciences, with work to be developed on the impacts of climate change on the economy and on social policies, among others. Some of these studies have focused on the impacts of climate change on the economy at a regional (country) level, such as the work by Mendelsohn and Neumann (2004), where the authors essentially dealt with climate change impacts on the economy of the United States [79]. On the other hand, many studies of a more global nature have emerged, already indicating a tendency for groups of researchers to always consider climate change as something that goes beyond the borders of countries. This was recommended by Tanner and Allouche (2011), who proposed a new climate change political economy and development, in which explicit attention is given to the way that ideas, power, and resources are conceptualized, negotiated, and implemented by different groups at different scales [80]. Sovacool and Linnér (2016) also focused on the political economy of climate change adaptation from a broader perspective, drawing on concepts in political economy, political ecology, justice theory, and critical development studies [81]. Batten (2018) addressed the impacts on macro-economics, stating that climate factors can directly affect economic outcomes, such as outputs, investments, and productivity, and understanding the economic consequences of climate change is a necessity not only for climate economists but also for a wider range of economic analysts [82]. Fekete et al. (2021) recently presented a review of successful climate change mitigation policies in major emitting economies and the potential of global mitigation, at a stage in which it is already possible to carry out comparative analyses on the mitigation policies implemented in five major emitting economies, such as China, the European Union, India, Japan, and the United States. Benadetti et al. (2021), on the other hand, addressed the risk of investment during a period of transition to a lower-carbon economy, since it is expected that the governments of major economies will act within the next decade to reduce greenhouse gas emissions, probably by intervening in the fossil fuel markets through taxation or carbon pricing [83,84].

This perspective on carbon taxation has been the subject of several recent studies, as it is this perspective that has aroused the interest of financial institutions. Crecente et al. (2021) are of the opinion that public funds are some of the tools used by countries in order to transform older and unsustainable growth economies into newer and sustainable development paths [85]. Stepanakis et al. (2021) introduced a new approach by including the circular economy concept of nature-based solutions for climate change adaptation [86]. The authors stated that while modern society enjoys the benefits of an economic growth that has never been seen before, at the same time, it is facing the existential threat of climate change, demonstrating that linear economic model cannot sustain actual life standards indefinitely.

Also in this period, approaches based on co-benefits have been presented, which relate the benefits from addressing problems originating from climate change and atmospheric pollution [87–89]. On the other hand, despite the relationship being evident, as verified by Markandya et al., there is not much evidence comparing the mitigation costs and economic benefits of air pollution reduction with alternative approaches to meet greenhouse gas targets [90]. These authors analyzed the extent to which health co-benefits can compensate mitigation costs of achieving the targets of the Paris Agreement (2 °C and 1.5 °C) under different scenarios in which the emissions reduction effort is shared among countries, in accordance with equity criteria previously established, and concluded that substantial health gains can be achieved from taking actions to prevent climate change.

3. Contributions from Different Areas of Knowledge

3.1. The Natural Sciences Approach

Without a shadow of a doubt, the natural sciences were the first group of disciplines that identified the problem of climate change and that studied it. There have been many different approaches over the last decades, and it is fair to emphasize the areas of meteorological and atmosphere sciences and oceanography. These were the ones at the forefront of identifying the problem in the first place, but secondly, also of identifying the causes, namely through the analysis of meteorological data and the determination of the chemical composition of the atmosphere and its monitoring. This monitoring allowed for the analysis of the evolution of concentrations of greenhouse gases in the atmosphere, with an emphasis on CO_2. From the moment there was a broad consensus that CO_2, or rather, the increase in CO_2 concentrations in the atmosphere, was the motto for triggering the imbalance within the earth system, leading to climate change, the different areas of knowledge that fall under the natural sciences have tried not only to quantify the impacts on ecological and environmental systems, but to also find ways of mitigating the effects.

Different natural sciences contributed to the global knowledge on climate change, each adding information and providing interpretations within its specialty. Each science, approaching the subject according to its perspective, had advantages and disadvantages for the evolution of knowledge about climate change. On the one hand, it provided answers that sometimes needed different approaches to understand the processes, causes, and consequences. On the other hand, monodisciplinary approaches sometimes do not allow for an understanding of the problem in its entirety, as the monodisciplinary perspective is usually supported solely by the principles and postulations of the scientific discipline itself.

For example, geology is probably, and parallelly to meteorological and atmospheric sciences, the science that has allowed for most approaches to be adopted, mainly due to the capacity of this science to relate the themes of the present with those of the history of the earth. This idea of relating climate variations along with the geological timescale, such as that presented by Farmsworth et al. (2019), Solomon et al. (2018), Alcalde et al. (2018), or Krissansen-Totton and Catting (2017), who presented approaches focused on geological cycles and with approaches on geological time scales, allowed for an understanding of the alternation and succession of events and cycles [91–94]. This analysis over geological periods is of particular importance for understanding the effects of climate change on systems. Kumar and Vermer (2021) focused on the geological records of climate change [95]. The authors assumed that the climate had been changing for billions of years with a regular shift from warm to cold, from glaciated to deglaciated, and from wet to dry and that these changes could be found in the fossil and sedimentological records, which can serve as a comparison for current phenomena and processes, following the uniformitarism principle [96]. For example, one of the mitigation measures that has been much discussed is the capture and sequestration of CO_2 in geological structures, as presented in several works, such as those by Soltanian and Dai (2017), Kuch (2017), Rao and Phadke (2017), Hassanpouryouzband et al. (2019), Middleton et al. (2020), and Yaw and Middleton (2021) [97–102]. For this possibility to become a reality, it is necessary that, after identifying the CO_2 emitters (sources), potential geological reservoirs (sinks), and candidate locations, the carbon capture and storage (CCS) process analysis must include the feasibility assessment and the estimation of the geological storage potential.

These issues are related to the prediction and modeling of events, which sciences, such as mathematics and physics, supported by computational sciences, present as complex, realistic simulation models that include an increasing number of variables, making them capable of recreating the reality of systems and showing how they behave when facing the variation of their components. These models are currently applied to regional issues, such as the study presented by Qin et al. (2017), where the authors used modeling to predict impacts of climate change on the potential distribution of an extremely endangered conifer species, since the authors understood that the analysis of detailed and reliable information about the spatial distribution of species provides essential information for species conservation management, especially in the case of rare species of conservation interest [103]. On the other hand, modeling has been mainly used in studies of a global nature where, through the analysis of one or several parameters, global scenarios were projected for extended time intervals, such as the cases presented by O'Gorman and Dwyer (2018), Vitousek et al. (2017), Doelman et al. (2018), Valipour et al. (2017), Lotze and Tittenson (2019), Deser et al. (2020), or Weyant (2020). As a common thread in all works, there was an attempt to predict events and their evolution, namely through the creation of scenarios that allow decision making and the choice of mitigating the effects of climate change [104–110].

With the evolution of information sciences, data mining, and data analysis, the use of machine learning processes for, for example, the evaluation of extreme events has become a reality, as it allows for the models themselves to replicate the reality of systems much more effectively. Numerous works have addressed the use of machine learning for tackling climate change. O'Gorman and Dwyer (2018), for example, stated that machine learning could be used to include new parameterizations directly from high-resolution model outputs. Crane-Droesch (2018) also used machine learning for climate change impact assessment [104,111].

Chemical and biological sciences have assumed an increasingly relevant role, mainly through the assessment of the impacts that climate change can have on the chemistry of ecosystems, such as pH and salinity, among others, but also on the level of physiological changes in living beings and how they may be affected, i.e., mainly, whether they will be able to adapt to the new conditions or not. This subject is of particular importance if the theme of food security is introduced, as presented by Bisbis et al. (2018) or Leisner (2020), where the focus is precisely on the impacts of climate change on crops [112,113]. The impacts on forests have also been extensively addressed in several works, as presented by Seidl et al. (2017), Morin et al. (2018), Popkin (2019), or Boucher et al. (2020). In these works, forests were presented and analyzed from different perspectives, namely from the perspective of productivity in a climate change scenario, as a source of raw materials for industry (wood pellets, pulp and paper, bioenergy, among others), in terms of the quality of natural forests, the preservation of ecosystems and biodiversity, and the quality of ecosystem service provision. In addition, and very significantly, regarding climate change mitigation, forests (and forest soils) can serve as carbon sinks, effectively contributing to the capture and storage of CO_2 [114–117].

As may be expected, meteorological sciences, atmospheric sciences, and oceanography, as pioneers in identifying and quantifying the problem, remain, without a doubt, at the forefront, mainly due to their ability to analyze meteorological phenomena. Due to the extreme nature that they have been acquiring, these phenomena are of great importance, as their increasingly frequent occurrence entails risks to the safety of people and goods all over the world [118,119]. Thus, these areas of knowledge contribute to the forecasting of events, making it possible for measures to be taken in advance and minimizing damage whenever possible. Vitart and Robertson (2018) presented the sub-seasonal to seasonal prediction project (S2S) related to the prediction of extreme events [120]. Bellprat et al. (2019) attempted to establish an analysis of public awareness regarding climate change and how extreme events can be efficiently classified and predicted [121]. Knutson et al. (2020) associated the occurrence of tropical cyclones with climate change assessments from the perspective of the projected response to anthropogenic warming [122]. Wang et al. (2021) presented an assessment of climate change on the monsoon regime and how this will impact the weather in southeast Asia [123]. All these perspectives are focused mainly on mitigating and predicting the development of events, especially extreme weather events or others associated with them, such as rural and forest fires.

3.2. The Approach of Social and Economic Sciences

The social and economic sciences group has only recently begun to contribute to the issue of climate change, and it is quickly understood why, since the effects of climate change have been felt more severely only in the last two decades, in such a way that it has just started affecting communities from an economic and social perspective. Currently (in recent decades), several activities have been affected by climate change and its impacts, to the point of changing the economic perspective of development, both of local communities and in a broader perspective, sometimes national or even transnational. For example, the effects on crops may lead to partial or total losses of expected yields, jeopardizing the food supply of populations and causing nations to be forced to go more frequently to international markets to meet their demands. In this way, countries that would be self-sufficient, or almost so, need to import products, disrupting their trade balance and making them dependent on external supplies and, most importantly, on price fluctuations. The same may be forecasted for other sectors, such as fisheries, forestry, livestock production, or one with the most significant impact on a social level, the access to drinking water. Concern with access of the population to drinking water acquires urgent contours, as this situation may be the origin of mass migrations, obliging increasingly larger groups to start marching in search of better livelihoods. These migrations most certainly will create imbalances in the communities that receive them, often on the verge of the limit and unable to accommodate those who arrive. Thus, conflicts between resident and migrant populations may be triggered, often based on ethnic differences. These vulnerable populations are then at the mercy of exploitation and human trafficking, and indeed, many cases have been reported and referenced by official bodies and NGOs.

It is relatively easy to associate negative economic factors with negative social impacts, as the creation of wealth, or lack of it, is easily associated with social problems. However, the economic impact of this type of population that lives in a subsistence/survival economy is also matched with the environmental impacts, such as, for instance, drought, insect plagues, or rural fires. Some negative impacts may be much more challenging to solve than a simple breakdown of the economic fabric, as populations lose their traditional way of life. The solution may involve, in limited situations, the cantonment of these populations in refugee camps, where social problems are intensified instead of being solved.

The economic perspective of the impacts of climate change emphasized some activities that acquire particular importance due to their scale. For example, the tourism industry has a growing weight, particularly on the most open economies in the world. However, the impact on developing economies, where tourism plays a determining role for economic growth and development, may be highlighted, since this sector already contributes to the balance of payments through the export of services and foreign exchange inflow into the country. It is an economic activity that is very dependent on weather conditions, and environmental conditions may also be much affected by climate change effects, driving tourists away. Dogru et al. (2019) analyzed the impacts of climate change on tourism and how the vulnerability of the sector and resilience may affect a country's entire economy [124].

The authors stated that fluctuating and extreme weather patterns are sensitive indicators of climate change, and these patterns may modify tourist activities and, consequently, the tourism industry is highly vulnerable to climate change.

Despite all the concerns that economic and social science studies have presented in the numerous research available, it should be noted that it is precisely the economic development that began with the industrial revolution that may be pointed out as one of the causes of climate change, mainly due to the production of energy using sources of energy of fossil origin. For this reason, and because economics are fundamental for the development of societies, the field of economic sciences should also contribute to the path of mitigation, presenting several alternatives. One of the paths assumed as the solution is the decarbonization of the economy through replacing fossil fuel energies with renewable sources. Papadis and Tsatsaronis (2020) stated that, in the context of recent discussions about climate change and energy transition, the competition among energy sectors for decarbonization options might lead to inconsistent environmental policies and public acceptance of energy production that may contribute to deep problems in the economy, instead of presenting a valuable solution [125]. This issue becomes even more relevant when there is a global energy growth that is outpacing the decarbonization capacity, leading to insufficient emissions reduction in developed countries, as presented by Jackson et al. (2018) [126]. This growing energy consumption has meant that the production of energy from renewable sources, instead of replacing fossil energy production, has been increasing the amount of fossil fuel available, thus boosting its consumption. To counteract this reality, on the one hand, there was the introduction of fees and taxes as an incentive for the reduction of carbon emissions. On the other hand, incentives that encourage the introduction of a price floor to drive low-carbon investments have also been proposed, as suggested by Edenhofer et al. (2017), Meckling et al. (2017), Rockström et al. (2017), or Lilliestam et al. (2021) [127–130]. All this research has pointed out that carbon prices in existing assets and pricing pollution and carbon in a climate change problem context, may help promote decarbonization.

Another path, or rather another need, identified and suggested by economic science is the proposal for the change from the traditional model of the linear economy to a model that creates an alternative for the use of more and more natural resources, through a new economic paradigm where all materials, in all stages, are reintroduced again into the production process. This new economic model, called circular economy, enables the reuse of materials to also contribute to the decarbonization of industrial processes through reducing energy and all materials consumption or through the energetic valorization of those materials. This new model also aims to increase the efficient use of the resources, as described by Durán-Romero et al. (2020) [131]. The circular economy model is considered one of the leading solutions for deaccelerating the negative impacts of human behavior on the environment, with several countries forcing its implementation. For example, Lausselet et al. (2017) documented the Norwegian waste-to-energy project case, while Christis et al. (2019) addressed the implementation at the city level of circular economy strategies and climate change mitigation in Brussels, and Preston et al. (2019) addressed the circular economy from an inclusive perspective for developing countries [132–134].

All these approaches led to the identification of another path, the so-called sustainable development. Sustainability based on three pillars—economic, social, and environmental—somehow combines all the issues raised so far. As presented by Nunes et al. (2019), this integrated approach makes it possible to face what is probably the most significant challenge humanity ever had. Indeed, the emissions of greenhouse gases are the leading cause accelerating climate change, and the solutions will pass through a perspective of sustainable development where the economy, now in a circular model, is based on the assumption of compliance and the importance of each of the pillars of sustainability [135].

3.3. The Human Sciences Approach

Human sciences are those that possibly generate the most confusion when associated with the study of climate change. However, what may seem strange at first sight can quickly be seen as a path through which it can bring contributions to the debate and the search for solutions. The human sciences, which are by definition associated with human creativity, encompass a set of disciplines where it is possible to collect information that allows for comparative studies on past events to be carried out, and thus, to analyze the causes and consequences of these events. The subjects that are currently taught in faculties of arts or faculties of letters around the world, such as history, archaeology, ethnography, human geography, cultural anthropology, or literature, among others, can and do contribute a lot to the clarification of situations that occurred in the past, which were related to climate change and that currently allow for the creation of scenarios and models. This perspective, which includes the use of all available approaches to understanding the phenomenon and its mitigation, has previously been defended by Bremer and Heisch (2017) in their review work on climate change research or by Siegner and Stapert (2020), where the authors acknowledged that it is a human issue requiring both technological and scientific solutions [136,137].

Werebbles (2021) also stated that there are many dimensions to look for in climate change, namely the underlying science and the responses to societal changes that are impacting societies economically, physically, and culturally [138]. For this author, it is also necessary to include the analysis of ethics, since, as stated by Goldman et al. (2018), to understand the broader epistemological and ontological policies of human dimensions of climate change, a political ecology approach can be adopted, informed by science and technology concepts and research on multiple ontologies [139]. Again, ethical and political questions have been raised regarding the way forward. Brooks (2020) stated that the global consensus is clear that human activity is mainly blamed for its harmful effects, but there is disagreement about what should be done and, significantly, the fact that decisions are often taken by more powerful nations, without considering the smaller ones, when they are often those who will directly suffer the consequences [140]. In other words, in addition to ethics, the inclusion of a moral perspective in political discourse and actions becomes urgent, as defended by Adger et al. (2017), who stated that the moral arguments and their prevalence in public discourse about climate change could contribute to the creation of a collective conscience and build on a significant theory and evidence of ethics and social awareness regarding the differentiation in vulnerability to the impacts of climate change [141].

4. Discussion

As seen so far, climate change has been the target of the most diverse studies and approaches, some of which present an opposite sense of opinion, including denial currents that refute the evidence presented by the majority. Despite this faction that denies the existence of climate change, the overwhelming majority believes in the evidence presented in the diverse works on the subject and is currently more concerned with finding solutions rather than trying to counteract these groups of weak arguments. However, as was also verified in the bibliographical analysis presented, there are different topics. Therefore, the opinions on the solutions and paths to be followed are also very diverse, leaving a broad spectrum open for discussion, not least because this discussion is carried out by participants from areas of knowledge that are increasingly distinct and diverse (from natural sciences to human sciences, passing through social and economic sciences).

It is precisely this diversity that, when the common path points to the search for solutions, encourages an interdisciplinary discussion that can foster a faster discovery of ways to mitigate the problems. In other words, an open view of the problem in which all areas of knowledge are considered, each one contributing with its different perspective of the problem, can enable the creation of a more complete and closer-to-reality model, which will serve as a starting point for the future, whether for the simple evolution of the current scenario without applying any measures, or for monitoring the evolution of different scenarios after the implementation of mitigation measures, which is precisely in line with the meaning given by Burroughs (2007), who considers this multidisciplinarity to define the type and intensity of the effects of climate change, but also the impacts and effectiveness of mitigating measures [142].

This multidisciplinary perspective presents itself as a product of the natural evolution of a theme that, after an initial period of development, reached a state of maturation whose foundations underpin the supporting knowledge, e.g., its origins and causes that were already found. However, this leaves a wide field of study on its consequences and interactions with other themes, mainly, what impacts climate change may have on other variables in the global system, and how these variables will react to and evolve with the changes that have occurred remains unknown, as stated by Harley et al. (2006), who added that anthropogenically induced global climate change has profound implications for systems and the interactions between them [143]. In other words, to acquire a global view of the problem in all its scope, there must be the contribution from all areas of knowledge that, when analyzing the theme of climate change in the light of the scientific method, can contribute new approaches and perspectives, which lead to the launching of new hypotheses for solving the problem or for mitigating its consequences.

The traditional distance that has always existed between the different areas of knowledge, namely between the areas of natural sciences and human sciences, is counterproductive regarding global issues such as climate change, as it is a theme in which the participation of all areas appears to be the path that can lead to a solution, or better, to solutions. Indeed, it is also understood that such a comprehensive, global, and diverse issue cannot be resolved with just one solution, but rather with the integrated and global combination of a set of solutions, and, as presented by Naustdalslid (2011), climate change interlinks with society because, unlike traditional environmental problems, modern environmental problems are internal to society and are societal problems as much as they are environmental problems [144].

The constitution of multidisciplinary teams seems to be, before any technical solution, the first step toward understanding the problem and understanding the different perspectives that the problem may present. The debate between different areas of knowledge, where each one contributes with a part of its specialty, must be seen as a function of adding factors. The result is superior to the simple sum of the parts, since this result should allow for a much broader, global, and comprehensive set of knowledge than the simple realization of several independent studies in each of the different areas of knowledge.

5. Conclusions

Climate change is the most prominent problem humanity faces, as it affects the planet on a global scale, not being limited to regions, nor choosing between which countries will suffer the consequences. Since it is an issue that is imminently within the scope of the field of natural sciences, the disciplines in this area of knowledge were the first to identify the problem and proceed with its quantification. However, with the maturation of knowledge and its evolution, other areas of knowledge, such as human sciences or social and economic sciences, have also started to contribute with new perspectives, allowing for new approaches to be adopted, thus contributing to the support of new hypotheses for the mitigation of the problem. The multidisciplinary approach presents itself as one that can contribute most comprehensively to the presentation of global solutions, with the contribution of all areas of knowledge framed within the scientific method.

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