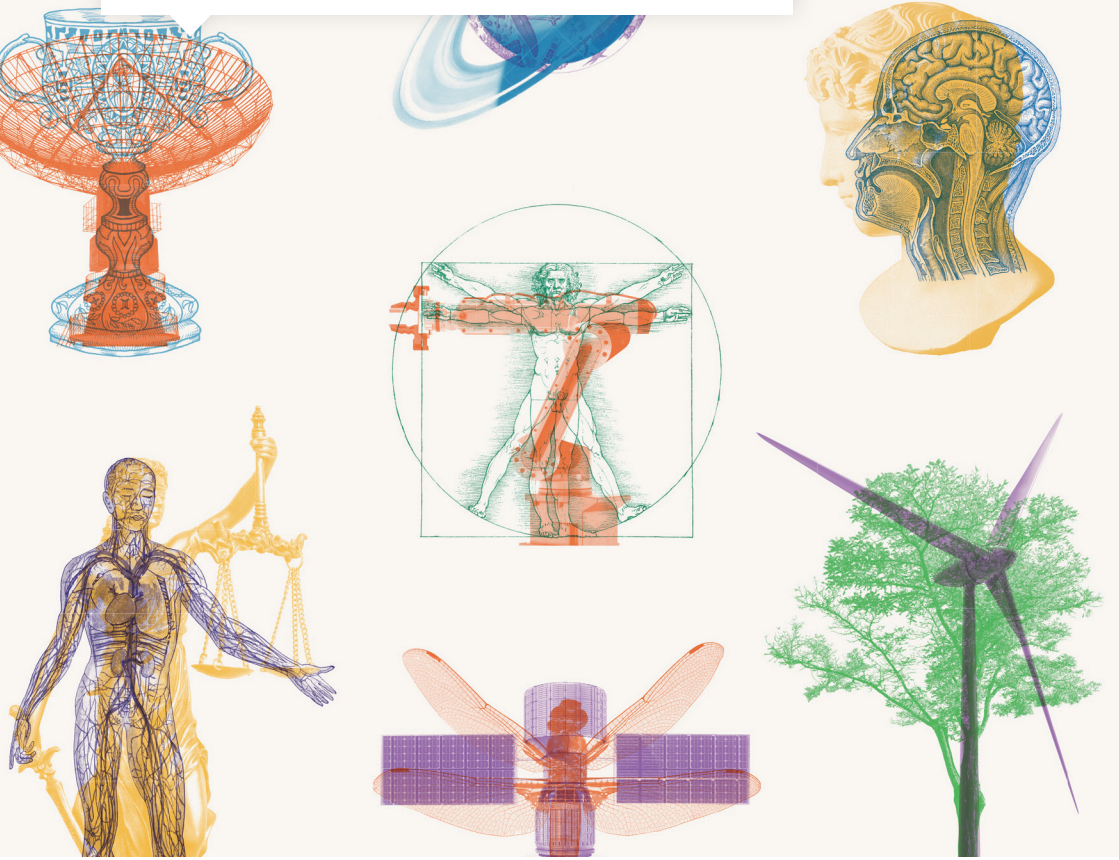
How will we reach the Paris climate goal?

Towards a broader analysis of policy and ambition

Prof. M.G.J. den Elzen



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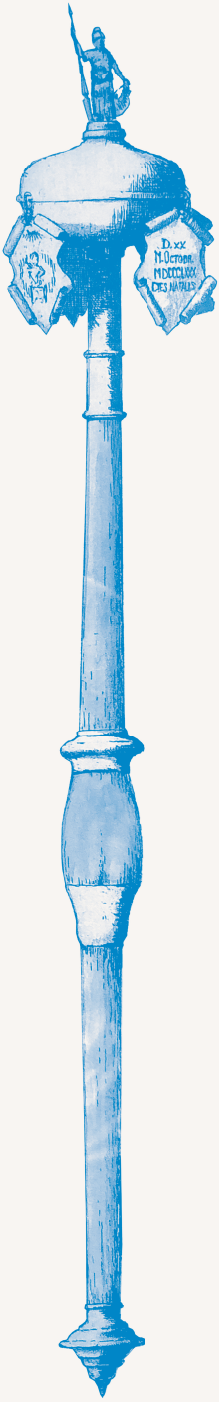

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Towards a broader analysis of policy and ambition

Inaugural lecture delivered on the occasion of the acceptance by special appointment, of the International Climate Policy and Mitigation of Climate Change Chair, instituted by the Netherlands Environmental Assessment Agency, at the Faculty of Science of the Vrije Universiteit Amsterdam, on 30 October 2025.

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Prof. Dr. Michel den Elzen

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1. Introduction

Mr. Rector Magnificus, colleagues, esteemed audience, family, and friends,

What an honour and pleasure to see you all here. I'm standing here as special professor International Climate Policy and Mitigation of Climate Change at the Vrije Universiteit Amsterdam. Of course, you don't become this overnight. I therefore want to take you back in time with me in this inaugural lecture, and briefly look at the path that led me to this honourable and special position. Then, I hope to interest you in my fascinating area of expertise by telling you more about the history of international climate policy and explaining a bit about what I want to research in the coming years.

So, first of all, let's go back to how it all started. It is 1988, I am 23 years old, and I'm studying mathematics at the Vrije Universiteit. I have an internship at the National Institute for Public Health and the Environment (RIVM) in Bilthoven, where I get to research the societal consequences of climate change for the Netherlands. This research introduced me to the IMAGE model, which was in its infancy back then. The objective of the IMAGE model is to analyse, on a global scale, what are the causes and consequences of the issue of climate change, ranging from (but not limited to) greenhouse gas emissions, global mean temperature increase and sea level rise.

A whole new world opened up to me. That time was truly a pioneering period for these integrated climate models. Indeed, the IMAGE model was one of the first integrated climate model in the world and I've been captivated by it ever since.

I officially started working at the RIVM in 1990 to further develop IMAGE. Together with Jan Rotmans and Rob Swart, we made IMAGE scenarios for the Intergovernmental Panel on Climate Change (IPCC) and then, in 1993, I completed my PhD on analysis with the IMAGE model at Maastricht University (den Elzen, 1993).

These were different, more hopeful times. Back then, we believed that countries could still reduce greenhouse gas emissions worldwide. In the 1990s, for example, we developed scenarios to explore what would happen if we could not reduce these emissions and reductions would be postponed until that faraway year of 2020. At the time, this was considered an extreme idea. Unfortunately, we now know that global emissions have only increased over the past few decades.

There were, however, some silver linings. One example is the well-known Paris Climate Agreement of 2015, which demonstrated how many countries are taking climate change seriously, who want to limit the rise in temperature and really want to reduce greenhouse gas emissions (UNFCCC, 2015). Indeed, more than 190 countries formulated specific reduction goals in their climate plans.

At PBL Netherlands Environmental Assessment Agency, where I've worked since 2008, I analyse such reduction proposals by countries together with my colleagues, as well as the measures these countries want to take to limit the consequences of climate change. We particularly analyse the progress of climate policies formulated by G20 economies and the global emissions gap between their efforts and what is needed to reach the Paris climate goal. With our analyses, we contribute to international climate reports, such as the renowned IPCC reports and the Emissions Gap Reports by the United Nations Environment Programme (UNEP), which have been published annually since 2010.

The IMAGE model still plays a crucial role in our work. Since my internship in the 1980s, IMAGE has evolved into an authoritative model for analysing the environmental consequences of our human activities.

The global conclusions of our and other climate analyses are generally well-known: the current national reduction targets and their implementation are insufficient to reach the Paris climate goal. The ambitions of many countries are far too low, and their policy lacks focus.

This is enough to discourage anyone, but it also provides determination. As special professor International Climate Policy and Mitigation of Climate Change at the Vrije Universiteit Amsterdam, I therefore continue with my research of analysing climate policy and policy scenarios, in order to answer the question: how do we reach the Paris climate goal?

I would like to elaborate on how I want to give shape to my position as special professor and my research. First of all, I want to discuss international climate policy and the progress that has been made already over the past few years.

2. International climate policy in its historical context

Since the 1990s, there have been efforts to make global agreements at international climate conferences. In the climate world, the conferences at Rio de Janeiro, Kyoto, and Copenhagen are generally well known. But a real breakthrough in international climate policy came in 2015, when the conference was organised in Paris. What had been unheard of until then happened: 195 countries and the European Union signed an agreement to agree to limit global temperature rise to 'well below' 2 degrees Celsius, preferably even 1.5 degrees Celsius. The agreement aims for greenhouse gas emissions to peak rapidly and then reduce them to zero in the second half of this century. It offers a binding foundation for future climate policy. Despite the consensus about a global objective, the implementation of the agreement takes place at the national level through voluntary contributions, known as Nationally Determined Contributions or NDCs. NDCs are climate plans in which countries indicate with how much they want to reduce their emissions and when. These plans were already submitted before the Paris Climate Summit. Nonetheless, it was already evident in

Paris that the impact of these voluntary concessions to reduction would be insufficient to reach the established climate goals. This was confirmed in 2016 in a publication by researchers in *Nature,* which included Joeri Rogelj, Niklas Höhne, and myself (Rogelj et al., 2016).

To tackle this problem, the signing parties agreed to frequently evaluate the impact of NDCs on global emissions and increase ambition where necessary. This happens at the hand of the **Global Stocktake** and the **ambition mechanism**. Ultimately, these two instruments have to ensure that the collective policy by countries is sufficient to reach the Paris climate goal.

As a result, we held climate negotiations in Glasgow in **2021**, which led to several significant objectives, including guaranteeing climate neutrality, realising net-zero emissions around the middle of the century, and reaching the 1.5-degree target. In the lead-up to Glasgow, many countries announced renewed and tightened NDCs as well as net-zero emission targets.

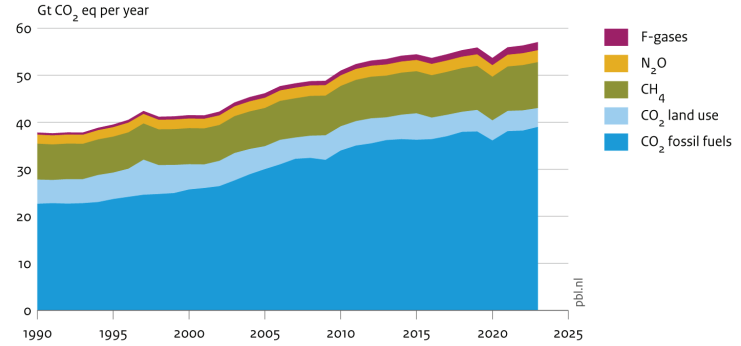
3. Progress of global climate policy

Even though numerous countries all over the world have developed climate policy, far too many greenhouse gases are still being emitted. I will show you why we're not on track to reach the Paris climate goal, based on the UNEP Emissions Gap Report of 2024 (UNEP, 2024). These Gap reports are published once a year and offer an evaluation of global climate policy. They analyse the emissions gap between the climate pledges countries made and what is actually needed to reach the Paris climate goal. I have acted as lead author on these annual reports since 2010, alongside colleagues like Takeshi Kuramochi, Niklas Höhne, Joeri Rogelj, Taryn Fransen, and Anne Olhoff (editor).

Global greenhouse gas emissions are consistently increasing at an alarming rate. In 2023, total emissions reached a record of 57.1 gigatonnes CO_2-equivalents ($GtCO_2eq$), which was an increase of 1.3% relative to 2022 (see Figure 1). This percentage exceeds the average annual increase of 0.8% in the decade before the COVID-19 pandemic (2010-2019). There is an increase in emissions of all gases, particularly fossil CO_2 emissions.

The six largest emitters, on a global scale, are China (30%), the United States (11%), the European Union and India (each 7%), the Russian Federation (5%), followed by Brazil. In 2021, these countries were, together with international transport, responsible for 65% of global emissions, while the G20 economies were responsible for approximately 75%. The low-income countries contributed less than 4% and smaller island states less than 1% (see Figure 2).

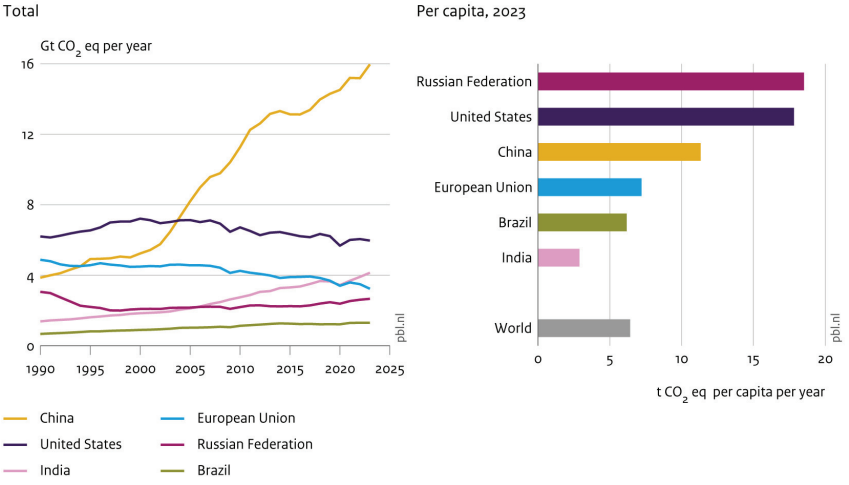
Global greenhouse gas emissions



Source: UNEP 2024

Figure 1: Global anthropogenic greenhouse gas emissions, 1990-2023. Source: UNEP (2024), EDGAR v9.0 database for all greenhouse gas emissions (Crippa et al., 2024), the Global Carbon Budget for CO_2 emissions from cement production emissions and CO_2 land use emissions (Friedlingstein et al., 2023). All CO_2-equivalent emissions are calculated on the basis of the Global Warming Potential (GWP) values from the IPCC Sixth Assessment Report.

Greenhouse gas emissions per country/region



Source: UNEP 2024

Figure 2: Trends in total and per capita greenhouse gas emissions (excl. land use emissions) of the six largest emitters. Source: UNEP (2024), EDGAR v9.0 database for all greenhouse gas emissions (Crippa et al., 2024).

There are, however, significant differences in per capita emissions. In 2023, the world average per capita emissions was 6.4 tonnes CO_2-equivalents. The United States and Russia emitted nearly triple that of the world average, China nearly double, while Brazil and the European Union remained around the world average. India remains far below world average.

Each year, we conclude that the current climate plans proposed by countries are insufficient to reach the Paris climate goal. The world is heading towards global warming that is twice as high as the agreed-upon 1.5 degrees Celsius.

Figure 3 below shows the global emissions gap, the difference between global emissions resulting from the full implementation of the latest NDCs, and the levels of emissions consistent with least-cost pathways that limit warming to 2 and 1.5 degrees Celsius, respectively. This gap remains significantly large and, mostly, unchanged. For 2030, a reduction of 28% relative to 2019 levels is needed to limit temperature rise to 2 degrees Celsius, and 37% for a rise of 1.5 degrees Celsius. Unconditional and conditional NDCs are currently leading to a reduction of just 4% and 10% relative to 2019 levels.

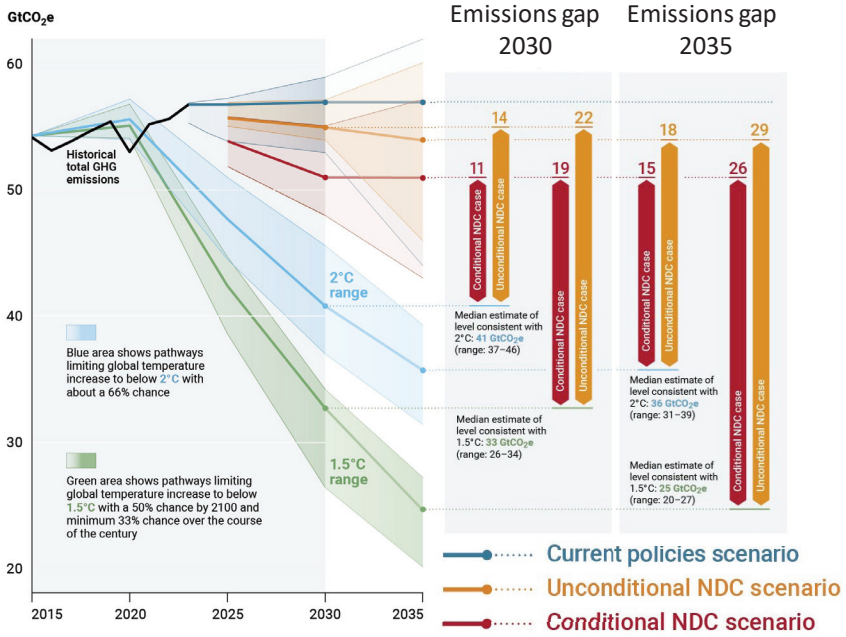


Figure 3: Greenhouse gas emissions in different scenarios and the emissions gap in 2030 and 2035. Source: UNEP (2024) and Rogelj et al. (2024).

This emissions gap influences temperature projections. On the basis of current policies, we are projecting a global warming of 3.1 °C by 2030; the probability of this happening is 66%. The full implementation of NDCs would lower this somewhat, to 2.8 °C in the case of unconditional reduction targets, and 2.6 °C in the case of only conditional reduction targets.

There has been some progress since the Paris Agreement, as the emissions projections of the UNEP Emissions Gap Reports demonstrate (Figure 4). In 2015, it was projected that emissions would increase to 64 $GtCO_2eq$ in 2030; currently, this projection has been adjusted to 57 $GtCO_2eq$, indicating a decrease of 7 $GtCO_2eq$ above the level projected in 2015. This decrease is due to several factors: (i) enhanced and updated climate policies, leading to decreasing emissions in the Annex I countries and, in the past two decades, to a plateauing of emissions growth in China; (ii) an increase in the use of solar and wind power, which are globally the fastest growing sources of energy; and (iii) macroeconomic developments, including a decrease in economic growth projections.

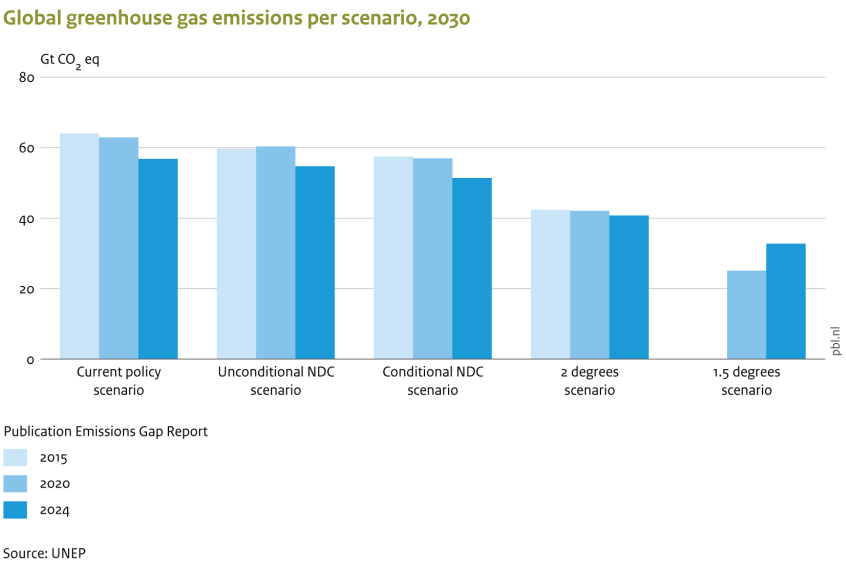


Figure 4: Greenhouse gas emission projections of scenarios in the UNEP Emissions Gap Report 2015, 2020, and 2024 (den Elzen et al., 2015; Rogelj et al., 2020, 2024). The projections in the reports of 2020 and 2024 have been corrected for updates in its method since the UNEP Emissions Gap Report 2022 (see Table 4.2).

In the meantime, the reduction targets in the NDCs have also been updated and strengthened, especially following the climate conference in Glasgow in 2021. Emissions projections on the basis of NDC scenarios show a similar decrease as do policy scenarios,

even under the 2015 levels. Unconditional NDCs have decreased with 5 $GtCO_2eq$ and conditional ones with 6 $GtCO_2eq$.

Hence, the emissions gap – the difference between emission levels under implemented climate policy and the levels needed to reach the reduction targets – has decreased to 2 $GtCO_2eq$ for unconditional NDCs and 5 $GtCO_2eq$ for conditional NDCs by 2030. This is an improvement compared to 2015. The emissions gap does, however, remain significant, but has decreased since 2015 with 3-4 $GtCO_2eq$ relative to the 2 degrees-target.

More effort is needed by countries to reach the climate goal
The core message remains that countries' collective efforts are still insufficient to reach the Paris climate goal. Additional efforts are needed from both national as well as decentralised governments and businesses. According to the Climate Agreement, countries have to indicate in 2025 which additional measures they will take to sufficiently reduce greenhouse gas emissions in 2030 and 2035. Recent analyses show, however, that the updated climate plans are, once again, not enough.

4. How can we reach the Paris climate goal?

That is the big question we must answer: how can we further reduce emissions and limit temperature increase to well below 2 degrees Celsius, and preferably even below 1.5 degrees Celsius? A massive gap lies between global emissions based on pledges by countries and what is actually needed to reach the Paris climate goal. There are, however, solutions in the form of raised ambitions and agreements by countries to bridge this emissions gap, even though the challenges remain significant.

By now, many countries have established or announced net-zero emission objectives as part of their long-term strategies within the Paris Agreement. The UNEP Emissions Gap Report (Rogelj et al., 2024) and other studies (Dafnomilis et al., 2024; Dafnomilis et al., 2023; Höhne et al., 2021; Rogelj et al., 2023) all show that the Paris climate goal is within reach only in the most optimistic scenario; the scenario in which all countries make good on their strictest pledges and both the conditional NDCs and net-zero emissions objectives are fully implemented. This would result in a projected temperature increase of 1.9 ^{o}C in 2100, with a chance of at least 66% (Figure 5).

The full implementation of the net-zero emission targets is crucial to reach climate goals
In a recent publication in *Science* (Rogelj et al., 2023), Joeri Rogelj, Taryn Fransen, Takeshi Kuramochi, and myself analysed the credibility and feasibility of the net-zero emission targets. Many of the current net-zero emission targets are not legally binding, are often not translated into an overarching plan for the long term, and there is often policy missing that would lead to decreased emissions in the short term. To get closer to the Paris climate goal, however, it is crucial to make these targets legally binding.

The degree to which the Earth is warming up remains largely uncertain. Scenarios that only incorporate current policy lead to a temperature increase of 2.9-3.1 degrees Celsius by 2100. The probability of this outcome varying between 50 and 66%. On the other hand, there are more optimistic scenarios which, on the basis of non-binding pledges and net-zero targets, project warming of 1.7-1.9 degrees, bringing the Paris climate goal within reach.

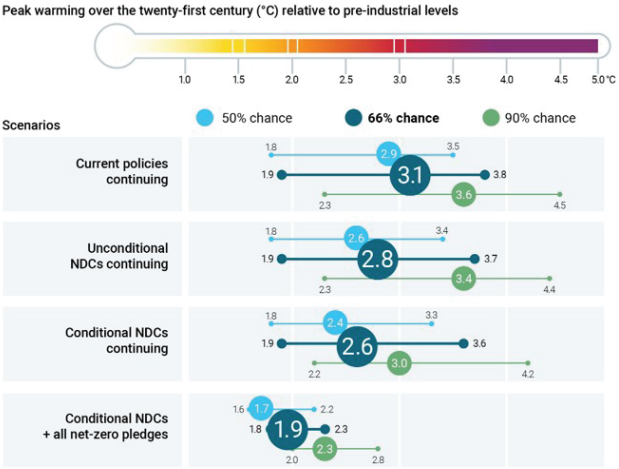


Figure 5: Projections of global temperature increase for various policy scenarios. Source: UNEP (2024).

To reduce any uncertainties surrounding optimistic and pessimistic scenarios, we have provided a confidence rating for net-zero targets. We analysed and evaluated the net-zero emission targets put forth by 35 countries that are responsible for at least 80% of global greenhouse gas emissions. Our evaluation applied three criteria: (i) whether the target is legally binding, (ii) whether the target is supported with a credible implementation plan, and (iii) whether concrete policy already foresee declining emissions in the next ten years? Based on these criteria, we evaluated whether the net-zero targets are 'very likely' to be implemented, 'less likely', or 'a lot less likely'. Several regions and countries, such as the EU, the United Kingdom, and New Zealand, scored 'very likely'. On the other hand, 90% of countries, including China and the United States, scored 'less likely' or 'a lot less likely'.

Using these results, we formulated five scenarios for future emissions and associated temperature increases, as recorded in Table 1 below. The table demonstrates that the Paris climate goal are only within reach when all net-zero targets are fully implemented. Without additional effort, however, this looks like wishful thinking, considering that the

implementation of most net-zero targets is already evaluated as 'less likely' or even 'a lot less likely'.

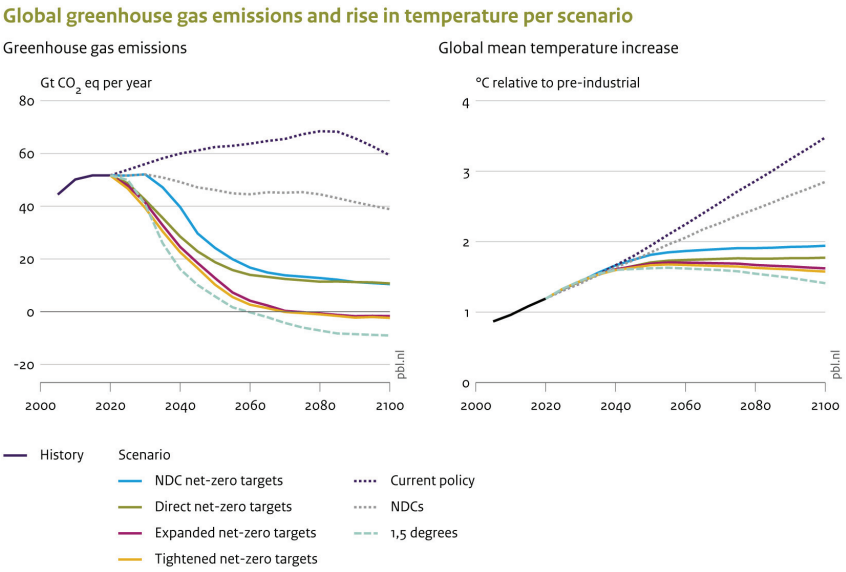
Table 1: Projections of global temperature increases for various policy scenarios. Source: Rogelj et al. (2024).

Maximum global temperature increase (°C) in 2100 relative to pre-industrial levels	
Scenario	**50% – 66% chance**
Case A: Current policies (conservative)	2,9 – 3.1 °C
Case B: Current policies + 'very likely' net-zero targets	2,5 – 2.7 °C
Case C: Current policies + 'very likely' and 'less likely' net-zero targets	2,2 – 2.3 °C
Case D: Current policies + 'very likely', 'less likely', and 'a lot less likely' net-zero targets	2,0 – 2,2 °C
Case E: All climate pledges: all conditional NDCs + all net-zero targets	1,7 – 1,9 °C

Secondly, together with Ioannis Dafnomilis and Detlef van Vuuren, we also developed Bridge scenarios with the IMAGE model. These scenarios aim to bridge the global emissions gap between current ambitions and the Paris climate goal by making assumptions about the expansion and reinforcement of the net-zero emission targets (Dafnomilis et al., 2024; Dafnomilis et al., 2023). These scenarios start with the full implementation of the emission targets formulated in countries' NDCs and the net-zero targets of 2023. We raised the climate ambitions by assuming that all countries will strive for a net-zero emission target and that existing net-zero targets will be achieved five years earlier than projected. This approach is meant to bridge the emissions gap with the emissions pathway towards 1.5 degrees Celsius.

The second scenario, with a linear reduction pathways towards net zero, results in lower cumulative emissions and a lower rise in temperature (Figure 6). However, global emissions are not fully reduced to net zero. Only in the fourth and most optimistic scenario — where the net-zero emission targets are expanded to all countries and tightened by achieving net-zero five years earlier — net-zero emissions are reached around 2070. As a result, there is a 90% reduction in the gap between the emissions projection of the current policy-scenario and the Paris-aligned pathway of 1.5 degrees by 2100. This means achieving the 1.5 degrees-goal is within reach. The study demonstrates that the fastest pathway towards reaching the Paris climate goal is reaching net-zero greenhouse gas emissions, where residual emissions are compensated with CO_2 removal. Additionally, it shows that each step towards a more ambitious scenario accelerates the transition to a low-carbon economy.

The 1.5 degrees-goal of the Paris Climate Agreement is feasible if all countries adopt and follow through strengthened net-zero emission targets



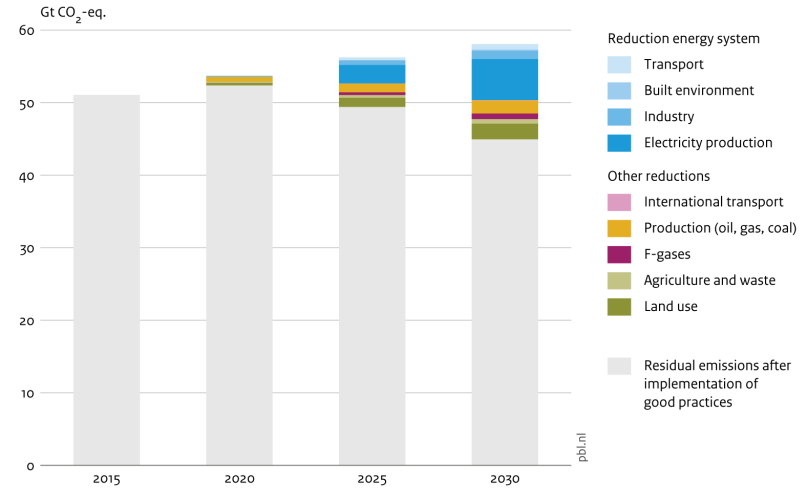
Source: Dafnomilis et al. 2023

Figure 6: Global emissions and temperature projection demonstrate that net-zero scenarios could bridge the emissions gap with the 1.5 degrees goal. The projections of global greenhouse gas emissions and temperature increase are available for current policy, NDCs and net-zero targets, the four net-zero target scenarios, and the existing IMAGE 1.5 °C scenario. Source: Dafnomilis et al. (2023).

Finally, we have also developed numerous scenarios in the past and analysed successful climate policy to bridge the emissions gap before 2030. Mark Roelfsema, Heleen van Soest, and I, together with colleagues from the NewClimate Institute, have finalised various Bridge scenarios (den Elzen et al., 2016b; Fekete et al., 2021; Roelfsema et al., 2018; van Soest et al., 2021) based on good-practice policy measures that can be implemented until 2030. These measures are based on successfully implemented policy in one or more countries which have led to a significant reduction in emissions in the past. However, success stories in one country are not always automatically taken up by other countries; they must first be adjusted to national circumstances. In one study, led by Hanna Fekete (Fekete et al., 2021), we analysed successful or good-practice policy measures for different countries, particularly in the fields of renewable energy sources in the electricity sector (especially the EU), the share of electric vehicles (Norway, China), and reducing historic deforestation emissions (Brazil).

If all proposed good-practice policy measures are implemented on a global scale, emissions in 2030 can be reduced by approximately 20% compared to current policy (Figure 7). Even though this reduction is still insufficient to keep temperature increases below 2 °C, it would put us on the right track. The measures would ensure a smoother transition towards sustainable energy, with less rapid emissions reductions, more time to phase out fossil fuels, and lower mitigation costs. These findings emphasise the importance of transition policy to reach the climate goals set out in the Paris Agreement.

Impact of good practices on global greenhouse gas emissions



Source: Fekete et al. 2021

Figure 7: Contribution of each sector to emissions reductions between current policy and the good-practice-scenario for global greenhouse gas emissions. The grey segment in each column shows the emissions projections for the good-practice-scenario in 2030, while the colourful segments show the emissions reductions achieved with the various good-practice policy measures. Source: Fekete et al. (2021).

5. The research agenda

What is the objective of the chair?

The Vrije Universiteit Amsterdam founded the chair for 'International Climate Policy and Mitigation of Climate Change'. The purpose of this chair, which I have the honour to hold, is – and it's a mouthful –: 'analysing the implementation of the Paris Agreement and analysing mitigation scenarios on the basis of current and additional climate policy to reduce greenhouse gas emissions by national governments'. Alongside this, I will also focus on the quantitative analysis of policy-relevant issues, questions, and choices in global climate

mitigation. Of course, I don't do this alone; I work together with my many colleagues within PBL, the Institute for Environmental Studies (IVM), and with others. If it's not clear yet what exactly I will research and analyse, don't worry; below, I will elaborate on this.

What are the research themes?
The aforementioned research objective of my teaching assignment can be subdivided into the following four research themes (see also Figure 8):

1) *Analysing climate policy scenarios*: Using model analyses, I explore the effect of energy use and production, greenhouse gas emissions, land use and associated climate effects, and the costs and macroeconomic effects for various diverse climate policy scenarios.

2) *Analysing the effects of the mitigation measures*: *I examine how national climate policies by countries* to reach their national reduction targets (NDCs) and net-zero targets, affect both global and national emissions level.

3) *Analysing various policy proposals for climate mitigation,* including various solution strategies.

4) *Applying uncertainty analysis and econometric and machine learning methods* for the analysis of ambition and effectiveness of current climate policy by countries.

These four themes are, of course, closely connected already. For example, the analysis of national climate ambitions in theme four can deliver valuable insights for developing scenarios for additional climate policy in theme one, as well as provide clarifications on why countries are not reaching their reduction targets in theme two.

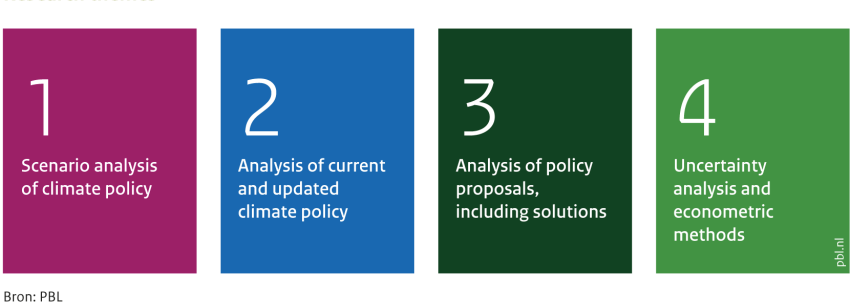


Figure 8: Research themes for the chair 'International Climate Policy and Mitigation of Climate Change'.

Expanded model analyses
I will not only analyse the current state of the implementation of the Paris Agreement, but also examine the effects are of current and planned climate policies, both globally as well as

for G20 economies and other countries. Additionally, together with my colleagues I aim to analyse the climate pledges countries have made to reduce their emissions and which scenarios to mitigate climate change are consistent with the Paris climate goal.

The central model for calculating the scenarios is the IMAGE model (Stehfest et al., 2014; van Vuuren et al., 2018). This model, which has been at my side throughout my whole career, was developed to gain insight into how global, long-term environmental and sustainability issues, such as climate change, develop because of human activities. The model simulates the changes in the energy and land-use systems for 26 world regions, resulting in emissions that have varying effects on our atmosphere, oceans, and terrestrial biosphere. This leads to global temperature increase and climate change, with ultimately wide-ranging consequences.

6. Four research themes

The four research themes of this chair are not completely uncharted territory; many have walked this path before me. That is why I now want to take stock of the existing knowledge on these four themes. Then, I will present my ideas for renewing these methods, to develop a more complete research agenda.

6.1 Scenario analysis of climate policy

This first theme focuses on analysing international climate policy and policy scenarios. Using model analyses, we explore their effects on greenhouse gas emissions, land use, and climate and economic consequences. The scenarios are primarily aimed at developing effective pathways that align with the Paris climate goal. We also research mitigation scenarios that arise from current climate policy and additional measures by national governments to reduce global emissions and bridge the emissions or ambition gap. The analyses are conducted on global, regional, sectoral, and national levels, using model calculations by IMAGE or from existing scenarios by integrated models.

Within the work programme on International Climate Policy at PBL, we address the following research questions: which pathways and measures are feasible for countries to comply with the Paris climate goal? How can additional policy bridge the global emissions gap? How do countries reach their NDC reduction targets and net-zero targets, and what role do mitigation options such as negative emissions play? What are the consequences of these policy pathways?

Recently, much has been written about the shortcomings of existing mitigation scenarios in the Sixth Assessment Report by the IPCC, developed using models such as IMAGE (Kanitkar and Jayaraman, 2025; Kanitkar et al., 2024). The criticism on this report is mainly because of the continuation of global inequalities in income, energy use, and emissions leading up to 2050. A challenge when developing IMAGE scenarios is to reach the climate goal not only by

looking at cost-effectiveness, but also at technological, economic, and societal feasibility and justice. Even though the acceleration of climate policy is essential, the costs have to be equitably distributed among countries and sectors. Within the PBL work programme, the central question is how feasible and how just international climate policy can be realised in order to limit climate change.

Regarding the further developments of scenarios around current and additional policy, as well as the implementation of the NDCs, we conduct a broader analysis of the effectiveness and feasibility of certain objectives. We often find that renewable energy targets, such as wind and solar capacity, are in the process of being realised. In the next few years, however, we will need to more closely examine their feasibility, paying particular attention to governmental and institutional barriers and taking into account national circumstances and existing policy. Additionally, we aim to make the implications of scenarios more concrete by providing information about the necessary mitigation measures, such as the required solar and wind capacity.

Of course, we also try, as much as possible, to consider ongoing geopolitical developments. The international climate negotiations are progressing slowly and with difficulty due to such geopolitical tensions. The United States has announced their withdrawal from the Paris Agreement and have reversed much climate policy. Meanwhile, low- and middle-income countries are calling for more international financing for both mitigation and adaptation measures.

Climate scenarios

Here, I want to give an example from our earlier studies based on IMAGE scenarios. In 2018, Detlef van Vuuren and I conducted a study with colleagues from the Joint Research Centre (JRC) in Seville, Spain, contributing to the EU impact assessment 'A Clean Planet For All' of the European Commission. This study focused on achieving net-zero greenhouse gas emissions for the EU in 2050 (European Commission, 2018a, b). The JRC has an integrated climate model called the POLES model, which is comparable to the IMAGE model. Together, we developed IMAGE and POLES scenarios to cost-effectively reach the 1.5 ^{o}C and 2 ^{o}C temperature targets, where all mitigation measures are fully operational and implemented (Esmeijer et al., 2018; Weitzel et al., 2019). We also created alternative scenarios with reduced availability of negative emissions technologies and bioenergy. The emission pathways for these scenarios show a significant reduction after 2020 and reach net-zero emissions around 2060-2070 in the 1.5 ^{o}C pathway, and near the end of the century for the 2 ^{o}C pathway (Figure 9). All sectors globally have to contribute to reach the temperature targets of 1.5 ^{o}C and 2 ^{o}C.

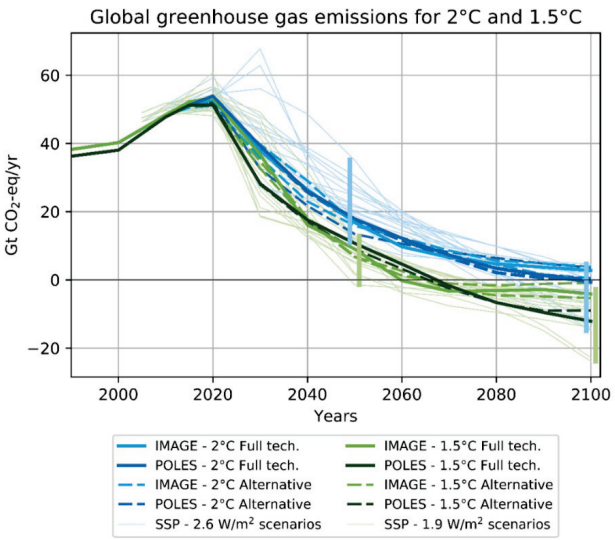


Figure 9: Projections of global greenhouse gas emissions to reach the 2 °C- and 1.5 ° temperature objectives, based on the POLES model and IMAGE model scenarios, as well as comparable scenarios for 2 °C and 1.5 °C (Esmeijer et al., 2018; European Commission, 2018b).

6.2 Analysis climate policy

The second theme, 'Analysis climate policy', focuses on researching the effects of national climate measures taken by countries to achieve their NDCs and net-zero targets, both globally and nationally. We address the following research questions: is current policy adopted by various countries sufficient to reach the Paris climate goal? Will countries achieve their national reduction targets in 2030? Are the NDCs and net-zero targets set by countries consistent with the Paris climate goal?

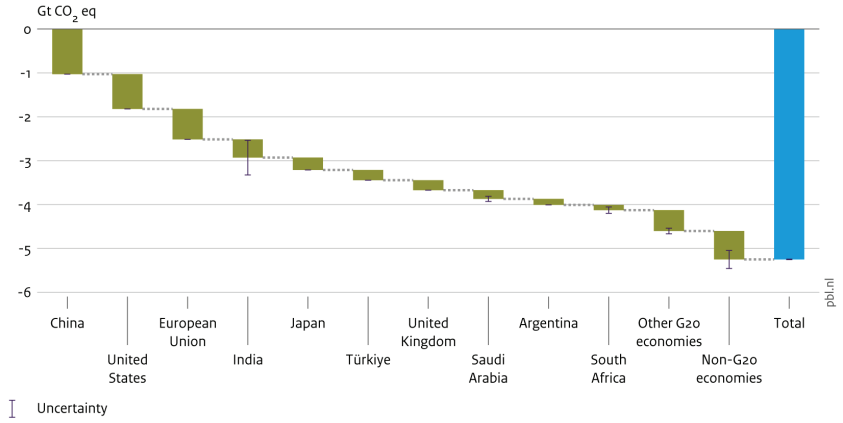
The analysis focuses on two sub-areas:

a) Global climate policy: this involves analysing current international climate policy and implementation of NDC targets and net-zero targets on a global scale. This analysis mainly investigates the global **emissions gap** or ambition gap between what individual countries promise, and what they have to collectively achieve to reach the Paris climate goal (den Elzen et al., 2022; den Elzen et al., 2011; Höhne et al., 2020; Höhne et al., 2021; Rogelj et al., 2016; Rogelj et al., 2023).
b) National climate policy: this involves analysing the progress of national climate policy by countries to comply with NDC reduction targets and national energy and climate targets (den Elzen et al., 2016a; 2022; 2016b; 2019; Kuramochi et al., 2019; Nascimento et al., 2024a; Roelfsema et al., 2020).

For this analysis, we specifically focus on evaluating the effectiveness and feasibility of climate policy. We will also further research the effectiveness of applied policy instruments. In the next few years, the analysis of the revised NDCs is a central focus, which include reduction targets for 2030 and 2035. Additionally, we study the climate effects of exceeding the 1.5 ^{o}C threshold (Forster et al., 2025). The current emission trends make it extremely likely that this threshold will be exceeded in the coming century, which can lead to a projected peak warming of 0.2 ^{o}C above the 1.5 ^{o}C, even with significant emissions reductions after 2025.

One example is the analysis of the effects of revised NDCs, submitted before and after the climate conference in Glasgow in 2021. The update of the unconditional NDCs, as submitted by countries, leads to 5 $GtCO_2eq$ lower global greenhouse gas emissions in 2030 relative to the original NDCs of the Paris Agreement (see Figure 10). We find a similar additional reduction in the case of the conditional NDCs. The most important contributions to this extra reduction come from China, the European Union, Japan, the United Kingdom, and the United States.

Impact of greenhouse gas emissions from revised NDCs from previous NDCs, 2030



Revised NDCs relate to unconditional NDCs as submitted in the period between January 2020 and November 2022.

Source: PBL 2025

Figure 10: The contribution of revised NDC targets by countries to the total additional global emissions reduction (as shown in the blue column), based on the full implementation of the unconditional NDC targets, compared with the original NDCs of the Paris Agreement (2015). The green columns show the additional reductions by individual G20 economies, the non-G20 countries as a group, with their stronger NDC targets (compared to their original NDCs). Source: based on den Elzen et al. (2022).

Current climate policy scenarios

Since 2015, we have annually analysed, together with the NewClimate Institute and IIASA, the progress of 25 countries regarding their existing policy relative to their national NDC targets (Dafnomilis et al., 2022; den Elzen et al., 2016a; Roelfsema et al., 2014; Roelfsema et al., 2022; Roelfsema et al., 2020). We developed policy scenarios based on existing climate policy. Our analysis of 2024 (Figure 11) has shown that twelve countries are likely to reach their unconditional NDCs, with emissions projections under these targets. On the other hand, twelve countries are not on track and they must tighten their policy to reach their NDC target.

The fact that a country is likely to reach its NDC target, does not automatically mean that it is taking stronger mitigation measures than a country that is not on track; the ambition levels of NDC targets vary per country. Our study does not evaluate the ambition of the justice dimension of NDC targets. Because NDCs are nationally determined and heterogeneous, a fair comparison of the ambition of NDCs by countries is not always simple and straightforward.

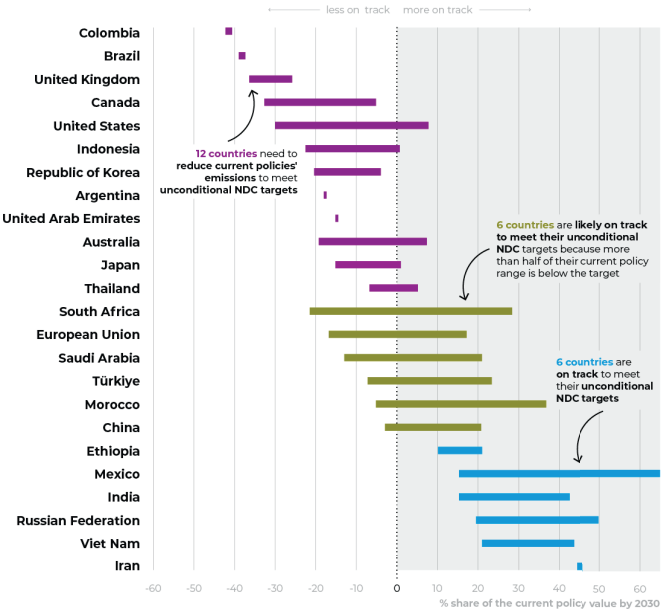


Figure 11: The total emissions projections for 2030 are based on the scenario with current policy and the full implementation of the unconditional NDCs by all 25 selected countries, with the exception of Egypt (that only has a conditional target). The percentages are calculated by comparing the full reach of the NDC targets with the emissions projections in the current policy-scenario. Source: (Nascimento et al., 2024b).

6.3 Analysis policy proposals

The third theme focuses on analysing policy proposals for climate mitigation, including various diverse solution strategies. This theme researches, for example, the contribution of countries to ongoing global warming. Together with Niklas Höhne and Jan Fuglestvedt, we calculated that when all greenhouse gases since 1850 are included, the United States, Europe, and China in 2000 contribute 20%, 15%, and 8%, respectively, to global warming (den Elzen et al., 2005). By 2021, these percentages were 17%, 10%, and 12%, respectively, with China overtaking the EU due to its current contribution of 30% to global emissions. Low-income countries contribute only 4% to global warming, but do experience the most negative climate effects.

In climate negotiations, the allocation of reduction targets on the basis of equity principles is crucial. The three most important equity principles are responsibility, capacity, and equity. Responsibility relates to the contribution to historical emissions; capacity concerns the literal capacity to finance mitigation; and equity relates to allocating the same amount of emission allowances per capita.

Niklas Höhne and I researched the impact of principles of justice on reduction targets for the IPCC Fourth Assessment Report, on the basis of existing literature (den Elzen and Höhne, 2008; Höhne et al., 2014). This study established that Annex I countries (mainly industrialised countries) must reduce their emissions in 2020 by 25-40%, and in 2040 by 80-95% relative to 1990, to limit the temperature increase to 2 ^{o}C. In the IPCC Fifth Assessment Report, we improved on this (Clarke et al., 2014), based on expanded literature on reduction targets according to the principles of justice (den Elzen et al., 2008; 2010; Höhne et al., 2014). Our research and later literature form a solid foundation to demonstrate that the current reduction targets of many countries are often insufficient according to principles of justice (Dekker et al., 2025). These principles can also support an equal distribution of international financing, where high-income countries and low and middle-income countries help the low-income countries with mitigation, adaptation, and climate damages (Dellink et al., 2009; Hof et al., 2009; Pachauri et al., 2022).

6.4 Uncertainty analysis and economic analysis

The fourth theme involves applying uncertainty analysis and econometric and machine learning methods to analyse the ambition and effectiveness of existing climate policy by countries. Econometric and machine learning methods generate quantitative estimations and projections based on modelling data, while uncertainty analyses help in evaluating the credibility and sensitivity of these model projections.

Together with Arthur Beusen and Ioannis Dafnomilis, we conducted an uncertainty analysis to evaluate the impact of policy-related and model uncertainties on emissions projections of national plans, both globally level and specifically for G20 economies only (den Elzen et al.,

2023). Important assumptions and uncertainties significantly impact the emissions projections of NDC scenarios. Policy-related uncertainties have approximately the same impact as model uncertainties, such as socioeconomic scenarios (Figure 12).

Together with two Master Science students of Climate Econometrics, as well as Arthur Beusen, I conducted an uncertainty analysis about net-zero targets (den Elzen et al., 2025). Although many studies suggest that global warming remains under 2 degrees Celsius under the full implementation of NDCs and net-zero targets, they often ignore important uncertainties, such as which greenhouse gases and sectors are involved, and the carbon uptake by forests. Our study examined how these uncertainties can influence the projected greenhouse gas emissions in 2050 for various countries with net-zero targets, and the total impact on global emissions. The global emissions projections for 2050 range from 40 to 75% relative to the emissions levels of 2015.

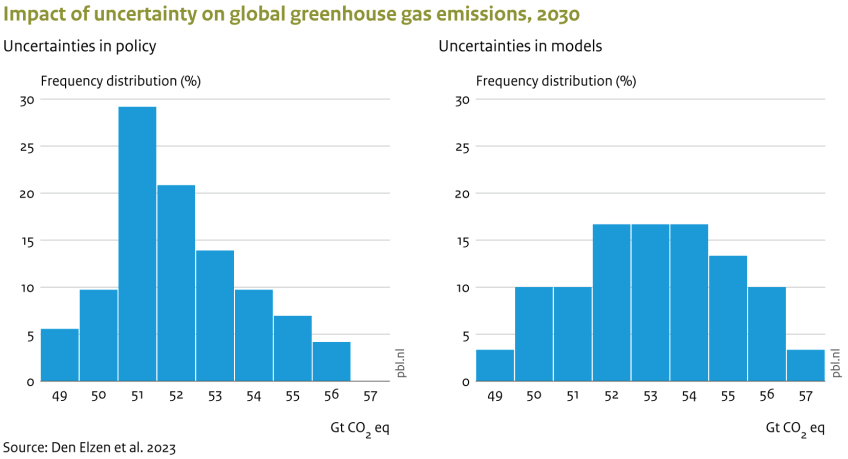


Figure 12: Frequency distribution of global greenhouse gas emission projections for 2030 based on the NDC targets, with the emphasis on (a) policy uncertainties and (b) model-technical uncertainties. Source: den Elzen et al. (2023).

7. Synergy with IVM research and education

This research closely connects with existing climate research by the Institute for Environmental Studies (IVM) and international climate policy research by PBL. The IVM at the Vrije Universiteit Amsterdam has a long tradition of analysing international climate policy. They have worked on linking national climate strategies and climate initiatives to non-state actors. Additionally, they have developed methods to estimate the consequences and risks of climate change and its associated costs, and issues in the field of climate governance. The expertise and networks of IVM enhance my research. In return, my active

role in international climate policy will reinforce and strengthen the applicability of IVM research.

Finally, the subjects of my special professorship are extremely relevant for the educational programmes at IVM in the field of Environmental Science, which includes the following Master Science programmes: Environment and Resource Management, Global Environmental Change and Policy, and Climate Econometrics. Students enrolled in these courses can, via internships at PBL, gain practical and modelling experience in the field of international climate policy and modelling. This also provides an opportunity to collaborate with the IMAGE team at PBL. As we speak, five Master Science students have successfully completed their graduation projects at PBL, resulting in three publications. Moreover, collaborating with students is always invigorating and inspirational.

8. Some final words

In conclusion, I want to thank several people who have made an important contribution to me reaching this milestone. I'll keep it brief, because there are always people you forget to mention. First of all, I want to thank my colleagues at IVM and PBL for their support in realising this chair position. I want to particularly thank Pieter Boot, Jaco Stremler, and Martine Uyterlinde. Pieter Boot really encouraged me with his enthusiasm to make progress in finalising the required documentation. Jaco Stremler and Martine Uyterlinde supported me and were always involved, especially in the recovery period following my back surgery.

Of course, I want to express my thanks for their support to the directors of IVM of the past period, Wouter Botzen and Pieter Beukering. Your enthusiasm, involvement, and spirit are the driving force of IVM. I also want to thank my many colleagues at IVM itself and their department on environmental economy. You make the IVM a pleasant and inspiring place to work.

My colleagues at NewClimate Institute, particularly Niklas, Takeshi, and Leo – I want to thank you for the intensive and great collaboration. Together, we have experienced many highs and lows during the climate negotiations of the last few years. I want to express my sincere appreciation for my colleagues at the UNEP Emissions Gap Report. Although I have already mentioned many of them, the whole team deserves recognition for successfully completing this challenging project with its tight deadlines, year after year.

I am extremely grateful for the support of my colleagues at PBL, especially the IMAGE team. The IMAGE model is really the core of our research and has grown into an authoritative model due to the excellent efforts under supervision of Detlef van Vuuren,.

Finally, I want to express my sincere gratitude to the support of family and friends. I particularly want to thank my parents for their ongoing support. Although my father is no longer with us to witness this milestone, I am deeply grateful for everything he meant to

me. I also want to thank my daughter Femke; you make my days better. And of course, a special word of thanks to Petra for your unremitting support, dedication, and love. Even though you sometimes think I work too much, I truly appreciate your patience and understanding.

I have spoken.

References

Clarke L, Jiang K, Akimoto K, Babiker MH, Blanford G, Fisher-Vanden K, . . . van Vuuren DP (2014) Assessing Transformation Pathways. in Edenhofer O, et al. (eds.) Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Cambridge, UK.

Crippa M, Guizzardi D, Pagani F, Banja M, Muntean M, Schaaf E, . . . Risquez Martin A (2024) GHG emissions of all world countries. Publications Office of the European Union, Luxembourg, JRC138862 https://edgar.jrc.ec.europa.eu/booklet/GHG_emissions_of_all_world_countries_booklet_2024report.pdf

Dafnomilis I, Chen H-H, den Elzen M, Fragkos P, Chewpreecha U, van Soest H, . . . van Vuuren DP (2022) Targeted Green Recovery Measures in a Post-COVID-19 World Enable the Energy Transition. Frontiers in Climate 4 https://doi.org/10.3389/fclim.2022.840933.

Dafnomilis I, den Elzen M, van Vuuren D (2024) Paris targets within reach by aligning, broadening and strengthening net-zero pledges. Communications Earth & Environment 5:48 https://doi.org/10.1038/s43247-023-01184-8.

Dafnomilis I, den Elzen M, van Vuuren DP (2023) Achieving net-zero emissions targets: An analysis of long-term scenarios using an integrated assessment model. Annals of the New York Academy of Sciences 1522:98–108 https://doi.org/10.1111/nyas.14970

Dekker MM, Hof AF, du Robiou Pont Y, van den Berg N, Daioglou V, den Elzen M, . . . van Vuuren DP (2025) Navigating the black box of fair national emissions targets. Nature Climate Change 15:752–759 https://doi.org/10.1038/s41558-025-02361-7.

Dellink R, den Elzen MGJ, Bergsma E, Aiking H, Berkhout F, Dekker T, Gupta J (2009) Sharing the burden of financing adaptation to climate change. Global Environmental Change, 19:411–421, https://doi.org/410.1016/j.gloenvcha.2009.1007.1009.

den Elzen M (1993) Global environmental change: An integrated modelling approach. PhD Thesis, Rijksuniversiteit Limburg, Maastricht.

den Elzen M, Admiraal A, Roelfsema M, van Soest H, Hof AF, Forsell N (2016a) Contribution of the G20 economies to the global impact of the Paris agreement climate proposals. Climatic Change 137:655–665 https://doi.org/10.1007/s10584-016-1700-7.

den Elzen M, Fuglestvedt J, Höhne N, Trudinger C, Lowe J, Matthews B, . . . Andronova N (2005) Analysing countries' contribution to climate change: scientific and policy-related choices. Environmental Science & Policy 8:614–636 https://doi.org/10.1016/j.envsci.2005.06.007.

den Elzen MGJ, Dafnomilis I, Forsell N, Fragkos P, Fragkiadakis K, Höhne N, . . . Sperling F (2022) Updated nationally determined contributions collectively raise ambition levels but need strengthening further to keep Paris goals within reach. Mitigation and Adaptation Strategies for Global Change 27:33 https://doi.org/10.1007/s11027-022-10008-7.

den Elzen MGJ, Dafnomilis I, Hof AF, Olsson M, Beusen A, Botzen WJW, . . . Rogelj J (2023) The impact of policy and model uncertainties on emissions projections of the Paris Agreement pledges. Environmental Research Letters 18:054026 https://doi.org/10.1088/1748-9326/acceb7.

den Elzen MGJ, Fekete H, Höhne N, Admiraal A, Forsell N, Hof AF, . . . van Soest H (2016b) Greenhouse gas emissions from current and enhanced policies of China until 2030: Can emissions peak before 2030? Energy Policy 89:224–236 http://dx.doi.org/10.1016/j.enpol.2015.11.030.

den Elzen MGJ, Fransen T, Höhne N, Winkler H, Schaeffer R, Sha F, Garg A (eds.) (2015) The emissions gap in 2025 and 2030, United Nations Environment Programme, Nairobi, Kenia.

den Elzen MGJ, Hof AF, Roelfsema M (2011) The emissions gap between the Copenhagen pledges and the 2oC climate goal: Options for closing and risks that could widen the gap. Global Environmental Change 21:733–743 https://dx.doi.org/10.1016/j.gloenvcha.2011.01.006.

den Elzen MGJ, Höhne N (2008) Reductions of greenhouse gas emissions in Annex I and non-Annex I countries for meeting concentration stabilisation targets. Climatic Change 91:249–274 https://doi.org/10.1007/s10584-008-9484-z.

den Elzen MGJ, Höhne N (2010) Sharing the reduction effort to limit global warming to 2oC. Climate Policy 10:247–260 https://doi.org/10.3763/cpol.2009.0678A.

den Elzen MGJ, Hooijschuur E, Dafnomilis I, Beusen AHW, Kuramochi T, Nascimento L (2025) Infographics PBL NDC Tool 2025, https://themasites.pbl.nl/o/climate-ndc-policies-tool/. .

den Elzen MGJ, Kuramochi T, Höhne N, Cantzler J, Esmeijer K, Fekete H, . . . Vandyck T (2019) Are the G20 economies making enough progress to meet their NDC targets? Energy Policy 126:238–250 https://doi.org/10.1016/j.enpol.2018.11.027.

Esmeijer K, den Elzen MGJ, Gernaat D, van Vuuren DP, Doelman J, Keramidas K, . . . Frank S (2018) 2 °C and 1.5 °C scearios with limited use of BECCS and bio-energy. PBL Netherlands Environmental Assessment Agency, The Hague. https://www.pbl.nl/en/publications/2-degc-and-15-degc-scenarios-and-possibilities-of-limiting-the-use-of-beccs-and-bio-energy.

European Commission (2018a) A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Communication COM(2018) 773 final , https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773. European Commission, Brussels, Belgium.

European Commission (2018b) In-depth analysis in support of the Commission Communication COM (2018) 773. A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Communication COM(2018) 773 final European Commission, Brussels, Belgium, https://climate.ec.europa.eu/document/download/dc751b7f-6bff-47eb-9535-32181f35607a_en?filename=com_2018_733_analysis_in_support_en.pdf.

Fekete H, Kuramochi T, Roelfsema M, Elzen Md, Forsell N, Höhne N, . . . Gusti M (2021) A review of successful climate change mitigation policies in major emitting economies and the potential of global replication. Renewable and Sustainable Energy Reviews 137:110602 https://doi.org/10.1016/j.rser.2020.110602.

Forster PM, Smith C, Walsh T, Lamb WF, Lamboll R, Cassou C, . . . Zhai P (2025) Indicators of Global Climate Change 2024: annual update of key indicators of the state of the climate system and human influence. Earth Syst. Sci. Data 17:2641–2680 https://doi.org/10.5194/essd-17-2641-2025.

Friedlingstein P, O'Sullivan M, Jones MW, Andrew RM, Bakker DCE, Hauck J, . . . Peters GP (2023) Global carbon budget 2023. Earth System Science Data 15:5301–5369 https://doi.org/10.5194/essd-15-5301-2023.

Hof AF, de Bruin KC, Dellink RB, den Elzen MGJ, van Vuuren DP (2009) The effect of different mitigation strategies on international financing of adaptation. Environmental Science and Policy 12:832–843 https://doi.org/10.1016/j.envsci.2009.08.007.

Höhne N, den Elzen M, Rogelj J, Metz B, Fransen T, Kuramochi T, . . . Fu S (2020) Emissions: world has four times the work or one-third of the time. Nature 579:25–28 https://doi.org/10.1038/d41586-020-00571-x.

Höhne N, den Elzen MGJ, Escalante D (2014) Regional greenhouse gas mitigation targets based on equity principles: a comparison of studies. Climate Policy 14:122–147 https://doi.org/10.1080/14693062.2014.849452.

Höhne N, Gidden MJ, den Elzen M, Hans F, Fyson C, Geiges A, . . . Rogelj J (2021) Wave of net zero emission targets opens window to meeting the Paris Agreement. Nature Climate Change 11:820–822 https://doi.org/10.1038/s41558-021-01142-2.

Kanitkar T, Jayaraman T (2025) Climate Justice and Equitable Futures: Addressing Gaps in IPCC AR6 Scenarios. Heinrich Boll Foundation. Germany. Retrieved from https://www.boell.de/en/2025/02/06/climate-justice-and-equitable-futures.

Kanitkar T, Mythri A, Jayaraman T (2024) Equity assessment of global mitigation pathways in the IPCC Sixth Assessment Report. Climate Policy 24:1129–1148.

Kuramochi T, Nascimento L, de Villafranca Casas MJ, Fekete H, de Vivero G, Lui S, . . . Gusti M (2019) Greenhouse gas mitigation scenarios for major emitting countries. Analysis of current climate policies and mitigation commitments: 2019 update, NewClimate Institute (Cologne, Germany), PBL (The Hague, the Netherlands), IIASA (Laxenburg, Austria), https://www.pbl.nl/en/publications/greenhouse-gas-mitigation-scenarios-for-major-emitting-countries-2019-update.

Nascimento L, den Elzen M, Kuramochi T, Woollands S, Dafnomilis I, Moisio M, . . . Araujo Gutierrez Z (2024a) Comparing the Sequence of Climate Change Mitigation Targets and Policies in Major Emitting Economies. Journal of Comparative Policy Analysis: Research and Practice 26:233–250 https://doi.org/10.1080/13876988.2023.2255151.

Nascimento L, Scheewel J-L, Kuramochi T, Dafnomilis I, Hooijschuur E, den Elzen MGJ, . . . Gusti M (2024b) Progress of major emitters towards climate targets: 2024 Update. NewClimate Institute (Cologne, Germany), PBL (The Hague, the Netherlands), IIASA (Austria), https://newclimate.org/resources/publications/progress-of-major-emitters-towards-climate-targets-2024-update

Pachauri S, Pelz S, Bertram C, Kreibiehl S, Rao ND, Sokona Y, Riahi K (2022) Fairness considerations in global mitigation investments. Science 378:1057–1059 https://doi.org/10.1126/science.adf0067.

Roelfsema M, den Elzen MGJ, Höhne N, Hof AF, Braun N, Fekete H, . . . Böttcher H (2014) Are major economies on track to achieve their pledges for 2020? An assessment of domestic climate and energy policies. Energy Policy 67:781–796 https://doi.org/10.1016/j.enpol.2013.11.055.

Roelfsema M, Fekete H, Höhne N, den Elzen M, Forsell N, Kuramochi T, . . . van Vuuren DP (2018) Reducing global GHG emissions by replicating successful sector examples: the 'good practice policies' scenario. Climate Policy 18:1103–1113 https://doi.org/10.1080/14693062.2018.1481356.

Roelfsema M, van Soest HL, den Elzen M, de Coninck H, Kuramochi T, Harmsen M, . . . van Vuuren DP (2022) Developing scenarios in the context of the Paris Agreement and application in the integrated assessment model IMAGE: a framework for bridging the policy-modelling divide. Environmental Science and Policy 135:104–116 https://doi.org/10.1016/j.envsci.2022.05.001.

Roelfsema M, van Soest HL, Harmsen M, van Vuuren DP, Bertram C, den Elzen M, . . . Vishwanathan SS (2020) Taking stock of national climate policies to evaluate implementation of the Paris Agreement. Nature Communications 11:2096 https://doi.org/10.1038/s41467-020-15414-6.

Rogelj J, Den Elzen M, Höhne N, Fransen T, Fekete H, Winkler H, . . . Meinshausen M (2016) Paris Agreement climate proposals need a boost to keep warming well below 2 °C. Nature 534:631–639 https://doi.org/10.1038/nature18307.

Rogelj J, den Elzen M, Portugal JP (2020) Chapter 3: The emissions gap. in Olhoff A, Christensen J (eds.) The Emissions Gap Report 2020. United Nations Environment Programme, Nairobi, Kenia.

Rogelj J, den Elzen M, Portugal JP (2024) Chapter 4: The emissions gap in 2030 and 2035. in Olhoff A, Christensen J (eds.) Emissions Gap Report 2024: No more hot air … please! With a massive gap between rhetoric and reality, countries draft new climate commitments. United Nations Environment Programme, Nairobi, Kenia.

Rogelj J, Fransen T, den Elzen MGJ, Lamboll RD, Schumer C, Kuramochi T, . . . Portugal-Pereira J (2023) Credibility gap in net-zero climate targets leaves world at high risk. Science 380:1014–1016 https://www.science.org/doi/10.1126/science.adg6248.

Stehfest E, van Vuuren DP, Bouwman AF, Kram T, Alkemade R, Bakkenes M, . . . Prins A (2014) Integrated Assessment of Global Environmental Change with IMAGE 3.0. Model description and policy applications, the Hague: PBL Netherlands Environmental Assessment Agency, http://www.pbl.nl/en/publications/integrated-assessment-of-global-environmental-change-with-IMAGE-3.0.

UNEP (2024) Emissions Gap Report 2024: No more hot air … please! With a massive gap between rhetoric and reality, countries draft new climate commitments. United Nations Environment Programme (UNEP), Nairobi, Kenia, https://doi.org/10.59117/20.500.11822/46404.

UNFCCC (2015) FCCC/CP/2015/L.9/Rev.1: Adoption of the Paris Agreement. UNFCCC, Paris, France, http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf, pp. 1–32.

van Soest HL, Aleluia Reis L, Baptista LB, Bertram C, Després J, Drouet L, . . . van Vuuren DP (2021) Global roll-out of comprehensive policy measures may aid in bridging emissions gap. Nature Communications 12:6419 https://doi.org/10.1038/s41467-021-26595-z.

van Vuuren DP, Stehfest E, Gernaat DEHJ, van den Berg M, Bijl DL, de Boer HS, . . . van Sluisveld MAE (2018) Alternative pathways to the 1.5 °C target reduce the need for

negative emission technologies. Nature Climate Change 8:391–397 https://doi.org/10.1038/s41558-018-0119-8.

Weitzel M, Vandyck T, Keramidas K, Amann M, Capros P, den Elzen M, . . . Saveyn B (2019) Model-based assessments for long-term climate strategies. Nature Climate Change https://doi.org/10.1016/j.enpol.2018.11.027.