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The 2 °C Global Temperature Target and the Evolution of the Long-Term Goal of Addressing Climate Change—From the United Nations Framework Convention on Climate Change to the Paris Agreement

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ABSTRACT

The Paris Agreement proposed to keep the increase in global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels. It was thus the first international treaty to endow the 2 °C global temperature target with legal effect. The qualitative expression of the ultimate objective in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) has now evolved into the numerical temperature rise target in Article 2 of the Paris Agreement. Starting with the Second Assessment Report (SAR) of the Intergovernmental Panel on Climate Change (IPCC), an important task for subsequent assessments has been to provide scientific information to help determine the quantified long-term goal for UNFCCC negotiation. However, due to involvement in the value judgment within the scope of non-scientific assessment, the IPCC has never scientifically affirmed the unacceptable extent of global temperature rise. The setting of the long-term goal for addressing climate change has been a long process, and the 2 °C global temperature target is the political consensus on the basis of scientific assessment. This article analyzes the evolution of the long-term global goal for addressing climate change and its impact on scientific assessment, negotiation processes, and global low-carbon development, from aspects of the origin of the target, the series of assessments carried out by the IPCC focusing on Article 2 of the UNFCCC, and the promotion of the global temperature goal at the political level.

1. Introduction

The ultimate objective determined by the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" [1]. As a framework convention, this expression only fixes the requirements of the stabilization of the concentration of greenhouse gases in the atmosphere in a qualitative manner, and does not define the quantitative level of concentration for avoiding "dangerous anthropogenic interference with the climate system." How to define a quantified long-term global goal to address climate change is one of the core issues for subsequent scientific assessment and international climate negotiation.

Previous Intergovernmental Panel on Climate Change (IPCC) assessment reports have made assessments of rising temperature and possible risks in the climate system under various emission scenarios. However, due to uncertainties in the science of climate change, limits in scientific cognition and development, the time lag and spatial difference between emissions and their consequences, and

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necessary value judgment other than scientific assessment for defining danger levels, the IPCC has never scientifically affirmed the indices that indicate "dangerous anthropogenic interference with the climate system," and thus cannot define the unacceptable extent of global temperature rise based purely on science.

Scientific research into the 2 °C temperature rise started a long time ago; however, the 2 °C global temperature target was not considered as the action goal until the decision of the Council of the European Union (EU) conference in 1996 [2]. After the Copenhagen Climate Change Conference in 2009 and the Cancún Climate Change Conference in 2010, limiting the global temperature rise to below 2 °C above pre-industrial levels became the consensus of the international community. In 2008–2014, the IPCC's Fifth Assessment Report (AR5) made a comprehensive assessment of the climate system change, risks, emission budget, and mitigation pathway choice of 2 °C global warming on the basis of the research results available. After scientific assessment and a series of political pushes, one of the three goals reached at the 2015 Paris Climate Change Conference was stated as "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" [3]. Thus, the long-term goal of addressing climate change has evolved from a qualitative expression of stabilizing the greenhouse gas concentration in the atmosphere, in Article 2 of the UNFCCC, to a global temperature target with specific value, in Article 2 of the Paris Agreement.

This article analyzes the evolution of the long-term goal for addressing climate change, and the related impact on future scientific assessments, negotiation processes, and global low-carbon development, from the aspects of the origin of the 2 °C global temperature target, the related IPCC conclusion for Article 2 of the UNFCCC, and the promotion of the global temperature goal at the political level.

2. Early scientific research related to the 2 °C target

Studies regarding the 2 °C temperature rise can be traced back to the 1970s, when an explorative study was carried out in the European natural and social sciences to push decisions related to climate change. According to the overview given by Randalls [4] on the history of the EU's temperature control goal, the proposal for the global temperature control goal was very strongly related to the scientific study of climate sensitivity. Equilibrium climate sensitivity (ECS) quantifies the response of the climate system to constant radiative forces on multi-century timescales. It is defined as the change in the global mean near-surface air temperature at equilibrium that is caused by a doubling of the atmospheric carbon dioxide (CO_2) concentration [5]. If the ECS is 2 °C, then the doubling of the CO_2 concentration (generally taken as 550 ppm) will result in a global average temperature rise of 2 °C [6]. In 1967, Manabe and Wetherald [7] used a heat balance model and estimated a temperature response of approximately 2 °C to doubling CO_2 concentrations; in subsequent climate change science, and particularly in the estimation of the climate system model, the doubling of CO_2 has been taken as the core scenario for calculation. Initially, the ECS value was estimated by experts, and in the subsequent IPCC's First to Third Assessment Reports, it was taken as 1.5–4.5 °C. In the IPCC's Fourth Assessment Report, ECS was determined as 2.0–4.5 °C [8]. However, on the basis of many subsequent studies, the IPCC's Fifth Assessment Report (AR5) made an elaborate analysis of this issue, considering it to be 1.5–4.5 °C, that is, extremely unlikely to be less than 1 °C and very unlikely to be greater than 6 °C [5]. With respect to mitigation, countermeasures and actions to address climate change involve a series of estimations and policy analyses on social and economic costs. In 1977, Nordhaus [9] made an explorative cost-benefit analysis of climate change using the CO_2 concentration-doubling scenario; subsequent cost-benefit analyses of addressing climate change began to take the doubling of CO_2 or the 2 °C scenario as the starting point of exploration, reaching many research conclusions [10].

In the 1980s, before the IPCC's First Assessment Report (FAR) was released, climate change studies mostly focused on the relationship between increased anthropogenic greenhouse gas emission and greenhouse gas concentration in the atmosphere, and the global average temperature, calling attention to possible threats from anthropogenic factors. However, there was insufficient basis to determine the indices that should be chosen and the specific figure that would be used as the global ultimate objective in addressing climate change. In addition, since addressing climate change involves complex fields, discussion at the political or policy level tends to give a relatively prudent expression of proposed reductions of greenhouse gas emissions, and to wait for further scientific research results [4]. At that time, some scholars proposed a study of the threshold value of climate change from wider perspectives, in order to determine the level at which climate change can be accepted or avoided; that is, they hoped to make a systematic assessment of various risks that may result from climate change, instead of paying attention only to carbon emission [11].

3. IPCC's First and Second Assessment Reports and decision of the European Council

In 1990, the IPCC released its FAR. Based on the progress of study in that period, the FAR pointed out that the emissions from human activities resulted in an obvious increase of the concentration of greenhouse gases in the atmosphere, aggravated the greenhouse effect, and caused the global near-surface air temperature to rise, thus inciting the international community to immediately effect political progress and discuss how to take action to deal with global climate change. In this report, the assessment was made under the "business-as-usual" emissions scenario (Scenario A), along with other scenarios with progressively increasing levels of the controls (Scenarios B, C, and D); these scenarios held that in around 2025, 2040, 2050, and 2100, respectively, the equivalent CO_2 would be two times that of pre-industrial-revolution levels, and the global average temperature would rise by 0.1–0.3 °C per decade. In order for the concentration to remain stable at the level of that period (1990), it would be necessary to immediately reduce the anthropogenic emission of greenhouse gases (mainly CO_2) by 60%, and reduce methane by 15%–20% [12]. The IPCC's FAR placed emphasis on the rising temperature effect due to the anthropogenic emission of greenhouse gases; the scientific basis was insufficient at that time to formulate suggestions for a specific goal. Considering that addressing climate change involves wide and complex fields, the UNFCCC was formed under the encouragement of the FAR, and established the qualitative expression of the ultimate objective.

As an important scientific support for the UNFCCC's negotiation process, the IPCC included an examination of approaches to the realization of Article 2 of the UNFCCC in the Second Assessment Report following a resolution of the Executive Council of the World Meteorological Organization. In addition, the IPCC specifically formulated a synthesis report to present information on the scientific and technical issues related to interpreting Article 2 of the UNFCCC [13]. In fact, since the IPCC's Second Assessment Report (SAR), providing scientific information to assist the quantification of the long-term goal for the UNFCCC's negotiation has been an important task in the IPCC's scientific assessments. According to the SAR published in 1996, the scientific, technical, economic, and social science literature does suggest ways to move toward the ultimate objective of the UNFCCC, but uncertainties remain for the judgment of what constitutes dangerous anthropogenic interference with the climate system and what needs to be done to prevent such interference. In the SAR, the conclusions related to the 2 °C temperature rise are that for the mid-range IPCC emission scenario (IS92), assuming the "best estimate" value of climate sensitivity and including the effects of future increases in aerosol concentrations, models project an increase in the global mean near-surface air temperature relative to 1990 of about 2 °C, an increase in sea level of about 50 cm, a greater risk for small islands and low-lying coastal areas, and extensions of the geographical range and season for vector organisms by 2100.

The clear proposition that the global average temperature should not exceed 2 °C above the pre-industrial level was first raised in the decision of the European Council's conference in 1996 [2]. Based on the IPCC's SAR and the IS92, and after considering the possible risks of climate change, the European Council held that global greenhouse gas emissions should be halved from the 1990 figure, and that CO_2 concentration in the atmosphere should be stabilized at approximately 550 ppm (twice the pre-industrial level), so as to realize the target of limiting the global average temperature rise to 2 °C above pre-industrial levels (the goal for global mitigation cooperation). The EU did not give a reason for this decision, and its definitive expression did not find support in the IPCC's SAR. The proposition does not currently receive wide international recognition.

4. IPCC's Third and Fourth Assessment Reports and promotion at the G8 Summit

In 2001, the IPCC released its Third Assessment Report (TAR), which provided newer and stronger evidence to prove that most of the warming observed over the last 50 years is attributable to human activities (probability > 66% but < 90%). The impacts of climate change include both advantages and disadvantages, but the larger and quicker the change, the more obvious the leading position of adverse impacts. In the Synthesis Report of the IPCC's TAR [14], Question 1 pointed out that the natural, technical, and social sciences can provide essential information and evidence needed for decisions on what constitutes "dangerous anthropogenic interference with the climate system." However, such decisions are value judgments determined through sociopolitical processes that consider development, equity, and sustainability, as well as uncertainties and risk. Since both the magnitude and rate of climate change are very important, the basis for determining what constitutes "dangerous anthropogenic interference" would vary in different regions, depending on local characteristics, as would the consequences, adaptation, and mitigation capacity of the impact of climate change.

Notably, the TAR introduced five "reasons for concern," thus conceptually expressing the reasons for emphasizing the risks of climate change (Fig. 1) [14]. These five reasons include: ① risks to unique and threatened systems; ② risks from extreme climate events; ③ distribution of impact; ④ aggregate impact; and ⑤ risks from future large-scale discontinuities. In Fig. 1, the global average annual temperature represents the magnitude of climate change; however, it is pointed out that future impacts will be a function of the magnitude and rate of global and regional changes in mean climate, climate variability, extreme climate phenomena, socioeconomic conditions, and adaptation, depending on multiple aspects. The TAR also stated that in the setting of the strategy, goal, and timetable to avoid "dangerous anthropogenic interference with the climate system," it is necessary to consider inertia and uncertainty in the climate, ecological, and socioeconomic systems; assess possible risks of climate change from more comprehensive and intuitive perspectives; and relate the risks with global mean near-surface air temperature. As shown in Fig. 1, although the TAR did not define which kind of temperature rise should become the index of "dangerous anthropogenic interference with the climate system," it showed that global warming above 4 °C would pose extremely large risks. These five reasons for concern have been used consistently in subsequent IPCC assessments.

In 2007, the IPCC released its Fourth Assessment Report (AR4), stating that the five "reasons for concern" identified in the TAR remain a feasible framework for considering critical vulnerabilities. In the AR4, many risks are affirmed with higher confidence. For example, the report stated that regarding "unique and threatened systems," observed climate change has had an impact on the polar and high mountain communities and ecosystems; if the global average temperature becomes 1.5–2.5 °C higher than that in 1980–1999, approximately 20%–30% of the plant and animal species assessed so far are likely to face increased risks of extinction; and an increase of about 1–3 °C in the sea surface temperature would result in more

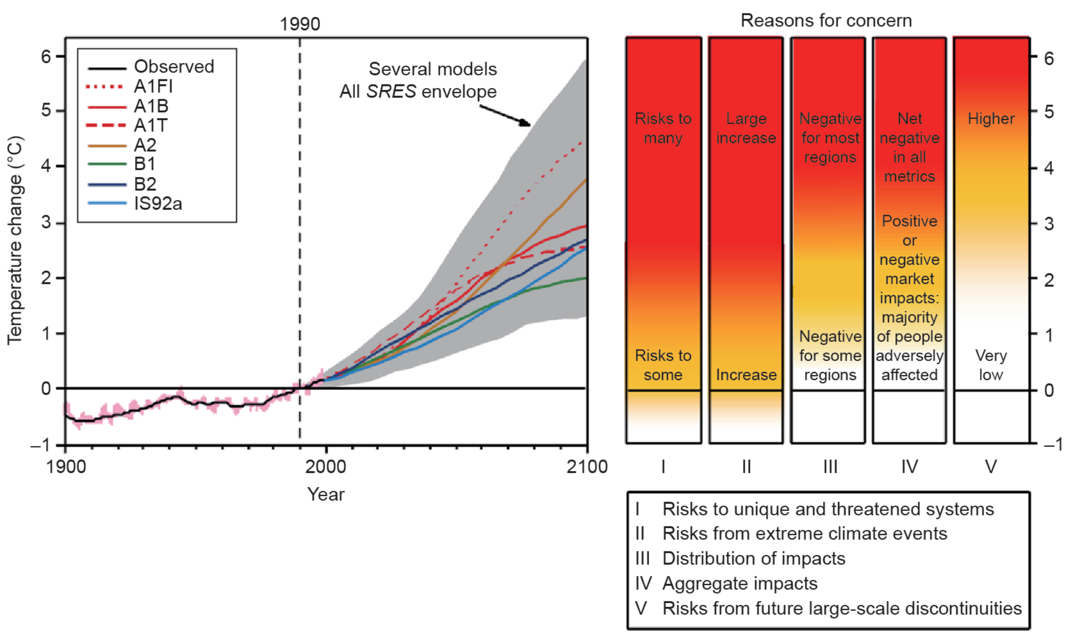

Fig. 1. IPCC's TAR: Corresponding figures for assessment and impact risks. *SRES*: *Special Report on Emissions Scenarios*; A1FI, A1B, A1T, A2, B1, and B2 are alternative development paths and related greenhouse gas emissions scenarios provide in *SRES*; IS92a: Scenario a in IPCC emission scenario 1992. Source: Ref. [14], Fig. SPM-2 in *Summary for Policymakers*, *Climate Change 2001*: *Impacts, Adaptation, and Vulnerability*.

frequent coral bleaching and widespread mortality. Regarding extreme weather, the projected droughts, heat waves, floods, and their adverse impacts would increase. Regarding the distribution of impacts, regions with the weakest economies are often the most vulnerable to climate change, and the low-latitude and less-developed regions face increasing risks. Regarding aggregate impacts, the net cost of impacts with increased warming would increase as time goes on. And finally, regarding the risks of large-scale singularities, global warming lasting for many centuries would result in a rise in the sea level, which would be much larger than that observed in the 20th century; melting of the Greenland and Antarctic ice sheets could occur on century timescales.

The IPCC's reports should be neutral with respect to policy; thus, the IPCC only provides comprehensive, objective, open, and transparent assessment reports, and leaves readers to make their own judgments. It does not define "dangerous anthropogenic interference with the climate system." Compared with the previous three assessment reports, the AR4 provided a clearer and more intuitive explanation and expression of risks, as shown in Fig. 2 [15]. The important progress at this stage is that the scientific community has confirmed the importance of risk assessment and value judgment of climate change for the determination of the long-term goal, thus pushing the discussion of a global temperature goal into the political process.

In February 2005, at the request of the European Council, the European Commission reported on a cost-benefit analysis of the medium- and long-term emission reduction strategy and goal [16]. This report assumed that, until 2100, the global average temperature would rise by 1.4–5.8 °C compared with that in 1990, and the European temperature would rise by 2.0–6.3 °C. If the temperature rise could be controlled to within 2 °C, the benefits would be sufficient to offset the cost of the mitigation policy; if the temperature rose over 2 °C, it would probably result in quicker and more unpredictable climate response, and even irreversible and disastrous consequences. Based on this report, European Parliament reiterated the 2 °C target in the same year, and held that the TAR's conclusion had indicated the necessity to strengthen emission reduction and limit global risks [17]. In July 2005, the British Prime Minister Tony Blair asked the Gleneagles G8 Summit to list climate change as one of two priority themes, as the UK served as the rotating president of the G8 Summit. However, the G8 did not reach consensus on a global temperature goal.

In 2006, Sir Nicholas Stern (the economic consultant for the British Prime Minister) published *The Economics of Climate Change: The Stern Review*, in which he wrote that if no timely actions were taken in the following decades, climate change would result in the loss of 5%–20% of global GDP; however, if immediate and powerful global mitigation actions were taken to stabilize the concentration of greenhouse gases in the atmosphere at 500–550 ppm, the cost could be controlled at about 1% of global GDP per year [18]. After the publication of the IPCC's AR4, climate change became one of the key topics of the G8 Summits in Heiligendamm (Germany) in 2007, in Toyako (Japan) in 2008, and in L'Aquila (Italy) in 2009. The final declaration made by the L'Aquila G8 Summit expressed willingness to limit the global temperature rise to within 2 °C of pre-industrial levels along with other countries, so that the global greenhouse gas emissions would be reduced by 50% before 2050, and so that developed countries should reduce emissions by 80% or more by 2050. Although the scientific significance of taking a 2 °C temperature rise as the goal was unclear [19], a strong push from the EU at the

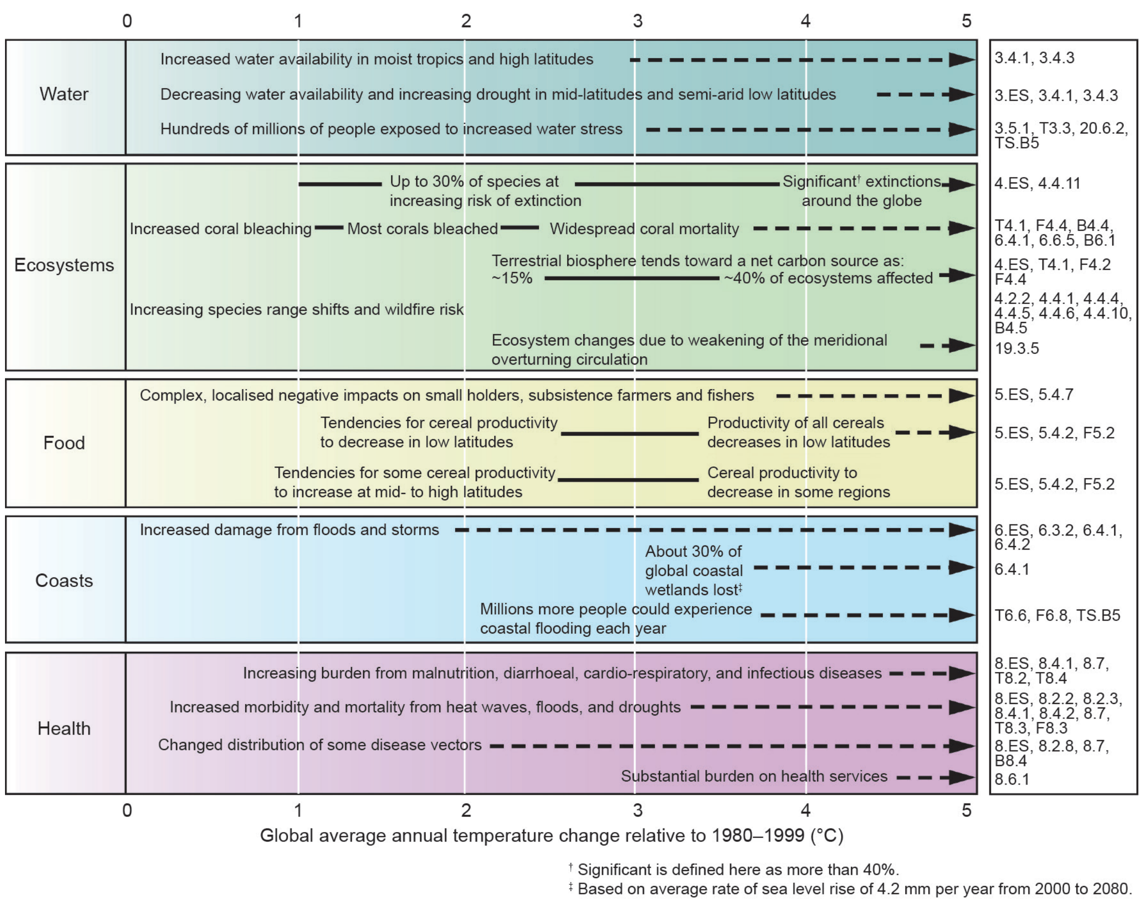

Fig. 2. IPCC's AR4: Impact examples related to rising global average temperature. Source: Adapted from Ref. [15], Fig. 3.6 in *Climate Change 2007: Synthesis Report*.

political level extended the discussion of the global temperature goal from the scientific level to the international political and diplomatic levels.

5. From the Copenhagen Climate Change Conference to the Paris Climate Change Conference

The 35th G8 Summit in July 2009 and the subsequent Major Economies Forum on Energy and Climate (MEF) were held just before the Copenhagen Climate Change Conference, attracting worldwide attention. The leaders of the 17 participating members of the MEF delivered a joint declaration requiring that the results of the Copenhagen Climate Change Conference comply with the UNFCCC's goal and scientific requirements, thus unanimously recognizing that the global average temperature rise shall not be over 2 °C higher than pre-industrial levels [20]. It was the first time that a consensus had been reached between the main developed and developing countries regarding the 2 °C target. This MEF Summit delivered a strong political signal to the Copenhagen Climate Change Conference at the end of the same year. Thanks to the efforts of major powers, the 2 °C global temperature target was written into the Copenhagen Accord. Since the Copenhagen Accord was not unanimously recognized by all parties, it did not have legal effect. Part I—"A shared vision for long-term cooperative action"—of the Cancún Agreements formulated at the 2010 Cancún Climate Change Conference stated that nations should work together in "… reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above pre-industrial levels, and that Parties should take urgent action to meet this long-term goal … strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5 °C" [21]. The 2 °C global temperature target was a global political consensus from then on.

Since 2009, the political consensus of the 2 °C global temperature target has had a major impact on the international scientific community. Corresponding climate change trend simulation, impact assessment, and emission reduction path studies have taken it as the object of scenario studies. Since the IPCC assessment is based on peer-reviewed scientific research, the AR5 of the IPCC fully assessed the scientific research related to the 2 °C global temperature target in 2014. A report from the AR5 Working Group I made the first quantitative assessment on the cumulative emission space under the 2 °C global temperature target. The global average surface warming in the 21st century and subsequent period would mainly depend on the cumulative emission of CO_2. In this report, transient climate response to cumulative carbon emissions (TCRE) is defined as the global mean near-surface air temperature change per 1000 GtC (the shorthand for gigatons of carbon) emitted into the atmosphere. It quantifies the transient response of the climate system to cumulative carbon emissions. According to the AR5, TCRE is likely to fall within the range of 0.8–2.5 °C per 1000 GtC; this applies for cumulative emissions up to about 2000 GtC, until the time temperatures peak. Limiting the warming caused by anthropogenic CO_2 emissions alone with a probability of > 33%, > 50%, and > 66% to less than 2 °C since the period between 1861 and 1880 will require cumulative CO_2 emissions from all anthropogenic sources to stay between 0 and about 1570 GtC (5760 $GtCO_2$), 0 and about 1210 GtC (4440 $GtCO_2$), and 0 and about 1000 GtC (3670 $GtCO_2$) since that period, respectively; however, an amount of 515 (445–585) GtC (1890 (1630–2150) $GtCO_2$), had already been emitted by 2011 [5].

Based on the assessment of different sectors, regions, and key risks, the AR5 Working Group II pointed out that in case of a temperature rise of 1 °C or 2 °C compared with pre-industrial levels, the risks incurred by the world would be on the medium to high level, and in case of a temperature rise over 4 °C or even higher, the risks would be high or very high [22]. The AR5 Working Group III provided the most viable scenario to achieve the goal of keeping the global temperature rise until 2100 within 2 °C compared with the pre-industrial level: to limit the greenhouse gas concentration to 450 ppm CO_2e (the shorthand for carbon dioxide equivalents). It will be necessary to reduce the global greenhouse gas emissions until 2030 to 50 Gt CO_2e, to reduce global greenhouse gas emissions in 2050 by 40%–70% compared with the 2010 level, and to limit greenhouse gas emissions to net zero in 2100. The Report also assessed the development and technical choice in sectors such as energy, transport, building, human settlements, infrastructure, and spatial planning under this goal [23].

In summary, the IPCC's AR5 Synthesis Report defined the relationship between cumulative anthropogenic emissions of CO_2, global average temperature change, and the potential risks to the climate system until 2050. As shown in Fig. 3 [24], the risk level indicated by any given global temperature rise and the five major reasons corresponds to the cumulative anthropogenic emissions of CO_2 within a certain range.

The AR5 did not clearly define the indices and values constituting "dangerous anthropogenic interference with the climate system." In fact, since it is highly sensitive for parties to consider the related information about Article 2 of the UNFCCC, when the AR5 Synthesis Report was reviewed and adopted at the IPCC's 40th Session in October 2014, the textbox providing information related to Article 2 of the UNFCCC was finally abandoned, and only the Preface of the Synthesis Report stated that the Report included information related to Article 2 of the UNFCCC. Nevertheless, the assessment conclusions drawn by the AR5 regarding the 2 °C global temperature target, as well as the scientific information required for decision-making (including emission budget, pathway, and technical choice) strengthened the scientific basis for this political consensus.

In 2011, the Durban Climate Change Conference established the Ad Hoc Working Group on the Durban Platform for Enhanced Action (hereinafter referred to as the Durban Platform). It launched the negotiation for an international mechanism applicable to all parties after 2020, and decided to strive for an ambitious global emission reduction goal with the timeframe for global greenhouse gas emission peaking before 2050, taking into account reports such as the IPCC's AR5 [25].

From the launch of the Durban Platform to the conclusion of the Paris Agreement at the Paris Climate Change Conference, parties held different views about the expression of the UNFCCC's principles, the scope of the agreement, and the legal form of the final results; however, the 2 °C global temperature target seemed indisputable. The bilateral joint declarations delivered by China with the US, France, and the EU before the Paris Climate Change Conference had mentioned that it was required to "consider a global temperature goal within 2 °C."[†] To a certain extent, this represented the consensus of China and the developed countries with respect to this issue. Based on scientific assessment and a series of political pushes, the Paris Agreement finally considered "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels," as one of three goals of the Agreement, and the 2 °C global temperature target was formally included in the international treaty with legal effect. During the 2016 Opening for the Signature of the Paris Agreement, held at the United Nations Headquarters in New York on 22 April, 175 parties (174 countries

[†] US-China Joint Presidential Statement on Climate Change on November 12, 2014, in Beijing, China; EU-China Joint Declaration on Climate Change on June 29, 2015, in Brussels, Belgium; France-China Joint Presidential Statement on Climate Change on November 2, 2015, in Beijing, China.

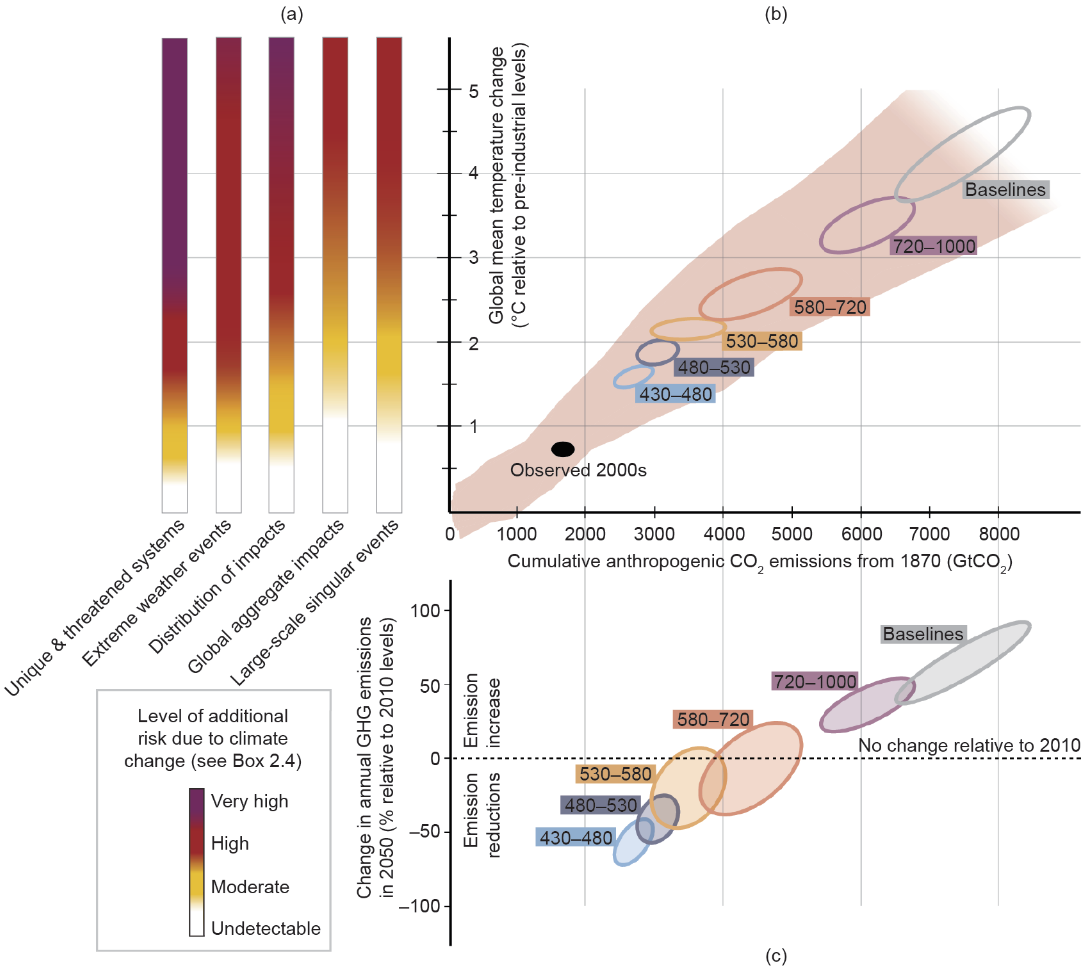

Fig. 3. The relationships among cumulative anthropogenic emissions of CO_2, global average temperature change, the potential risks to the climate system, and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across "reasons for concern" (a) would imply a limit for cumulative emissions of CO_2 (b) which would constrain annual GHG emissions over the next few decades (c). Source: Ref. [24], Fig. SPM.10 in *Climate Change 2014: Synthesis Report*.

and the EU) signed the Agreement, which created a record for the most countries at the first opening day of an international treaty.

6. The way forward

Since the UNFCCC came into effect, negotiation about the long-term goal has been a continuous process of concretization and quantification. The Paris Agreement was the first international treaty to give the 2 °C global temperature target legal effect. The efforts in Article 2 of the UNFCCC on avoiding "dangerous anthropogenic interference with the climate system" have evolved into the performance of Article 2 of the Paris Agreement: keeping the global temperature rise within 2 °C compared with the pre-industrial level, and pursuing a limit of 1.5 °C. The global temperature goal is a political consensus based on scientific assessment. It reflects not only a scientific basis, but also political need, including a certain degree of flexibility and a guarantee of the effectiveness of the response. Within this relatively detailed goal, the bottom-up Nationally Determined Contribution (NDC) and a systematic global stock-taking every five years from 2023 on will help the international community to increase the level of ambition in a gradual and orderly manner, and will significantly help the implementation of the Paris Agreement.

It should be further emphasized that after the adoption of the global temperature goal, the corresponding greenhouse gas mitigation goal, emission budget, and emission reduction pathway will become inevitable issues for scientific research and negotiation. Since there is still uncertainty in the study of the current earth system model, emission reduction pathway, and emission reductions, it is still quite difficult to affect the conversion process from the global temperature goal to the emission reduction actions of the parties [26]. When the EU proposed the 2 °C global temperature target, it actually raised the suggested goal of reducing the global greenhouse gas emission in 2050 by 50% compared with 1990. Since this goal was radical, and since there is scientific uncertainty, there was a very large discrepancy among the parties. The IPCC's AR5 Working Group III also pointed out that compared with the 450 ppm scenario, if the greenhouse gas concentration at the end of this century is maintained at 500 ppm CO_2e, there is still a possibility of realizing the 2 °C global temperature target, but only by allowing atmospheric concentrations of greenhouse gases before 2100 to transiently exceed 530 ppm CO_2e and then moving back to the lower level concentration, which would require the implementation of more ambitious deep-emission reduction in the later period of this century. It means that there is more than one choice in fixing the atmospheric concentrations of greenhouse gases, the cumulative emission budget, and the emission reduction pathway corresponding to the global temperature goal. In subsequent system design, there is still a huge challenge to reach a consensus in the issues above, as well as regarding responsibility sharing; more support is also required from natural and social sciences with regard to climate change.

Since small island states and the least-developed countries are concerned that the 2 °C global temperature target still poses risks to the most vulnerable regions, they favor a further enhancement of the global temperature goal from 2 °C to 1.5 °C. Considering this, the Paris Agreement proposed to make efforts toward the 1.5 °C temperature goal while affirming the 2 °C global temperature target. However, in the scientific community, there is no systematic assessment on the climate system risks and realization pathway for the 1.5 °C temperature goal. The IPCC has accepted the invitation of the Paris Climate Change Conference to formulate a special report regarding the impact on the climate system under the 1.5 °C temperature goal and the global greenhouse gas emission path for achieving this goal, in the sixth round of assessment reporting. Generally speaking, this is a more ambitious goal. No matter how the IPCC concludes its special report, this goal means that countries need a quicker low-carbon transformation.

It should be pointed out that climate policy decision-making under such a huge uncertainty is a challenge. When the IPCC tries to understand the climate system and provide recommendations to policy makers, it pays high attention to reducing the uncertainty of attribution in society toward climate change, and to providing directions to guide policy makers on how to make decisions under uncertainties; for example, cost-benefit analysis and cost-effectiveness analysis can enable decision makers to examine costs and benefits that would reduce uncertainty in climate policies, and formalized expert judgments and elicitation processes could improve the characterization of uncertainty for the design of climate change strategies [27]. One of the key concepts in dealing with these uncertainties, as we pointed out previously, is that although the temperature goal set by policymakers is more a political consensus on the basis of scientific assessment than science itself, it does provide a firm direction for action. Although uncertainty still exists, with this understanding, all countries and civil societies can take positive action to address climate change, especially if such action would be a no-regret choice; this is also in line with the principle of precaution set out in the UNFCCC.

The adoption of the Paris Agreement has manifested the determination and wisdom of global cooperation to address climate change and low-carbon and sustainable development. It represents the new starting point of the international system in coping with climate change. As described in the *Summary for Policymakers* of the IPCC's TAR, decision-making on climate change is substantially a gradual process with universal uncertainty. Decision-making must address these uncertainties, including nonlinear risks and/or irreversible changes, and shall balance the risks from other inadequacies or radical actions [14]. The 2 °C global temperature target adopted by the Paris Agreement has guided future action on mitigation and adaptation, low-carbon investment, and technological development, including the green information and communication technologies that are crucial for addressing climate change and synergic sustainable development issues in a big data era [28]. Although there are many challenges in the subsequent system design and international cooperation, huge historic progress has been made.

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Compliance with ethics guidelines

Yun Gao, Xiang Gao, and Xiaohua Zhang declare that they have no conflict of interest or financial conflicts to disclose.

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