En route to Paris?

Implications of the Paris Agreement for the German transport sector

Publication Details

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Preface

Dear readers,

When the global community ratified the Paris Agreement four years ago, its goal was to hold global warming well below 2°C and to pursue efforts to limit it to 1.5°C above pre-industrial levels. Yet global greenhouse emissions in the ensuing years have continued to hit record levels. To put it bluntly, the climate measures taken so far have been woefully inadequate, and the Paris targets risk slipping out of reach.

This ever-widening gap between what the global community is doing and what it needs to be doing was one of the reasons for undertaking this project. We wanted to know more about Germany's role in closing this gap and therefore commissioned a study to determine whether the country in general and its transport sector in particular are on track to meet the Paris targets.

The study's findings are a sobering read. The package of climate-related measures that the government recently put into effect hardly suffices to reach Germany's own 2030 targets, let alone those needed to keep global warming below 1.5°C. On its current course, Germany would not even meet the previous target of 2°C, which was the global standard before the Paris Agreement.

The new EU Commission, under the leadership of Ursula von der Leyen, plans to recommend within the next 100 days that Europe significantly increase its greenhouse gas reductions targets for 2030, from the current 40 per cent to 50–55 per cent relative to 1990 levels. The German presidency of the European Council in the second half of 2020 and the scheduled revisions of the National Determined Contributions (NDCs) for 2020 offers Germany the opportunity to finally make good on its Paris Agreement commitments. But Germany must not only ensure that its emission targets are consistent with the Paris goals. It must enact the measures needed to reach them.

This study identifies how quickly emissions must fall for the Paris climate targets to be achievable. Further reductions for 2030 represent an immense challenge, especially in the transport sector, whose emission levels have changed little since 1990. But anyone who is serious about fighting global warming must be ready to take on this challenge.

Christian Hochfeld
Executive Director, Agora Verkehrswende
Berlin, December 2019

Key Messages

1 To do its part in meeting the Paris Agreement targets, Germany must rapidly reduce its greenhouse gas emissions across all sectors. In its Special Report on Global Warming of 1.5°C, the IPPC identified mitigation pathways consistent with the Paris Agreement. From these, national and sectoral carbon budgets and emissions pathways can be derived that minimise overall global mitigation costs. For a least-cost pathway for limiting global warming to 1.5°C, Germany has to reduce its total domestic greenhouse gas emissions by 73 per cent by 2030 and by 98 per cent by 2050 relative to 1990 levels. The least-cost pathway for limiting global warming to 2°C would require Germany to cut its emissions by 68 per cent by 2030 and by 90 per cent by 2050.

2 Germany and the EU will have to raise their medium-term reduction targets if they are to be compatible with the Paris Agreement. Germany currently aims to reduce its domestic greenhouse gas emissions by 55 per cent by 2030. This is now not enough: Germany needs to set its sights on a more ambitious target. Moreover, it must urge the EU to significantly increase its current 2030 reduction target of 40 per cent. The Paris Agreement and Germany's Climate Action Plan 2050 require both to present these new, more ambitious plans in 2020.

3 A massive escalation of mitigation efforts is needed in the transport sector. Currently, Germany's Climate Action Plan calls for the reduction of transport sector emissions by 40–42 per cent by 2030. This goal is inconsistent with the Paris Agreement targets. For Germany to be on a least-cost pathway to keeping global warming below 1.5°C, its transport sector emissions need to fall by 53 per cent by 2030 relative to 1990 levels. Even limiting global warming to 2°C would require Germany to reduce its transport emissions by 44 percent by 2030. With the current policy trend, transport sector emissions in 2030 will be more than double the level permissible under the least-cost Paris Agreement 1.5°C pathway. If current trends continue beyond 2030, the German transport sector will have released, cumulatively, 5.4 billion tonnes of CO_2 between 2016 and 2050. This figure is more than twice the transport sector carbon budget of 2.6 billion tonnes consistent with staying on the 1.5°C pathway and still well beyond the 2°C pathway budget of 3 billion tonnes.

4 For the sake of climate equity, Germany's overall mitigation contribution needs to be higher than the level required by a least-cost emissions reduction pathway. In order to contribute its fair share to meeting the 1.5°C target, Germany would have to reduce its emissions – according to a central estimate – by 87 per cent by 2030 relative to 1990 levels. This exceeds its least-cost domestic reduction target by around 14 percentage points. Germany could close this gap by, for example, increasing its funding for international mitigation efforts.

5 Fast reductions of transport sector emissions and its full decarbonisation by 2050 are possible. Key elements in achieving these goals are a strongly accelerated electrification of passenger and freight transport linked to an intensified expansion of renewable electricity generation, a switch to public transport and other more sustainable forms of travel (such as walking or cycling), an increase in rail freight, and an overall more efficient organisation of the transport sector overall. To this end, alongside infrastructural and regulatory measures, pricing instruments – effective carbon pricing in particular – are of central importance.

Content

Executive Summary

Global budget for fossil fuel and industry related CO_2 emissions consistent with Paris Agreement Long-Term Temperature Goal

The PARIS Agreement Long-Term Temperature Goal (PA LTTG) aims at "[h]olding 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, recognising that this would significantly reduce the risks and impacts of climate change" (Art. 2.1 PA). This is, by design, a strengthening of the former "hold below 2°C" goal.

The IPCC Special Report on 1.5°C (SR15), adopted and published in October 2018, outlines pathways for limiting global warming to 1.5°C. We estimate a global budget for fossil fuel and industry related CO_2 emissions by calculating the cumulative CO_2 emissions resulting from socioeconomic pathways assessed by the IPCC to be consistent with the PA LTTG from 2016 (the year after the adoption of the PA) until the year these emissions reach net zero (around 2060). This budget amounts to 680 $GtCO_2$ (range 625-800 $GtCO_2$). Besides this 1.5°C budget, we also assess the implications for Germany of a global carbon budget that likely holds global warming below 2°C (1020 $GtCO_2$,, range 902-1199 $GtCO_2$).

The German Climate Action Plan and the Paris Agreement Long-Term Temperature Goal

The German Climate Action Plan 2050 aims at "extensive greenhouse gas neutrality" by 2050 and, specifically for the transport sector, a "virtually decarbonised" transport sector by 2050. The Climate Action Plan 2050 establishes specific sectoral targets for 2030 that add up to the 2030 national target of at least a 55% greenhouse gas (GHG) reduction from 1990 emission levels. For the transport sector, the sectoral target for 2030 is set as a reduction by 40–42 percent compared to 1990 emission levels.

While specific reductions at certain points in time – e.g. 2030, 2050 – are essential for planning and mapping out the required energy-economic transformations, the cumulative emissions that correspond to the overall emissions pathway are ultimately decisive for achieving the PA LTTG. The current targets need to be reviewed critically in this context.

A core objective of this study is to derive plausible CO_2 emissions pathways and corresponding budgets for the German transport sector consistent with the PA LTTG and discussing this in the context of current climate and transport policy in Germany.

The sectoral budgets derived from this study are aimed at defining a benchmark against which to assess the current transport policies, in particular in the context of implementing the Climate Action Plan 2050, with regard to the overall impact on global warming and the achievement of the PA LTTG.

German least-cost emissions pathways and budgets consistent with PA LTTG

We estimate PA compatible cost-optimal pathways and corresponding cumulative emissions for the transport sector as well as for the overall energy system in Germany. We do this by making use of Climate Analytics' SIAMESE (Simplified Integrated Assessment Model with Energy System Emulator) model to downscale the International Energy Agency (IEA) "Beyond 2 Degree Scenario" (B2DS) – as a proxy for a PA compatible 1.5°C pathway – from the EU28 to Germany, from 2014 to 2050. We assume a benchmark of zero energy-related emissions by 2050 in Germany. This is to reflect a German energy-related emissions pathway consistent with the PA and the German Climate Action Plan 2050, which aims to achieve GHG neutrality, and specifically, fully decarbonised electricity generation, a "mostly climate-neutral" building stock, and a "virtually decarbonised" transport sector by mid-century.

In addition, we have made two adjustments, to accurately reflect current national trends in emissions in the transport sector as well as in overall fossil fuel and industry CO_2 emissions:

- First, we harmonise the pathway to observed emissions in the starting year of the original scenario (2014) and derive a PA compatible carbon budget for the transport sector as well as for total fossil fuel

and industry CO_2 emissions for 2016–2050 for this pathway.
- Second, we take into account the observed emissions in Germany until 2018, and modify the emissions trajectory between 2019 and 2050, so that the total emissions budget derived from the original pathway is not exceeded. This requires faster reductions after 2019 and emissions reaching a lower level than in the original pathway at some point in time to fully compensate by 2050 for exceeding the original pathway early on (between 2014 and 2018). ("PA 1.5°C Pathway Delayed Start" in Figure 1ES).

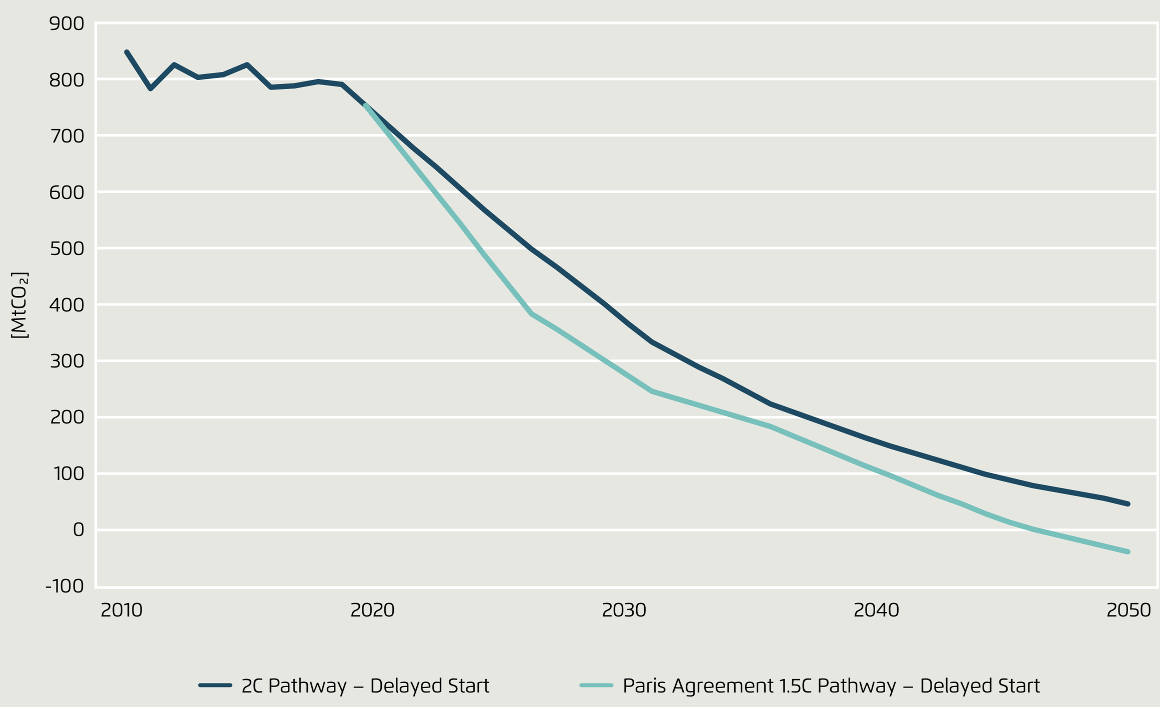
For the 1.5°C least-cost pathway taking into account historical emissions until 2018,, fossil fuel and industry CO_2 emissions have to be reduced by 76% by 2030 compared to 1990, and reduced to below zero by 2050.

We compare this 1.5°C pathway with a pathway and corresponding cumulative emissions that is consistent with the former "hold below 2°C" goal. We apply the same methodology as for the 1.5°C pathways, but use the IEA "2 Degree Scenario (2DS)" as a basis, and without any additional constraints, given the full decarbonisation target was introduced in the German Climate Action Plan based on the PA's more stringent LTTG. For the 2°C least-cost pathway, fossil fuel and industry CO_2 emissions have to be reduced by 68% by 2030 and by 95% by 2050 compared to 1990.

Comparision with results from equity approaches

Given that there are no agreed guidelines on what would constitute a fair level of contribution to the global mitigation effort, beyond the general understanding of it to reflect the "highest possible ambition" and "common but differentiated responsibilities and respective capabilities, in the light of different national circumstances" (PA,

Overall fossil fuel and industry CO_2 emissions in Germany under PA 1.5°C and 2°C pathways — Figure 1ES



Climate Analytics, own calculations

Article 4.3), for this study we include a wide range of views for what is an equitable contribution for Germany.

The scientific community and governments have put forward many equity proposals, based on different criteria and metrics. Our approach is to consider these views, if quantifiable, and not limit the analysis to any one in particular . We therefore evaluate a range of equity proposals, criteria and metrics in order to understand Germany's fair share of the responsibility in reducing emissions.

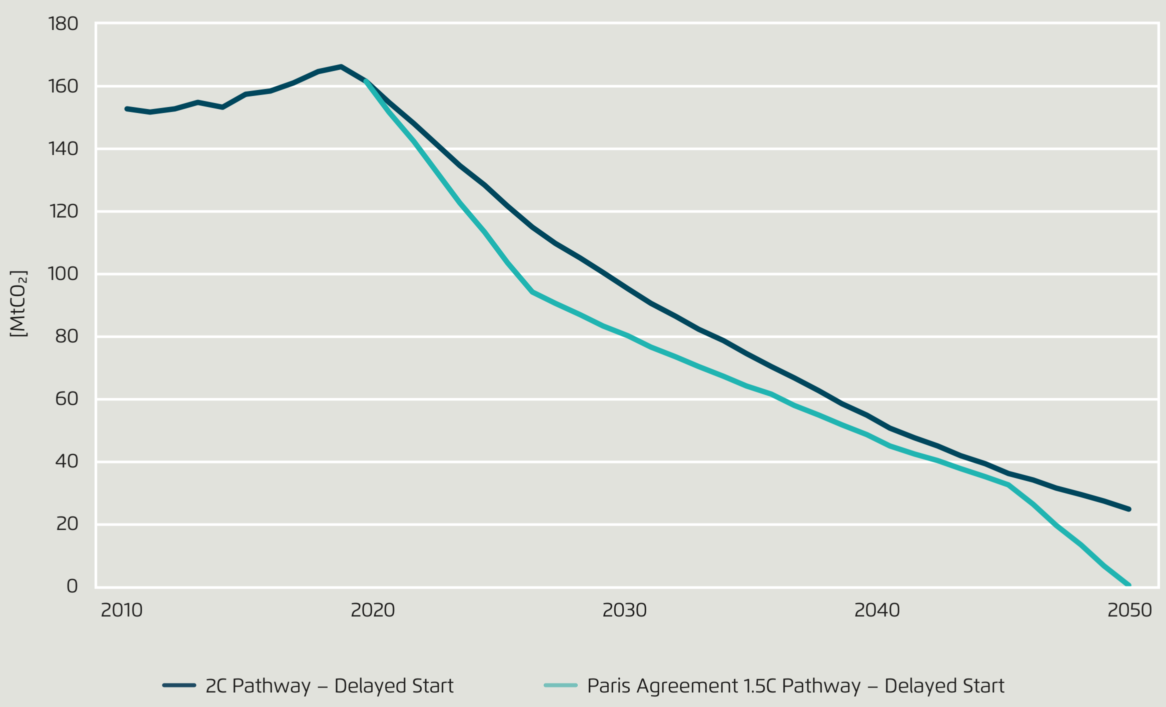
For a PA consistent 1.5°C pathway, overall GHG emissions have to decline by 73–74% compared to 1990 by 2030 in a least-cost pathway. This falls within the range of equity approaches of between 64 and 113% which we found, and below the central estimate of 87% reduction. All of these equity approaches imply higher reductions than the current 2030 reduction target for Germany (minus 55% for all GHG emissions). Most equity approaches imply, in addition to the already larger domestic reductions in the least-cost pathway, substantial additional investments in reducing emissions in other regions (developing countries).

German transport emissions: PA consistent pathways and emissions budgets

Results for the least-cost mitigation pathways for the transport sector are shown in Figure 2ES. Given the failure to reduce emissions in the past, delayed actions require deeper and faster emissions reductions between now and 2050.

A PA compatible 1.5°C emissions pathway for the German transport sector would require emissions be significantly lower in 2030 (53% below 1990 levels) than under the Climate Action Plan which assumes of 40-42% reduction. The current sectoral target of 40-42% reduction by 2030

CO_2 emissions from Transport under PA 1.5°C and 2°C pathways — Figure 2ES



Climate Analytics, own calculations

is therefore not consistent with the 1.5°C goal as well as with the overarching decarbonisation goal of the German Climate Action Plan 2050. Projections based on current policies show emissions would be more than twice as much as the 1.5°C consistent emissions level and more than 60% above the 2030 Climate Action Plan sectoral target. Germany is thus far from being on track to achieving the current – insufficient – sectoral target.

The transport sector carbon budget from 2016 to 2050 for a PA compatible 1.5°C pathway is about 2.6 $GtCO_2$. Present policy trends, if continued beyond 2030 until 2050, would lead to cumulative emissions of about 5.4 $GtCO_2$, more than double the 1.5°C budget, over the 2016-2050 period.

The 2°C budget for the transport sector from 2016 to 2050 of around 3 $GtCO_2$ is about 0.4 $GtCO_2$ higher than the budget for the 1.5°C goal. This is still much lower than the present policy trends could be expected to emit between 2016 and 2050. With a view to the transport sector's 2030 emissions target, it also holds for the former "hold below 2°C" goal that the sectoral target would need to be more ambitous (i.e., 44% reduction) than currently formulated in the Climate Action Plan 2050.

This underlines the mismatch between the current sectoral (and overall) 2030 emissions reduction targets and the overarching goal of the Climate Action Plan 2050 to implement the stronger PA LTTG.

Policy implications

We have shown that the current domestic 2030 mitigation targets, overall and for the transport sector in particular, are not consistent with the PA. Our analysis shows that the current 2030 sectoral target for transport emissions as currently defined in the Climate Action Plan is quite close – though still somewhat short of ambition - to those reductions required for the 2°C limit. Yet, it is clearly too weak for the stronger 1.5°C goal in the PA. The 2030 sectoral target is also not consistent with a least-cost pathway towards almost full decarbonisation of the transport sector in 2050, as layed out by the Climate Action Plan 2050.

Thus, the sectoral target for 2030 needs to be revised by 2020, together with the overall 2030 target, in line with the PA timeline and as agreed in the Climate Action Plan. This is consistent with the need for Germany to push for the EU to ratchet up its 2030 NDC target.

We also conclude that a PA pathway does not allow for any further delay in comprehensive mitigation action, especially in sectors like transport where negative emission technologies are not available. The more emissions reductions are delayed, the higher reductions have to be later on to stay within the limits for cumulative emissions, implying higher costs. Shifting reductions to other sectors is not an option, given the need to ratchet up overall emissions reductions.

Therefore, urgent measures are needed to reduce emissions and get on a pathway towards decarbonisation. Given recent technology developments, in particular vast reductions in renewable energy and energy storage costs, battery-electric (and fuel-cell vehicles) are opportunities for faster emissions reductions than envisaged in scenarios that were developed even just a few years ago. Besides contributing to achieving Germany's climate targets, deep emissions reductions in the transport sector bring along additional benefits, in particular through avoided health costs . These should be estimated and taken into account when defining the sector's climate strategy.

Key robust strategies for decarbonising the transport sector have been identified at global scale, as well as for the EU and Germany. The following measures, linked to the decarbonisation of electricity generation, are essential steps to get on track towards decarbonisation of the transport sector, with important further benefits such as avoided air pollution and creating more liveable cities:

- Speed up electrification of the transport sector; by 2035, only zero emissions passenger vehicles should be sold
- Support infrastructure development for electrification of both passenger and freight transport
- Policies to support a modal shift in passenger transport to public transport, cycling and walking
- Policies to support a modal shift in freight transport to rail in particular
- Implementation of targeted regulatory policies and pricing instruments, particularly effective carbon pricing

01 | Introduction

The German Climate Action Plan 2050 (Klimaschutzplan 2050) adopted by the German government and submitted to the UNFCCC in 2016 as Germany's Long Term Strategy was "guided by the Paris Agreement", with the aim to prevent the worst impacts of climate change, and based on the IPCC findings that even at a temperature of two degrees higher than preindustrial levels, impacts would "seriously compromise the basis underpinning our economic activity, food security and social cohesion worldwide".[1] The German Climate Action Plan 2050 was fully endorsed by the current government in its coalition agreement (Coalition Agreement 2018[2]). The Climate Action Plan 2050 aims at "extensive greenhouse gas neutrality" by 2050 and a "virtually decarbonised" transport sector by 2050, such as it "will not depend on fossil fuels containing carbon, which means it will also be largely greenhouse gas neutral". The Climate Action Plan affirms the overall greenhouse gas (GHG) reduction targets agreed in 2010 with the 'Energy concept': a reduction of all GHGs by at least 55% by 2030, and at least 70% reduction by 2040, and a reduction by 80–95% by 2050, all compared to 1990.[3] Overall "extensive greenhouse gas neutrality" by 2050 is generally interpreted as being consistent only with the most ambitious end of the range for 2050 (a 95% reduction). In §1 of its recently adopted Climate Protection Law (Klimaschutzgesetz), the federal government also confirmes the long-term target of GHG neutrality by 2050.

A new element introduced with the Climate Action Plan 2050 is the establishment of specific sectoral targets for each of the emitting sectors (energy, transport, buildings, industry, agriculture) that add up to the 2030 target of an at least 55% reduction. For the transport sector, the sectoral target for 2030 is set as a reduction by 40 to 42% compared to 1990.

1 Climate Action Plan 2050, Introduction. German Government (2016)

2 "Ein neuer Aufbruch für Europa Eine neue Dynamik für Deutschland Ein neuer Zusammenhalt für unser Land". Koalitionsvertrag zwischen CDU, CSU und SPD 19. Legislaturperiode. Available at: https://www.bundesregierung.de/resource/blob/975226/847984/5b8bc23590d4cb-2892b31c987ad672b7/2018-03-14-koalitionsvertrag-data.pdf?download=1

3 The targets refer to national emissions, without international aviation and shipping emissions, and without land use, land-use change and forestry (LULUCF) emissions

Already in 2016, the Climate Action Plan 2050 implicitly recognised the need to enhance the 2030 targets. It includes a review process for the intermediate targets, aligned with the ratcheting-up timeline of the Paris Agreement. It refers explicitly to the need for enhancing Nationally Determined Contributions (NDC) by 2020 – including the EU, which implies an enhanced 2030 target for Germany, the largest contributor to GHG emissions in the EU. The German Government agreed to hold the first review of the Climate Action Plan and its targets in 2019 or early 2020.

While targets for specific reductions at certain points in time – e.g. 2030, 2050 – are essential for planning and mapping out the required energy-economic transformations, the cumulative emissions that correspond to the overall emissions pathway are ultimately decisive for achieving the long-term temperature goal (LTTG) of the Paris Agreement (PA). In this context, a critical review of the current targets needs to take place.

This study focuses on assessing how to define the appropriate contribution of the German transport sector to achieving the PA LTTG and whether current climate policy in Germany is adequate in this context.

For this purpose, the study includes the following key elements:

- A science-based and transparent overview of current scientific understanding of pathways and corresponding CO_2 emission budgets (cumulative emissions), consistent with the PA LTTG, based on the IPCC Special Report on 1.5°C.
- An assessment of national emissions pathways and sectoral emissions pathways for the German transport sector as well as corresponding budgets, consistent with the PA LTTG, based on "least-cost" pathways - and a discussion of mitigation effort allocation approaches based on equity/fairness.
- Contrasting these pathways and budgets with current trends and projections for the German transport sector.
- Political assessment of the importance of the concept of emissions budgets/allowable cumulative emissions in the context of the PA LTTG and an outline of the implications of exceeding a sectoral budget for the transport sector.

The core objective of the study is to deduct plausible CO_2 emissions pathways and corresponding budgets for the German transport sector consistent with the PA LTTG and to discuss this in the context of current climate and transport policy in Germany.

The sectoral budgets derived in this study are aimed at defining a benchmark against which current political processes can be assessed, in particular in the context of implementing the Climate Action Plan 2050, with regard to the overall impact on global warming and the achievement of the PA LTTG.

02 | Pathways, cumulative emissions and budgets – Current scientific understanding and implications for policy

2.1 The Paris Agreement Long-Term Temperature Goal and its operationalisation: PA consistent mitigation pathways

With the Paris Agreement, the international community has adopted the objective of "[h]olding 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, recognising that this would significantly reduce the risks and impacts of climate change" (Art. 2.1 PA).

Article 4.1 of the PA is designed to operationalise the LTTG with global emission goals "in order to achieve the long-term temperature goal set out in Art. 2.1" – to peak global emissions "as soon as possible", followed by "rapid reductions thereafter", and to reach a "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century". The reductions are to be determined "according to best available science" so as to be consistent with the LTTG. The PA LTTG is, by design, a strengthening of the former "hold-below-2°C" goal.

The IPCC Special Report on 1.5°C (SR15) adopted and published in October 2018 outlines pathways for limiting global warming to 1.5°C and assesses global, regional, and sectoral transformations in the near-, mid- , and long-term, as well as synergies and trade-offs for sustainable development. With this, the SR15 currently provides the best available science for operationalising the LTTG. It provides the most comprehensive and up-to-date assessment of mitigation pathways consistent with the PA LTTG. The IPCC SR15 clearly shows that rapidly reducing emissions by 2030 – by around 45% compared to 2010 globally – is an important strategy in achieving the PA 1.5°C target and to avoid the risk of institutional and economic lock-ins with carbon intensive infrastructure, which will then be costly or more difficult to phase out later. Delaying emissions reductions would reduce the flexibility of future response options and increase the reliance on Carbon Dioxide Removal (CDR). All pathways require a rapid decarbonisation of energy systems by 2050, with global anthropogenic CO_2 emissions at net zero by around 2050.[4]

The IPCC SR15 found GHG emissions would have to fall to a level of 25-30 $GtCO_2eq$/year by 2030 under all pathways consistent with the PA LTTG. This is about half the level of emissions implied by full implementation of the current NDCs (52-58 $GtCO_2eq$/year). The IPCC therefore concludes that pathways reflecting the ambition level of the current NDCs would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030. The Climate Action Tracker (CAT) shows this pathway reflecting the ambition level of current NDCs leads to warming reaching 3°C by 2100.[5]

The PA's LTTG is a strengthening of the previous goal of holding warming "below 2°C", as agreed by the international community in Cancun in 2010. Pathways in the scientific literature, including in IPCC's Fifth Assessment Report (AR5), compatible with the former "below 2°C" goal have a typical peak warming of up to 1.8°C, and have a 66% or higher probability of holding warming during the 21st century below 2°C, but generally less than 50% probability of holding warming below 1.5°C. Note that in the underyling scientific literature, probabilities of holding warming below a certain level for a particular emissions pathway take into account uncertainties in the global carbon cycle and climate system. In this context, for example, a "median" warming level associated with a particular global emissions pathway means that 50% of a large collection of climate/carbon-cycle models shows warming above, and 50% shows warming below, the specified median warming level for that particular emissions pathway.

Given the strengthening of the LTTG in the PA, compared to the Cancun Agreements, emissions pathways compatible with the PA must increase substantially both the margin and likelihood by which warming is kept below 2°C when compared with these former "below 2°C" emis-

4 IPCC (2018)

5 Climate Action Tracker (2018a)

sions pathways, and simultaneously be consistent with the 1.5°C limit of the PA. This is reflected in the SR15 Summary for Policymakers (SPM) establishing 1.5°C compatible mitigation pathways as being pathways with no- or limited overshoot of 1.5°C. More specifically, this includes mitigation pathways that limit median global warming to 1.5°C throughout the 21st century without exceeding that level ("no-overshoot"), or that allow warming to drop below 1.5°C by the end of the century (around 1.3°C warming by 2100) after a brief and limited overshoot of median peak warming below 1.6°C around the 2060s ("low-overshoot").

Table 1 shows these two categories of 1.5°C pathways from the IPCC SR15 consistent with the PA LTTG. The IPCC SR15 also assessed two other categories of pathways that can both be related to the "below 2°C" goal and are shown in the lower half of Table 1. [6]

6 Climate Analytics (2019)
7 SR15 label is "1.5°C-no-OS"
8 SR15 label is "1.5°C-low-OS"
9 SR15 label is "1.5°C-high-OS"
10 SR15 label is "Lower-2°C"
11 Values in this table were taken from Table 2.A.12 in Chapter 2 Annex of the IPCC Special Report.

The focus on no- and limited overshoot pathways is important because the level of overshoot temperature drives many climate impacts. The IPCC SR15 is very clear about the increases in climate risks between 1.5°C and 2°C, which relate to the clause of the LTTG that holding warming well below 2°C significantly reduces the risks and impacts of climate change. This provides a clear argument for a lower limit to peak warming. The "hold below 2°C" pathways discussed in much of the literature and in the IPCC reports predating the PA do not provide a perspective on limiting the temperature increase to 1.5°C. Their 2030 emissions levels are far above those in 1.5°C-compatible pathways (no- and limited overshoot), as shown in IPCC SR15, so that 1.5°C would be out of reach, unless extreme CDR levels are achieved by 2050, which the Special Report does not deem feasible for technical, economic and sustainability reasons. [12]

In the context of defining the broad features of these pathways, it is important to note that the IPCC SR15 identified limits based on sustainability and economic constraints for CDR. The IPCC finds limits for a sustainable use of the two main CDR options: bioenergy with carbon capture and storage (BECCS)[13] as well as aforestation

12 Wachsmuth, Schaeffer, Hare (2018)
13 Bioenergy with Carbon Capture and Storage, defined in

Selected pathway characteristics from IPCC Special Report on 1.5°C focused on climate-projections. Values represent median (25th to 75th percentile) levels across pathways. Table 1

SR15 pathway category	Peak warming (°C above PI)	Probability of peak warming <2°C	Probability of warming by 2100 <1.5°C	Probability of warming by 2100 <2°C
No-overshoot 1.5°C ("Paris Agreement 1.5°C pathways")[7]	1.5°C (1.4–1.5°C)	95% (93–96%)	84% (76–88%)	97% (94–98%)
Low-overshoot 1.5°C ("Paris Agreement 1.5°C pathways")[8]	1.6°C (1.5–1.6°C)	90% (86–93%)	72% (55–83%)	93% (88–96%)
Below 2°C – return to 1.5°C by 2100 ("Cancun Agreement 2°C pathways")[9]	1.7°C (1.6–1.9°C)	82% (66–89%)	66% (50–80%)	92% (86–96%)
Below 2°C ("Cancun Agreement 2°C pathways")[10]	1.7°C (1.5–1.8°C)	74% (66–88%)	35% (20–49%)	80% (66–87%)

Climate Analytics (2019)[11]

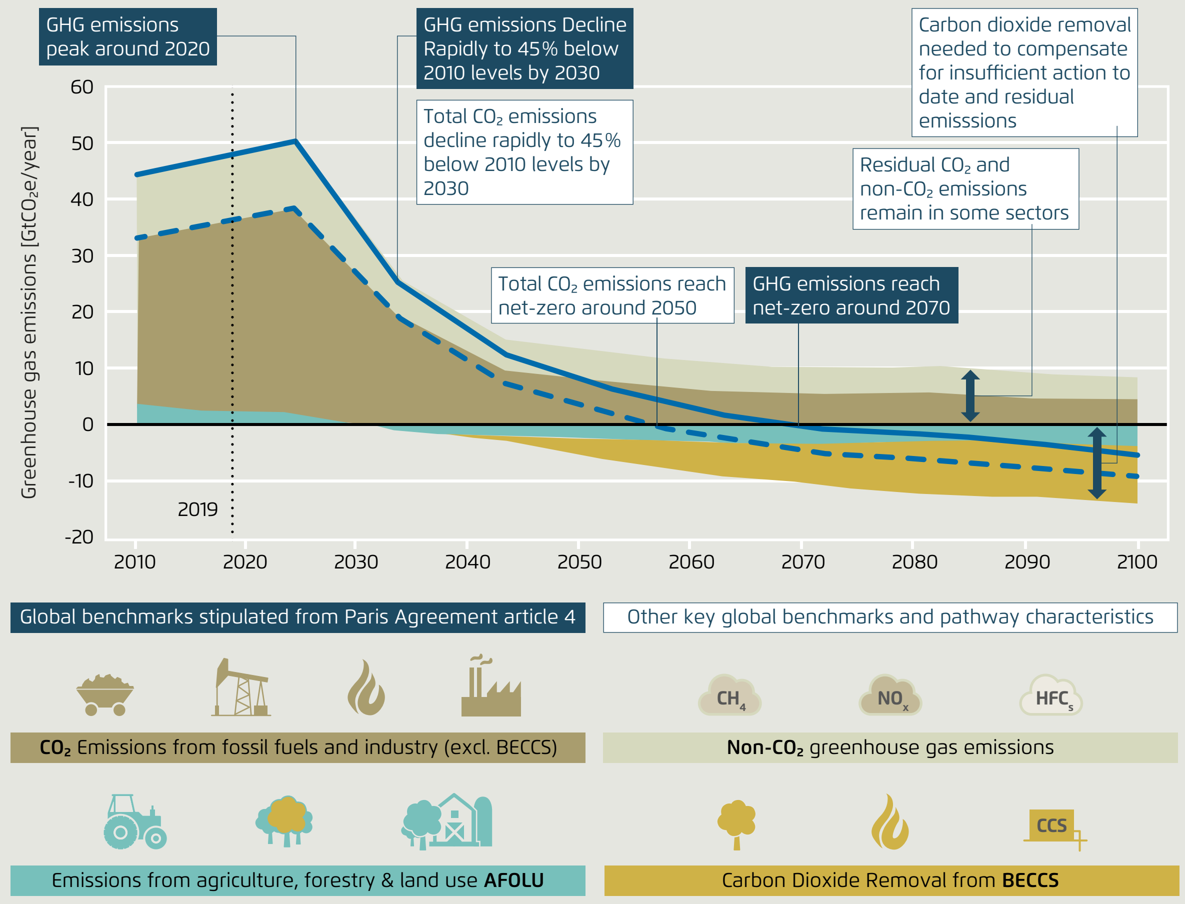
and reforestation. The IPCC assesses these limits, globally in 2050, as below 5 $GtCO_2$/yr for BECCS and below 3.6 $GtCO_2$/yr for sequestration through afforestation and reforestation. The SR15 and underlying literature note that data on limits to the sustainable use and economic and technical potential beyond 2050 is much more limited. However, in general, SR15 pathways that deploy CDR by 2050 within sustainability limits around that time also have more limited use of CDR in the post-2050 period than pathways that exceed 2050 limits. Excluding pathways that exceed sustainability limits identified in the IPCC SR15 implies less possibility to rely on carbon dioxide removal and therefore imply faster reduction of GHG emissions by 2030.

SR15 glossary as: "Carbon dioxide capture and storage (CCS) technology applied to a bioenergy facility. Note that depending on the total emissions of the BECCS supply chain, carbon dioxide can be removed from the atmosphere."

14 Benchmarks in Paris Agreement Article 4.1 for operationalisation of Article 2.1 (dark blue boxes) and global decarbonisation benchmarks (white box). This representative pathway is the median across all 1.5°C-compatible pathways from the IPCC SR15 that reach levels of Carbon Dioxide Removal (CDR) below the upper end of estimates

Illustration of the three stages to achieve the PA LTTG[14] — Figure 1

What the UN Intergovernmental Panel on Climate Change Special Report on 1.5°C tells us about global pathways to achieve Paris Agreement 1.5°C temperature goal that take into account sustainability goals



Climate Analytics (2019)

Figure 1 illustrates the PA 1.5°C pathways and the three stages of global transformation and mitigation strategies as outlined in Art. 4.1 (peak, rapid decline and zero GHG emissions) as well as key mitigation benchmarks for decarbonisation (zero net CO_2 emissions around 2050).[15] This figure is based on the set of Integrated Assessment Model (IAM) pathways assessed in the IPCC SR15, filtered to include only pathways with no or limited overshoot as explained above, and to exclude those that exceed the sustainability limits of carbon dioxide removal around the 2050s.

In these PA 1.5°C mitigation pathways, total GHG emissions peak around 2020 and decrease rapidly to global net zero around 2070. CO_2 emissions also peak around 2020 and decrease to global net zero around 2050. Negative emissions are necessary afterwards, in order to compensate for insufficient action to date and for remaining emissions from sectors where emissions cannot be reduced to zero (such as agriculture) or are seen as more difficult/more costly to reduce in the models. At the same time, the global population, GDP and economic activity continue to grow throughout the century. Even with the full extent of energy efficiency improvements and decarbonisation of most sectors, the pathways show remaining CO_2 emissions from fossil fuels (especially oil and gas), for instance in the transport sector, from aviation in particular, and in the industry sector where full electrification is considered possible, but very expensive, e.g. in steel making and other high-temperature industrial processes.

for sustainable, technical and economic potential around 2050 from SR15 in the sector of Agriculture, Forestry and Land-Use (AFOLU), as well as via Bioenergy combined with Carbon Capture and Storage (BECCS). All emissions and removals where calculated from the median emissions levels across the 46 pathways in the SR15 scenario database that are 1.5°C compatible, that satisfied the limits to CDR mentioned, and that reported data for all variables included here (Source: SR15 scenario database https://data.ene.iiasa.ac.at/iamc-1.5c-explorer, accessed 22 October, 2018)

15 Climate Analytics (2019)

2.2 Approaches to global budgets in line with the PA LTTG

One approach to estimating the remaining carbon budget has been derived in the scientific literature from multiple lines of evidence and the physical understanding of the relationship between cumulative carbon dioxide emissions and global warming. This physical understanding provides the basis for the linear relationship between temperature and cumulative CO_2 emissions. It should be emphasized that this linearity is therefore an empirical finding from scientific evidence and is not an assumption.[16] The literature underlying this approach to quantifying carbon budgets applies to total net CO_2 emissions, including both fossil-fuel and land-use emissions.

The response of the carbon-cycle/climate system is indifferent to shifts in emissions and reductions between the fossil-fuel and land-use components, as long as the total net emissions remain the same. The relation between cumulative net CO_2 emissions and temperature increase implies that the year in which global net CO_2 emissions become zero (and hence cumulative net CO_2 emissions no longer increase) generally coincides with the year of peak warming. As mentioned above, this is en empirical finding derived from multiple lines of evidence. The net warming effects of non-CO_2 emissions change this general relationship somewhat, so that in most 1.5°C pathways peak warming occurs about 10 years before CO_2 emissions reach net zero, primarily due to strong reductions in CH4 emissions preceding net zero CO_2. Accounting for remaining warming effects of non-CO_2 emissions which cannot be eliminated completely, total global net CO_2 emissions would subsequently have to turn negative to allow warming to gradually decline from peak warming levels, and stronger net-negative emissions would be needed for a higher probability of driving temperatures below 1.5°C by the end of century.

Here, we follow an approach that allows for policy-relevant conclusions related to the adequacy of mid- and long-term emissions reduction targets. It takes into account important factors that affect the achievement of a temperature limit or goal: emissions pathways need to be technically and economically feasible and take into account limits for the use of CDR based on sustainability

16 IPCC (2014), Meinshausen (2009)

and economic considerations. This approach therefore links directly to the operationalisation of the PA LTTG through Art. 4.1. and the way in which a GHG budget consistent with the LTTG could be "spent" according to Art. 4.1. and as laid out towards the end of the article: "on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty".

We therefore calculate a global budget for fossil fuel and industry related CO_2 emissions (incl. BECCS) by calculating the cumulative CO_2 emissions from 2016 (the year after the adoption of the Paris Agreement) to the year of zero net global (fossil fuel and industry related) CO_2 emissions (incl. BECCS), resulting from socioeconomic pathways assessed by the IPCC to be consistent with the PA LTTG.

PA LTTG consistent pathways as outlined in the previous section reach global net zero total CO_2 emissions around 2050 (including land use and land-use change emissions, and "negative emissions" in these and other sectors), and reach net zero fossil fuel and industry CO_2 emissions (incl. BECCS) some 10 years later. The resulting cumulative fossil fuel and industry CO_2 emissions from 2016 to the year of (net) zero emissions for these PA 1.5°C pathways are 680 $GtCO_2$ (range 625-800 $GtCO_2$) and about 72 $GtCO_2$ less from 2018 onwards, to account for historical emissions 2016-2018.[17] The cumulative emissions from 2016 to 2100 amount to 540 $GtCO_2$ (range 395-775 $GtCO_2$). The cumulative CO_2 emissions (incl. BECCS) until 2100 are somewhat lower (and uncertainty is larger), because of negative emissions increasingly happening in the second half of the century to compensate for emissions that cannot be reduced to zero (such as some of the agriculture and industry process related emissions) as well as for excessive emissions in the past.[18] Note that if CO_2 emissions from land use, land-use change and forestry, are included, the resulting total cumulative CO_2 emissions from 2016 until end-of-century – including the land-use sector - are substantially lower (370 $GtCO_2$, range 250-620 $GtCO_2$ not shown in table 1), because of the carbon dioxide removals that the models typically show in the land-use sector in 1.5°C (and 2°C) compatible pathways from time of zero total CO_2 emissions to end of century.

Table 2 shows the comparison of these results for PA 1.5°C pathways and for those pathways that are consistent with the "hold below 2°C" goal agreed by the international community in Cancun in 2010, and which was the basis for the EU and Germany adopting a long term target of reducing emissions by 80-95% by 2050 compared to 1990. All pathways analysed here are from the IPCC SR15 database (see also Table 1 for details).

17 LeQueré et al (2018)

18 For pathways that overshoot 1.5°C by a larger amount and apply higher levels of CDR to return to below 1.5°C, the cumulative emissions until the end of the century are substantially lower than cumulative emissions until the year of zero total CO_2 emissions and peak warming. These pathways are not included in the set of PA LTTG pathways for reasons explained earlier.

19 Values represent median (and 50% ranges) across all 1.5°C-compatible and 2°C pathways from the IPCC SR15 database (Climate Analytics (2018a)) that reach levels of carbon dioxide removal (CDR) below the upper end of estimates for sustainable, technical and economic potential around 2050 from SR15 in the agriculture, forestry and landuse (AFOLU) sector, as well as via bioenergy combined with carbon capture and storage (BECCS).

Cumulative fossil-fuel and industry emissions of CO_2 for PA 1.5°C-compatible and "hold below 2°C" pathways[19]

Table 2

Warming limit	2016–to year of zero emissions	2018–to year of zero emissions	2016–2100	2018–2100
Paris Agreement 1.5°C pathways	680 (625–800)	610 (555–730)	540 (395–775)	470 (320–700)
Cancun Agreement 2°C pathways	1020 (902–1199)	950 (830–1128)	925 (846–1196)	855 (776–1124)

Climate Analytics (2019)

03 | Quantifying national budgets for energy related CO_2 emissions for Germany

3.1 National contribution to mitigation effort: Least-cost and equity approaches

Integrated Assessment Models (IAMs) are used to develop mitigation pathways as described in section 2.1. They provide an estimate of domestic mitigation contributions across geographic regions, as well as for all sectors, aiming at minimising overall global mitigation costs whilst meeting a climate or carbon budget target. By doing so, IAMs take into account the interactions between economic development, energy consumption and climate change emissions, under "idealised" conditions (for example a global carbon price or emissions trading scheme). The outcome is an estimate of "economically optimal" domestic contributions. IAMs have clear limitations, such as the way most of the models are set up, where mitigation of climate change is always more expensive than non-action (resulting from assessing least-cost pathway mitigation costs compared to a business-as-usual (BAU) scenario, and starting from the assumption that the BAU scenario is already economically optimal). [20] Also, by relying on the assumption of a cost minimising allocation of mitigation efforts through applying a uniform carbon price, they abstract from any market imperfections. Furthermore, in general, avoided negative externalities, such as the damages due to climate change or the costs of air pollution from continued use of fossil energy, are not included. This means that net ecomomic costs of meeting the PA 1.5°C limit are likely to be lower than the top level findings of the IAMs which represent only the direct mitigation costs and not the co-benefits of mitigation. Further, these models represent past technologies and trends much better than newer technologies whose future costs and deployment pathways are harder to predict. As a consequence, experience shows that most IAMs tend to have a conservative view of the potential for transformational change.

In contrast to IAMs, equity approaches try to answer a very different question: what is a "fair share" for a country / region in the global mitigation effort? The results of IAMs can help to interpret the results of equity approaches but they cannot be compared on a like-for-like basis. A range of criteria for defining a "fair share" have been proposed such as (historical) responsibility, capability, and equality, and used to implement different quantitative equity approaches. In general, these approaches do not assume that mitigation occurs fully where the effort is being allocated based on equity approaches. The difference between the mitigation effort for a region or country based on an equity approach on the one hand, and the least-cost contribution on the other hand, if the latter leads to larger reductions than the former, can give an indication of the need for financial or other support (typically for developing countries) in achieving the mitigation effort that corresponds to the least-cost distribution. Conversely, if the equity consideration leads to larger reductions than the least-cost approach, these provide an indication of the expectation for a country (typically developed) to contribute to financing and/or supporting mitigation efforts in other countries.

Given that the targets defined for the German emissions reductions are all related to domestic mitigation efforts, the least-cost distribution is the best estimate for the mitigation effort that Germany should aim at in its domestic climate policy to be consistent with the PA LTTG.

The IPCC database of mitigation pathways used for the analysis at global scale in Section 2.1 does not provide data at the level of the EU separately, let alone for Germany. We therefore use a scenario with a higher geographical resolution, which can be shown to be consistent with the PA 1.5°C compatible mitigation pathways: the IEA "Energy Technology Perspective" (ETP)[21] so-called "Beyond 2°C Scenario" (B2DS).[22]

20 Climate Analytics (2018a)

21 IEA (2017)

22 Climate Analytics (2018b). See Climate Action Tracker (2018b) for a detailed explanation: The warming impact of the IEA B2DS depends on the assumptions made for non-energy-related and non-CO_2 emissions. The IEA estimated a peak global warming of 1.75°C. However, if the average assumptions are applied as in comparable mitigation scenarios as analysed by the IPCC, and if the pathway is extended beyond 2060 (the final year in B2DS) allowing for net negative emissions in the energy sector, at a level similar to that in other scenarios assessed by the IPCC, then we find that the B2DS reaches peak warming of 1.6°C and warming drops below 1.5°C before 2100. With these additional assumptions B2DS would therefore fully classify as what IPCC SR15 calls a no- or limited overshoot pathway. Indeed, IPCC SR15 in Chapter 2 notes "… this [B2DS] scenario can give information related to a 1.5°C overshoot pathway up to 2050."

The IPCC Special Report on 1.5°C assessed the B2DS and found that characteristics of the energy system in this scenario are comparable to the range of mitigation pathways that achieve the 1.5°C limit with no- or limited overshoot, and B2DS would thus be consistent with the PA LTTG. Similarly, the IEA ETP "2°C Scenario" (2DS) provides a close analogue to a "hold below 2°C" pathway.[23]

We estimate the PA compatible cost optimal pathway for domestic emissions reduction in Germany for the transport sector as well as for the overall energy system by making use of Climate Analytics' SIAMESE (Simplified Integrated Assessment Model with Energy System Emulator) model.[24] This approach is consistent with other studies looking at national implications of results from global and regional energy models.[25]

3.2 Least-cost pathways and benchmarks for a decarbonised energy system

The IEA B2DS scenario leads to decarbonised electricity generation before 2050, in 2045, with net negative emissions thereafter. While the scenario achieves decarbonisation partly including fossil fuel use with CCS, as well as nuclear, this can also be achieved through 100% renewable energy and therefore completely fossil fuel free electricity generation[26].

The IEA B2DS scenario appears very conservative in its assumptions about the mitigation options in the transport sector, both for passenger and freight transport.[27]

23 SR15 in Chapter 2 notes "... IEA-2DS stays in the range of 2°C-consistent IAM pathways." Global cumulative CO_2 emissions from fossil fuels and industry are about 950 $GtCO_2$ in the ETP 2DS scenario over its time frame 2015–2060. This is within the range of IPCC SR15 "lower 2°C" pathways (840–1030) over that same time). With a probability to hold warming below 2°C of at least 66% (66-78%), the "lower 2°C" pathway category would reflect what we call in this report "hold below 2°C" Cancun goal pathways (see supplementary material to Chapter 2 Table 2.SM.12 of IPCC SR15 and also Table 1 in this report).

24 Sferra, et al. (2019)

25 Climate Analytics (2018b)

26 Climate Action Tracker (2018b)

27 This also holds for the IEA 2DS scenario, see section 3.4

In particular, in this scenario, the transport sector is not yet fully decarbonised by 2050 in the EU28, even though it does show a transition towards technological options that allow full decarbonisation through electrification or use of alternative fuels. The scenario does not envisage a prominent role for hydrogen in the transport sector. However, recent studies see a more viable future in green hydrogen-powered vehicles especially for fuel cell trucks to cover long range freight transport, given the rapid decrease in the cost of generating electricity from renewable energy.[28]

Based on more recent analysis of mitigation potential in the transport sector, both for passenger and freight road emissions, including a faster electrification and introduction of renewable hydrogen (or synthetic fuels generated with electricity from renewable energy), the benchmark for achieving a fully decarbonised passenger[29] and freight land transport[30] should be 2050.

Such a benchmark would result in a faster decarbonisation of the transport sector and therefore reduce reliance on CDR options for negative emissions. It can be achieved based on existing technical and economic options for zero emissions transport including renewable energy based battery-electric and fuel-cell vehicles, in addition to higher efficiency, demand reduction and modal shifts from road to rail. Developments are happening faster than expected and than is reflected in model analysis such as in the IEA/ETP B2DS.

Aiming for decarbonised, fossil fuel free passenger and freight transport by 2050 is also consistent with the goal of the German Climate Action Plan 2050 to achieve a "virtually decarbonised" transport sector by 2050.

The scope of emissions covered by the transport sector in this study is consistent with the sectoral definition in the Climate Action Plan 2050 – covering all direct emissions (that is, not emissions resulting from electricity generation),[31] and including domestic aviation and shipping (but not international aviation and shipping) and excludes

28 RenewEconomy (2018)

29 Climate Action Tracker (2016)

30 Climate Action Tracker (2018c)

31 Hence emissions from production of Efuels are covered under the electricity sector

construction sector transport (allocated to the industry sector) and agricultural transport (allocated to the agriculture sector). Here we only look at CO_2 emissions, which cover about 99% of all GHG emissions within the sector, with only a small share of non CO_2 emissions, mostly N2O emissions.[32]

3.3. Quantifying Paris Agreement compatible 1.5°C pathways and budgets for Germany's energy and industry related emissions

Looking at the overall fossil fuel and industry CO_2 emissions, global PA 1.5°C mitigation pathways are characterised by a fully decarbonised primary energy supply approximately by mid-century, that is, a zero-emission energy supply system based on renewable energy including sustainable biomass use, and fossil fuel use only with CCS. These pathways also are characterised by fully decarbonised electricity generation before 2050, mainly through the increase of the use of renewable energy, but also other options such as nuclear and fossil fuel use with CCS. As fossil fuel use with CCS does not reduce emissions to zero, these need to be compensated through the deployment of negative emission technologies such as BECCS or direct air capture (DAC); this also applies to other residual fossil fuel emissions (for example aviation, industry). However, fossil fuel use with CCS - and also nuclear energy - can be replaced with renewable energy, with lower costs. An increasing number of studies show the feasibility of scenarios for 100% renewable energy for power generation. Another charactericstic of the IAM pathways assessed by the IPCC in the SR15 is the electrification of end-use sectors (transport, buildings, and some industry processes) as well as decarbonisation[33] of final energy other than electricity (for example through the use of biofuels, hydrogen, or other energy carriers for aviation, shipping, and some industry processes).

32 Öko-Institut (2018)

33 The IPCC SR15 (IPCC, 2018) Glossary defines "Decarbonisation" as the "the process by which countries, individuals or other entities aim to achieve zero fossil carbon existence. Typically refers to a reduction of the carbon emissions associated with electricity, industry and transport".

To reflect this for the German energy related emissions pathway, and consistent with the German Climate Action Plan 2050 goal of achieving extensive GHG neutrality by mid-century, fully decarbonised electricity generation and a "mostly climate-neutral" building stock, we assume a benchmark of net zero emissions by 2050 for all energy related emissions for Germany, which can include the use of negative emissions. We also take into account the decision to phase out nuclear energy by 2022 and the targets for renewable energy share in the power mix of at least 40% by 2025 and 65% by 2030.

We employ the SIAMESE model (see Annex 1) to downscale the IEA B2DS PA compatible pathway from the EU28 to Germany, from 2014 to 2050, with the additional constraint of achieving complete decarbonisation of all energy and industry sectors by 2050 (including the option of negative emissions technologies) which then still leaves space for some remaining non-energy-related/non CO_2 emissions. The PA least-cost pathway consistent with the nuclear phase out leads to a higher share of renewable energy of 85% by 2030 in the power sector than the current target of 65%.

To reflect accurately current national trends in emissions in the transport sector and in overall fossil fuel and industry CO_2 emissions, we made two adjustments to the downscaled pathway for Germany:

- First, we harmonise the pathway to reflect observed emissions in the starting year of the scenario (2014) and derive a PA compatible carbon budget for transport as well as for overall fossil fuel and industry CO_2 emissions for 2016–2050 in this pathway.
- Second, we take into account the historical emissions in Germany until 2018, and modify the emissions trajectory between 2019 and 2050, so that the total emissions budget derived from the original pathway is not exceeded. This requires faster reductions after 2018 and emissions reaching a lower level than in the original pathway at some point in time to fully compensate by 2050 for exceeding the original pathway early on (between 2014 and 2018). ("Delayed start pathway" in Figure 2).

As explained in section 3.1, an important qualifier, among others, for least-cost pathways is that these are derived without taking co-benefits into account, which

Overall fossil fuel and industry CO_2 emissions and carbon budgets under 1.5°C pathways for Germany[35]

Table 3

	1.5°C Pathways		Current policy projections
	Climate policies from 2014	Climate policies from 2019	
2030 Emissions ($MtCO_2$)	256 (76% below 1990)	252 (76% below 1990)	645 (39% below 1990)
2050 Emissions ($MtCO_2$)	-32 (103% below 1990)	-32 (103% below 1990)	
Cumulative emissions (2016-2050) $GtCO_2$	9.7	9.7	

Climate Analytics, own calculations

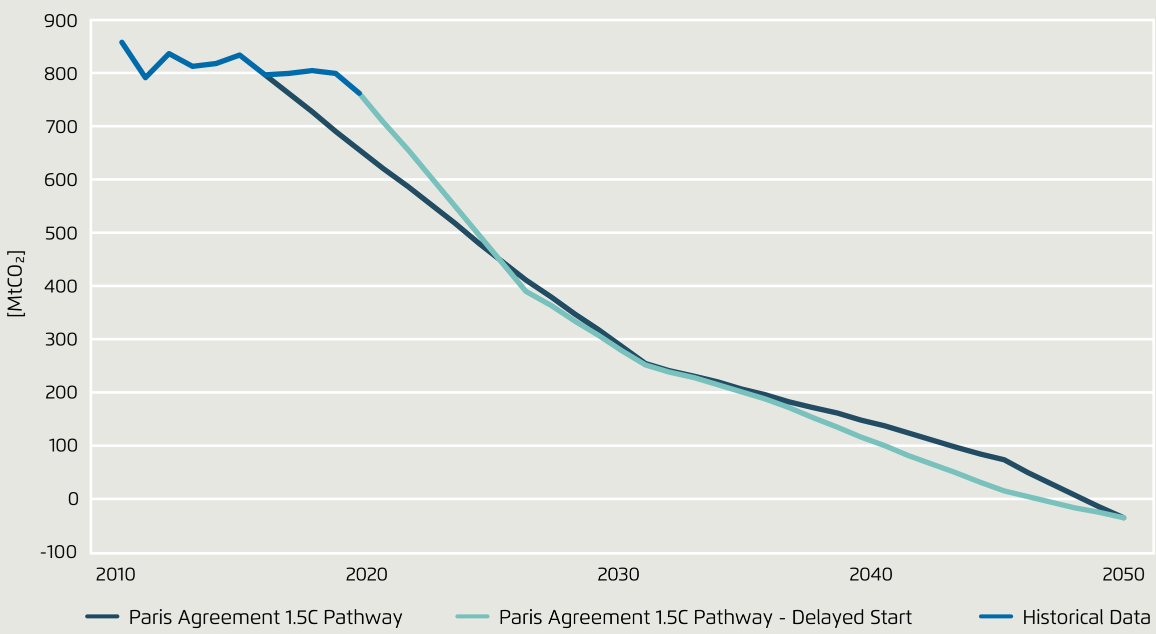
are particularly pertinent for the transport sector such as avoided health costs (associated with reduced air pollution) . These are known to be quite large in Germany and deeper reductions would result in related economic benefits.

34 With a 100% decarbonisation goal across sectors by 2050, with climate policies starting in 2014 or 2019. Current policy projections: With Measures Scenario (WMS); see 2019 Projection Report (Table 100). Pathways include negative emissions.

35 Pathways starting in 2014 (based on original IEA B2DS pathway) and with delayed start in 2019. Historical emissions until 2018 (Source: UBA (2019a, b). Pathways are in line with the 2050 goal in Germany's long term strategy, aiming at a full (100%) decarbonisation goal in all energy related sectors by 2050.

Overall fossil fuel and industry CO_2 emissions in Germany under PA 1.5°C pathways[36]

Figure 2



Authors' figure

3.4 Comparison with results for 2°C pathways

Prior to the adoption of the Paris Agreement, the EU recognised the 2°C limit (Council of the European Union, 2007), which was eventually agreed internationally in Cancun in 2010. After a review process ended in 2015, the UNFCCC concluded that warming of 2°C cannot be considered safe (UNFCCC, 2015c), which paved the way for the PA's LTTG. The PA goes beyond the former 2°C goal and aims to hold the rise in temperature to well below 2°C and to pursue efforts to limit warming to 1.5°C. This has important implications for the emissions pathways in Europe and Germany as deeper emissions reductions are needed by 2030 and the achievement of net zero GHG emissions (in line with Article 4.1) needs to be earlier than under the former "hold below 2°C" goal.

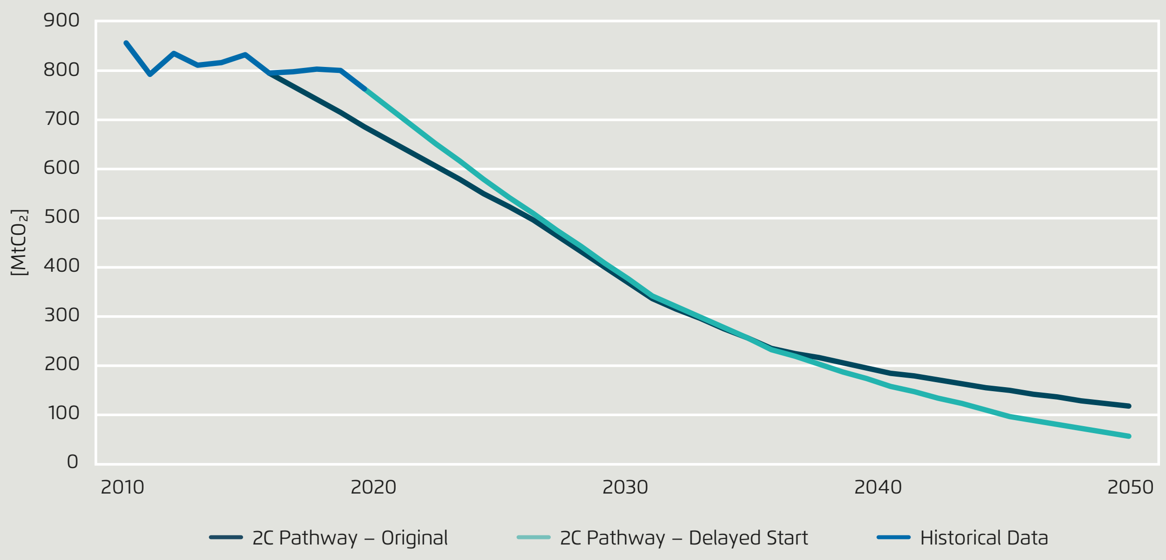
Here, we analyse a hold below 2°C pathway and corresponding cumulative emissions applying the same methodology as for the 1.5°C pathway (section 3.3), but for the IEA 2DS Scenario, and without any additional constraints, given the full decarbonisation target was introduced in the German Climate Action Plan based on the PA and its more stringent LTTG. The reductions in 2050 are within the previously agreed range (80-95%) that was defined before the PA.

A key difference between the results for a PA consistent 1.5°C pathway (based on the IEA B2DS and additional constraint of full decarbonisation as shown in section 3.3) and the 2°C pathway based on IEA 2DS (see Figure 3) relates to the 2030 emissions level. By 2030, overall fossil fuel and industry CO_2 emissions in Germany need to be reduced by 76% compared to 1990 for a 1.5°C pathway (Table 3), whereas the reduction would be 68% for the 2°C pathway (Table 4).

The 2°C budget is 2.2 Gt larger than for the 1.5°C pathway, but is smaller than the cumulative emissions resulting from the pathway implied by the Energy concept/Climate Action Plan 2050 targets, which amount to more than 15 Gt CO_2 even for the 95% overall GHG reduction target (see UBA 2017, which calculates a budget of more than 20 Gt for 2010-2050, which results in 15.2 Gt for 2016-2050, deducting historical emissions for 2010-2015).

36 Pathways starting in 2014 (based on original IEA 2DS pathway) and with delayed start in 2019. Historical emissions until 2018 (Source: UBA (2019a, b).

Overall fossil fuel and industry CO_2 emissions in Germany under 2°C pathways[37] — Figure 3



Authors' figure

Overall fossil fuel and industry CO_2 emissions and carbon budgets under 2°C pathways for Germany[38]

Table 4

	2°C Pathways		Current policy projections
	Climate policies from 2014	Climate policies from 2019	
2030 Emissions ($MtCO_2$)	332 (68% below 1990)	338 (68% below 1990)	645 (39% below 1990)
2050 Emissions ($MtCO_2$)	114 (89% below 1990)	54 (95% below 1990)	
Cumulative emissions (2016–2050) $GtCO_2$	11.9	11.9	

Climate Analytics, own calculations

That is, even for the former hold below 2°C goal, the current level of mitigation needs to be ramped up. Ratification of the PA just adds on to this, given that the PA's LTTG goes beyond the former hold below 2°C goal.

3.5 Comparison with results from equity approaches

Given that there are no agreed guidelines on what would constitute a fair level of contribution to the global effort, beyond the general understanding of it to reflect the "highest possible ambition" and "common but differentiated responsibilities and respective capabilities, in the light of different national circumstances" (PA, Article 4.3), for this study we include a wide range of views on what is an equitable contribution for Germany.

The scientific community and governments have put forward many equity proposals, based on different criteria and metrics (see Box for two examples). Our approach is to consider these different views, if quantifiable, and not limit the analysis to any particular one of them. We therefore evaluate a range of equity proposals, criteria and metrics in order to understand Germany's responsibility for emissions reduction, using our Equity Analysis tool.[38]

Based on a wide range of equity proposals and concepts, we defined roughly 40 equity regimes to allocate mitigation efforts across countries in the world, with the goal of capturing the widest possible range and outcomes in terms of emissions reductions for Germany. These regimes are based on the following proposals, criteria and metrics:

- Different methodologies: Greenhouse Development Rights (GDR)[39], per capita convergence[40], South North Proposal, South African proposal, Chinese proposal, proposal based solely on historical responsibility, proposal based on historical responsibility and capability, proposal based on potential, historical responsibility, and capability (see Annex 2 for more detailed information on the different proposals).
- Different starting years for historical period (1950, 1970, 1990)
- Different weighting schemes for the criteria (e.g. 50/50 responsibility and capability vs 75/25)
- Different metrics for the criteria (e.g. capability measures in terms of Human Development Index (HDI) or Gross Domestic Product based on Purchasing Power Parity (GDPPPP) and their different impacts)

For a more detailed description of the equity methodology, see Annex 2. In Table 5, we compare results from equity approaches with the results for least-cost pathways outlined in section 3.3.

37 With climate policies starting in 2014 or 2019. Current policy projections: With Measures Scenario (WMS); see 2019 Projection Report (Table 100).
38 Climate Analytics(2016)

39 Kartha et al. (2009)
40 Agarwal and Narain (1991); Meyer (2000)

Examples of equity approaches (for more details see Annex 2)

Greenhouse Development Rights - The Greenhouse Development Rights Framework (GDR framework) seeks to not only acknowledge the right to development but to actually place that right at its structural core. Individuals that find themselves below a specific development threshold are given the opportunity to develop and are not supposed to shoulder the burden of solving the climate problem. Capacity is thus defined as income, excluding all income below the development threshold. Similarly to capacity, a clear distinction is made in the definition of responsibility between "survival emissions" and "luxury emissions". Hence, while calculating levels of national responsibility, emissions that derive from a level of consumption below the development threshold are excluded. A weighted product of capacity and responsibility yields the *responsibility and capacity indicator* (RCI) and defines a country's final share of the adaptation and mitigation burden.

Per capita convergence - The per capita convergence approach starts from the assumption that the atmosphere is a global common good to which all are equally entitled. It defines emission rights or allocations on the basis of a convergence of per capita emissions at a certain point in time in the future under a (contracting) global emission envelope. Based on the choice of a global atmospheric greenhouse gas concentration target (or on the basis of some other assumed climate goal) an associated global emission envelope over time (usually to 2100) can be defined. Within this envelope at each time period emissions are allocated to regions/countries in such a way that their per-capita emissions converge to emissions which equal the global per-capita emission target in the convergence year (typically 2050). The path towards convergence can be linear or non-linear.

The equity approaches result in a wide spectrum of emissions reductions in 2030 and 2050 for Germany. German greenhouse emissions would have to decrease by 64% to 113% (with a median of 87%) in 2030 and by 95% to 245%

41 Values include all GHG emissions, without land use, land-use change and forestry. The central estimate corresponds to the median of emissions levels derived from the wide variety of equity approaches and the lower/higher end of reductions correspond to 80th/20th percentiles. For comparison, reductions based on least-cost pathwaysare shown, with ranges referring to the 2014 and 2019 pathway cases, as well as the targets of the Climate Action Plan.

Note that the Climate Action Plan includes the objective of "extensive greenhouse gas neutrality" for 2050 and the former target range 80-95%.

Emissions reduction ranges for PA 1.5°C pathways for Germany based on a range of equity approaches[42] — Table 5

Reductions from 1990 levels	2030	2040	2050
Lower end of reductions	64%	89%	95%
Central estimate	87%	132%	185%
Higher end of reductions	113%	169%	245%
Least-cost pathway	**73–74%**	**84–88%**	**98–99%**
Climate Action Plan 2050	55%	70%	Extensive GHG neutrality (80–95%)

Climate Analytics, own calculations

Emissions reduction ranges for 2°C pathways for Germany based on a range of equity approaches[43]

Table 6

Reductions from 1990 levels	2030	2040	2050
Lower end of reductions	56%	79%	92%
Central estimate	65%	101%	153%
Higher end of reductions	84%	132%	210%
Least-cost pathway	**67%**	**81–83%**	**88–92%**
Climate Action Plan 2050	55%	70%	Extensive GHG neutrality (80–95%)

Climate Analytics, own calculations

with a median of 185% in 2050, in comparison to 1990. Emissions reductions compatible with the "hold below 2°C" goal would be 56% to 110% (with a median of 65%) for 2030 and 92% to 210% (with a median of 153%) for 2050. The deepest reductions result from approaches focusing on historical responsibility, while the less stringent ones focus on per capita emissions convergence as these start with a grandfathering approach and then move toward equal per capita emissions (typically by 2050).

Given the equity approaches have been applied to overall GHG emissions, not just energy and industry related emissions, we have to add non-CO_2/non-energy-related emissions to the pathways outlined in the previous section – which only included the energy and industry related CO_2 emissions – to be able to compare resulting reductions with the reductions from equity approaches (see Annex for details).

For a 1.5°C PA consistent pathway, overall GHG emissions have to be reduced by 73–74% by 2030 compared to 1990 in a least-cost pathway,[43] which is within the range of equity approaches of 64 to 113% and below the central estimate of 87%.[44] All of these imply higher reductions than the current 2030 reduction target for Germany (minus 55%). For 2050, the 1.5°C pathway leads to a virtual GHG neutrality, consistent with the Climate Action Plan 2050, whereas the 2°C pathway leads to a range of 88–92% reduction, which is within the more ambitous end of the 80–95% reduction range agreed before the Paris Agreement, and also referred to in the Climate Action Plan. For both the 1.5°C pathway and the 2°C pathway, the least-cost emissions reductions for 2050 are at the low end of equity-based mitigation targets, thereby implying additional efforts to support and finance further GHG reductions outside Germany.

42 Values include all GHG emissions, without land use, land-use change and forestry. The central estimate corresponds to the median of emissions levels derived from the wide variety of equity approaches and the lower/higher end of reductions correspond to 80th/20th percentiles. For comparison, reductions based on least-cost pathwaysare shown, with ranges referring to the 2014 and 2019 pathway cases, as well as the targets of the Climate Action Plan. Note that the Climate Action Plan includes the objective of "extensive greenhouse gas neutrality" for 2050 and the former target range 80–95%.

43 Höhne et al (2019) derive a reduction of around 70% by 2030 for total GHG emissions in Germany by assuming a reduction rate corresponding to an average *global* reduction rate of IPCC pathways consistent with 1.5°C. This is not directly comparable with our approach, as we derive a specific least-cost pathway for Germany's fossil and industry CO_2 emissions, rather than applying a *global* average reduction rate that may not reflect specifics for Germany.

44 Höhne et al. (2019) also derive a wide range of equity-based reductions, from sampling the literature. Their range is -60% to -135% (central estimate -100%) below 1990 levels by 2030. Instead of a sampling of the available literature, which may introduce inconsistencies across studies, we include in our calculations the same range of approaches, but we ensure full consistency of the underlying carbon budget being distributed within the different equity approaches, and elimitate risk of bias of the estimates due to inclusion of old studies, which do not reflect the most recent socioeconomic and emissions trends. See Annex 2 for details on the Climate Analytics equity analysis tool.

04 | Quantifying a CO_2 budget and pathway for the German transport sector

Results for the least-cost emissions reduction pathway for the German transport sector are shown in table 7. These show that, given the failure to reduce emissions in the past, deeper and faster emissions reductions are required between now and 2050. We conclude that a PA 1.5°C pathway does not allow for any further delay in comprehensive mitigation action, especially in sectors like transport where negative emission technologies are not available. Also a 2°C pathway implies more ambitious action.

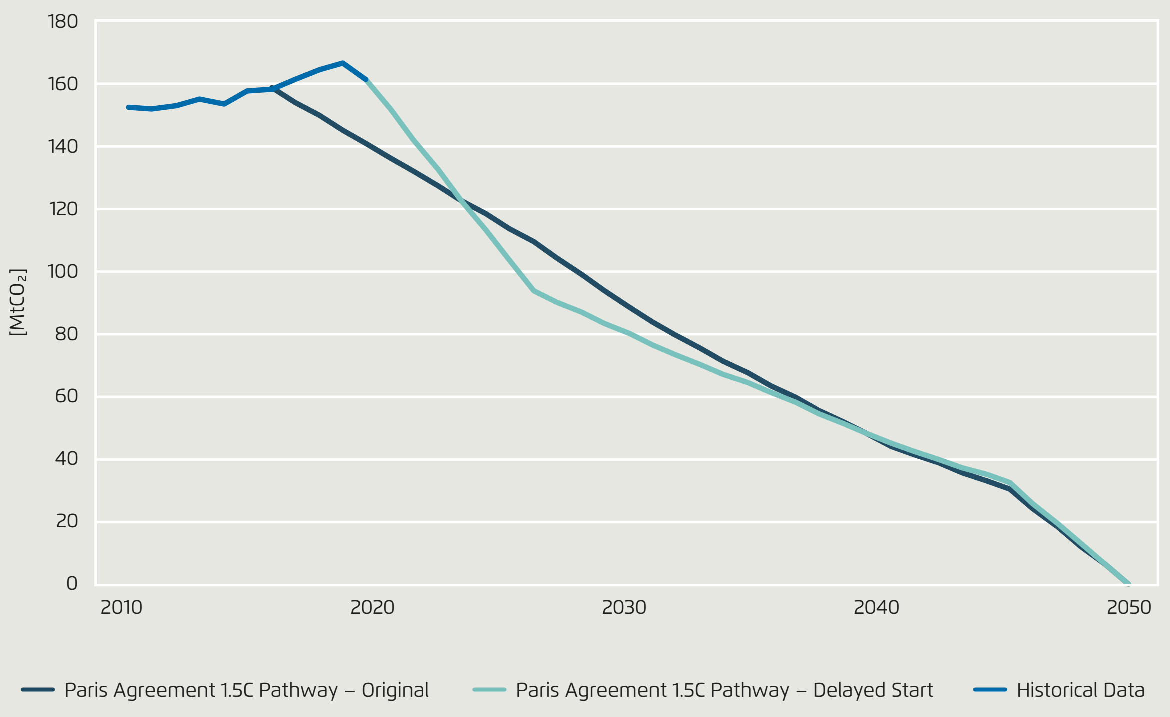
Even though the emissions reductions in the transport sector by 2030 (48% below 1990 for a pathway starting with policies in 2014; and 53% in a pathway starting with policies in 2019) are less steep than overall energy-related emissions reductions (76%, see table 3), they are still steeper than in the current sectoral target of the Climate Action Plan 2050 (40-42% below 1990). This is consistent with the fact that the overall reductions needed for 1.5°C are higher than the overall GHG reduction target in the Climate Action Plan 2050 as outlined in the previous section.

In a comparative analysis of a range of mitigation scenarios for the German transport sector, the resulting emissions reductions compared to 1990 range between 35% and 58% in 2030, and 75 to 100% by 2050, with higher reductions in 2030 in those scenarios that aim for higher reductions in 2050.[46] The analysis of mitigation scenarios that had been published by that time shows that for studies with mitigation scenarios aiming at overall GHG emissions reductions – across all sectors – of 80% by 2050, the transport sector emissions are reduced

45 Pathways starting in 2014 (based on original IEA B2DS pathway) and with delayed start in 2019. Historical emissions until 2018 (Source: UBA (2019a, b). Pathways are in line with the 2050 goal in Germany's long term strategy, aiming at a "virtually decarbonised" transport sector by 2050.

46 Öko-Institut (2016)

CO_2 emissions from the German transport sector under PA 1.5°C pathways[46] Figure 4



Climate Analytics, own calculations

by 41-42% in 2030 and 75-80% in 2050. For scenarios aiming at 90-100% overall GHG reductions (across all sectors), the transport sector emissions are reduced by 45-58% in 2030, and 87-100% in 2050.

UBA analysed scenarios consistent with the objective of a nearly GHG-neutral transport sector ("KSBV").[47] They derive cumulative direct CO_2 emissions between 2010 and 2050 for national transport of 3.6 to 3.7 Gt CO_2 and remaining annual emissions in 2050 of around 1 Mt CO_2. This implies cumulative direct CO_2 emissions during the period 2016-2050 of 2.7-2.8 GtCO_2 for the German transport sector, slightly higher than the 1.5°C budget derived from our analysis (2.6 Gt) The UBA scenarios were developed before the Climate Action Plan was adopted and result in slightly higher emissions in 2030 than in the sectoral target.[48]

BDI analysed two pathways for the German economy: one achieving 80%, the other achieving 95% reduction of all GHG emissions in 2050 compared to 1990.[49] It explicitely has conservative technology assumptions, with "game changers"[50] such as development of a hydrogen economy not explicitely modelled. The pathways are particularly conservative for the short and midterm, and therefore lead to very high cumulative emissions compared to other scenarios with similar 2050 reductions. The 95% pathway implies full decarbonisation by 2050 (phase out of fossil fuels), and achieves the Climate Action Plan's 2030 target for all GHG (with 57% reduction from 1990), but falls short of the 2030 sectoral target in transport (with only 26% reduction from 1990). The BDI 80% pathway does not achieve the overall 2030 emissions reduction target from the Climate Action Plan, including the transport sectoral target. Overall, even the 95% pathway leads to higher cumulative transport emissions (3.7 Gt CO_2) than the least-cost 2°C pathway, let alone the PA 1.5°C pathway shown here and is therefore not consistent with the PA based on our analysis.

47 UBA (2017)
48 UBA (2016)
49 BDI (2018)
50 BDI (2018)
51 UBA (2017)
52 BMU (2019)

Transport emissions and carbon budgets under 1.5°C pathways with 100% decarbonisation by 2050

Table 7

	Paris Agreement 1.5°C Pathways		Action Plan Sectoral target	Current policy projections	UBA (2017)	Oko Institut (2016) (for overall 90–100% reduction by 2050)	BDI (2018) (95% overall GHG reduction by 2050)
	Climate policies from 2014	Climate policies from 2019					
2030 Emissions ($MtCO_2$)	83.5 (48% below 1990)	76.3 (53% below 1990)	95-98 (40–42% below 1990)	150- 159 (2–8% below 1990)	100-103 (36–38% below 1990)	69-90 (45–58% below 1990)	122 (26% below 1990)
2050 Emissions ($MtCO_2$)	0 (100% below 1990)	0 (100% below 1990)	0–8 (95–100% below 1990)	141 (36% below 1990)**	1 (99% below 1990)	21–0 (87%–100% below 1990)	0 (100% below 1990)
Cumulative emissions (2016–2050) $GtCO_2$	2.6	2.6	2.9–3.0***	5.4**	2.7–2.8*	2.4–2.9***	3.7****

*UBA calculated the budget for the 2010–2050 period: 3.6–3.7 Gt. Deducting historial emissions 2010-2015 results in 2.7–2.8 $GtCO_2$ for the period 2016–2050 used in this study[52]
**Trend estimate (based on 2014–2035 emissions data from Projection report 2019, table A3 (value in footnote: 150 Mt). (Note this is CO_2eq)[53]
***Own calculations, assuming a linear intrepolation for missing data. 2050 target range: interpretation of the objective of "virtual decarbonisation"
****Own calculations, based on BDI (2018) figure 40 (page 169), assuming a linear intrepolation for missing data (Note: CO_2e)

Climate Analytics, own calculations

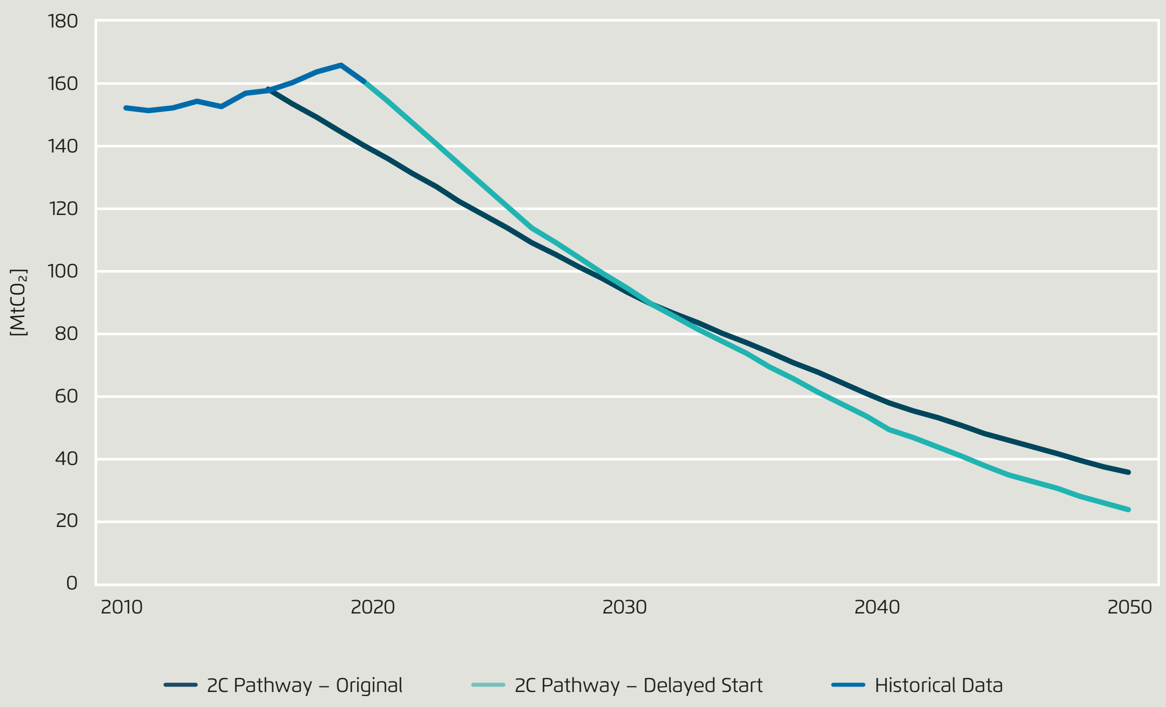
Our results for the PA 1.5°C pathway are in the range of results from existing mitigation scenarios that aim for an at least 90% overall (all GHG) reduction by 2050, whereas the 2°C results are more in line with existing mitigation scenarios that are based on an overall (all GHG, all sectors) 80% reduction in 2050 (with the exception of the BDI pathways).

While typically 2030 reductions in the transport sector are less stringent than in other energy-related sectors, given the lack of reductions in the past, an important conclusion is that the current sectoral target of a 40-42% reduction by 2030 is not consistent with the PA's 1.5°C target and with the German Climate Action Plan's overarching goal of extensive GHG neutrality by 2050. This underlines the mismatch between the current sectoral target and the goal of the Climate Action Plan 2050 to implement the stronger PA LTTG. To live up to that goal, both the overall target and the sectoral target have to be revised.

Instead, as Table 8 confirms, the current 2030 reduction target for transport (40-42% reduction by 2030 compared to 1990) is more in line with the former "hold below 2°C" target. Yet, due to delayed action, even for staying on a 2°C pathway, ambition in the transport sector needs to be further raised rather than discussing more lenient targets for the transport sector (see Table 8 and Figure 5).

53 Pathways starting in 2014 (based on original IEA 2DS pathway) and with delayed start in 2019. Historical emissions until 2018 (Source: UBA (2019a, b).

CO_2 emissions from transport under 2°C pathways[54] Figure 5



Climate Analytics, own calculations

Transport emissions and carbon budgets under 2°C pathways

Table 8

	Paris Agreement 2°C Pathways		2030 Climate Action Plan Sectoral target	Current policy projections	UBA (2017)	Oko Institut and Fraunhofer (2016) (overall 80% reduction)	BDI (2018) 80% overall reduction
	Climate policies from 2014	Climate policies from 2019					
2030 Emissions ($MtCO_2$)	90.2 (44% below 1990)	90.2 (44% below 1990)	95-98 (40–42% below 1990)	150-159 (2–8% below 1990		95-97 (41–42% below 1990)	128 (22% below 1990)
2050 Emissions ($MtCO_2$)	36.5 (77% below 1990)	24.7 (85% below 1990)	0-8 (95–100% below 1990)	141 (36% below 1990)**	1 (99% below 1990)	33-41 (75–80% below 1990)	45 (73% below 1990)
Cumulative emissions (2016-2050) $GtCO_2$	3.0	3.0	2.9-3.0***	5.4**	2.7-2.8*	3.2-3.3***	4.1****

* UBA calculated the budget for the 2010–2050 period: 3.6–3.7 Gt. Deducting historial emissions 2010–2015 results in 2.7–2.8 $GtCO_2$ for the period 2016-2050 used in this study[55]

** Trend estimate (based on 2014–2035 emissions data from Projection report 2019, table A3 (value in footnote: 150 Mt). (Note this is CO_2eq)[56]

*** Own calculations, assuming a linear intrepolation for missing data. 2050 target range: interpretation of the objective of "virtual decarbonisation"

**** Own calculations, based on BDI (2018) figure 40 (page 169), assuming a linear intrepolation for missing data (Note: CO_2e)

Climate Analytics, own calculations

54 UBA (2017)

55 BMU (2019)

05 | Contrasting the PA LTTG consistent budgets and sectoral pathways with current emissions trends in Germany's transport sector

Current emissions in the transport sector are still at about the same level as in 1990. Projections based on current policies ("With Measures Scenario", Projection Report 2019) show that transport emissions in Germany would reach 150-159 $MtCO_2$ by 2030 (only 2-8% below 1990). This level of emissions would be almost twice as much as the 1.5°C consistent emissions level and more than 60% above the 2030 Climate Action Plan sectoral target. Germany is thus far from being on track to achieving its current – for PA implementation insufficient – sectoral target.

A 1.5°C compatible emissions pathway for the transport sector in Germany would require emissions to be significantly lower in 2030 (53% below 1990 levels) than prescribed by the Climate Action Plan, which assumes a 40-42% reduction.

In carbon budget terms, from 2016 to 2050, the transport sector budget for a PA compatible 1.5°C pathway is about 2.6 $GtCO_2$. If further continued beyond 2030 until 2050, current policy trends would lead to cumulative emissions of about 5.4 $GtCO_2$ between 2016 and 2050, more than 100% above the 1.5°C compatible budget.

The 2°C budget for the transport sector from 2016 to 2050 is higher than for the 1.5°C target by about 0.4 $GtCO_2$, with the budget being around 3 $GtCO_2$. The 2°C budget for the transport sector corresponds roughly to the budget implied by the Climate Action Plan (2.9-3 $GtCO_2$, see table 8) with the Climate Action Plan requiring a much steeper reduction after 2030. This budget is still much lower than the emissions expected between 2016 and 2050 with the present policy trends.

06 | Policy implications

We have shown that the current sectoral target for the 2030 transport emissions is not consistent with the PA's 1.5°C target. Instead, our analysis shows that the current 2030 sectoral target for transport emissions as currently defined in the Climate Action Plan is quite close to the emissions reductions required by the former hold below 2°C goal, which has now been replaced by the stronger temperature goal of the PA. Moreover, the 2030 sectoral target is also not consistent with a least-cost pathway towards full decarbonisation of the transport sector in 2050; that is, the pathway laid out in the Climate Action Plan 2050 would lead to higher costs as it requires steeper reductions after 2030 to achieve "virtual decarbonisation".

Therefore, the 2030 sectoral target for transport needs to be revised by 2020, together with the overall economywide 2030 target, in line with a least-cost pathway to achieving decarbonisation by 2050 and implementing the PA temperature goal. Both the PA and the Climate Action Plan foresee a review of targets by 2020. Germany should thus also push for the EU to ratchet up its 2030 NDC target by 2020.

We also conclude that a PA consistent pathway does not allow for any further delay in comprehensive mitigation action, especially in sectors like transport where negative emission technologies are not available. The more emissions reductions are delayed, the higher reductions have to be later on to stay within the limits for cumulative emissions, implying higher overall mitigation costs. Shifting reductions to other sectors is not an option, given the need to ratchet up overall emissions reductions.

Therefore, urgent measures are needed to reduce emissions and get on a pathway towards decarbonisation. Recent technology developments, in particular vast reductions in renewable energy and energy storage costs, advances in battery-electric vehicles (as well as fuel-cell vehicles, particularly for freight transport and buses) offer opportunities for faster emissions reductions than envisaged in scenarios that were developed even just a few years ago. Besides contributing to achieving Germany's climate targets, deep emissions reductions and a (technological) transformation in the transport sector also bring along additional benefits, in particular through avoided health costs . These should be taken into account when defining the sector's climate strategy.

Key robust strategies for decarbonising the transport sector have been identified at global scale,[56] as well as for the EU[57] and Germany[58]. The following measures, linked to the decarbonisation of electricity generation, are essential steps to get on track towards decarbonisation of the transport sector, with important further benefits such as avoided air pollution and creating more liveable cities:

- Speed up electrification of the transport sector; by 2035, only zero emissions passenger vehicles should be sold
- Support infrastructure development for electrification of both passenger and freight transport
- Policies to support a modal shift in passenger transport to public transport, cycling and walking
- Policies to support a modal shift in freight transport to rail in particular
- Implementation of targeted regulatory policies and pricing instruments, particularly effective carbon pricing

56 Climate Action Tracker (2016)
Climate Action Tracker (2018c)

57 Climate Action Tracker (2018b)

58 Agora Verkehrswende (2018), UBA (2017), Öko-Institut (2016)

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Annex 1 | Methodology for least-cost pathway

In this report we downscale the results of the IEA/ ETP 2017 scenarios by using a model-based approach: SIAMESE (**S**implified **I**ntegrated **A**ssessment **M**odel with **E**nergy **S**ystem **E**mulator). [59]

SIAMESE is a reduced complexity IAM (Integrated Assessment Model), which provides cost-optimal emission pathways at the country level while considering the complex interactions between economic growth, energy consumption and climate change. For example, higher economic growth entails higher energy consumption leading to higher emissions (also depending on low carbon technology developments, costs and climate change targets). While downscaling the energy-sector results from a given model, SIAMESE takes into account a coherent set of assumptions in line with a "middle of the road" storyline. [60] [61] This storyline relies on a continuation of historical trends regarding technological developments and GDP growth at the country level. At the same time, SIAMESE assumes all countries would need to equally contribute (from a cost optimisation perspective[62]) in reducing emissions in line with the Paris Agreement long term goal.

The SIAMESE downscaling approach can be applied to the overall economy (e.g. scaling down the overall primary energy consumption and emissions), or to individual sectors (e.g. transport, power and others). SIAMESE is calibrated to replicate the historical data at the base year (2014). The historical data are based on the IEA Energy Balances, which are also in line with the Government data, available until 2017. [63]

To better estimate a policy-relevant emissions pathway, SIAMESE considers current policies in place in the German transport sector (excluding international bunkers), in the power sector[64] [65] and for the overall economy. The SIAMESE sectorial definition is in line with the Climate Action Plan 2050. At the same time, in order to reflect historical development in CO_2 emissions in Germany, we harmonise the original downscaled pathway (with climate policy starting in 2014) to the reported CO_2 emissions until the last reported year (2017). Finally, we make sure that total emissions budget derived from the original pathway is not exceeded as a consequence of higher historical emissions in Germany until 2017, since adoption of the Climate Action Plan in the light of the Paris Agreement.

A key strength of SIAMESE is its ability to provide pathways at the country level congruent with the "mother" scenarios (in this case the IEA/ETP 2017, B2DS66), under a coherent set of assumptions. As a result, SIAMESE can provide key insights to policy makers on how to realistically improve current policies and pledges in line with the Paris Agreement long term temperature goal.

This report extends the energy and industry CO_2 emissions pathways by adding non-CO_2 emissions using a methodology in line with the Climate Action Tracker for extending pathways until the end of the century (CAT 201867). We assume non-CO_2 emissions in Germany will grow according to a RCP 2.6 W/m2 (radiative forcing) pathway, based on the IAM MESSAGE (SSP database, v2.0), which have been extensively used for likely 2°C pathways. This assumption is motivated by literature findings, showing that a key difference between Paris Agreement compatible pathways and "likely below 2°C" scenarios relies mainly on CO_2 emissions, because the non-CO_2 mitigation potential is basically the same as "likely below 2°C" scenarios68. Finally, we calculate GHG emisisons (excluding land use, landuse change and forestry) by adding CO_2 emissions (from SIAMESE) and non CO_2 emissions.

59 Sferra et al (2019)
60 Fricko et al (2016)
61 Dellink et al (2017)
62 SIAMESE allocates energy consumption (and therefore emissions) at the country level by equalising the marginal cost of energy (for each fuel) across all countries.
63 IEA (2016)
64 Climate Analytics, (2018b)
65 Sferra and Schaeffer (2018)
66 IEA (2017)
67 CAT (2018): Climate Action Tracker 2018 " Some progress since Paris, but not enough, as governments amble towards 3°C of warming" Climate Action Tracker Warming projections Global Update, December 2018.
68 Rogelj et al (2015, 2018)

Annex 2 | Methodology for equity analysis

Description of the Equity Analysis Tool

The PRIMAP group at the Potsdam Institute for Climate Impact Research (PIK) developed the Potsdam Real-time Integrated Model for the probabilistic Assessment of emission Paths (PRIMAP model). The Emissions Module of the Potsdam Real-time Integrated Model for the probabilistic Assessment of emission Paths (PRIMAP has been developed as part of this model and allows for the flexible combination of data sources into composite datasets, and the calculation of national, regional and global emission pathways following various emission allocation schemes. At the core of the Emissions Module is a custom-built emissions database, the so-called PRIMAPDB. [69]

Climate Analytics and the PRIMAP group developed an Equity Analysis Tool for the assessment of equity principles and indicators, embedded in the Emissions Module.[70] Currently implemented in the tool we have the following published equity methodology proposals:

- Greenhouse Development Rightsthat such a program is only possible if the international effort-sharing impasse is decisively broken, and that this impasse arises from a severe, but nevertheless surmountable, conflict between the climate crisis and the development crisis. It argues, further, that the best way to break the international climate impasse is, perhaps counter-intuitively, by expanding the climate protection agenda to include the protection of developmental equity, which can and should be specified in terms of the UNFCCC's notion of "common but differentiated responsibilities and respective capabilities." The Greenhouse Development Rights (GDRs - The Greenhouse Development Rights Framework (GDR framework) seeks to not only acknowledge the right to development but to actually place that right at its structural core. Individuals that find themselves below a specific development threshold are given the opportunity to develop and are not supposed to shoulder the burden of solving the climate problem.). Capacity is thus defined as income, excluding all income below the development threshold. Similarly to capacity, in the definition of responsibility a clear distinction is made between "survival emissions" and "luxury emissions". Hence, while calculating levels of national responsibility, emissions that derive from a level of consumption below the development threshold are excluded. A weighted product of capacity and responsibility yields the responsibility and capacity indicator (RCI) and defines a country's final share of the adaptation and mitigation burden. [71]
- South North Proposal- with own methodology for downscaling emissions from groups to country level based on GDP and population projections (- The "South-North Dialogue" proposal differentiates the mitigation efforts for each country based on three criteria relating to responsibility, capability and mitigation potential. It dynamically assigns countries to one of six groups, depending on their overall weighted score on the three criteria. Annex I – non-Annex II - and Annex II countries are the first two groups. Newly industrialized countries (NICs), rapidly industrializing developing countries (RIDCs), least developed countries (LDCs) and "other" developing countries (ODCs) are the remaining four groups. Which group countries are assigned to, depends on their so-called differentiation index. This index is a composite index based on three sub-indexes describing the responsibility, the capability and the potential to mitigate for each country. Countries with an index of one standard deviation or higher than the mean are classified as newly industrialized countries (NICs). Rapidly industrializing developing countries (RIDCs) fall within the range of the mean plus or minus one standard deviation (SDEV) and with additional condition related to relative per capita income and annual growth in the period 1991 and 2000. Other developing countries (ODCs) and least developed countries (LDCs) fall below the mean minus one standard deviation.[72]
- Per capita convergence - The per capita convergence approach starts from the assumption that the atmosphere is a global common to which all are equally entitled. It defines emission rights or allocations on the basis of a convergence of per capita emissions at a certain point of time in the future (typically 2050) under a (contracting) global emission envelope. Based on the choice of a global atmospheric greenhouse gas concentration target (or on the basis of some other

69 Nabel et al (2011)

70 Climate Analytics (2016)

71 Kartha et al (2009)

72 Ott et al (2004)

assumed climate goal) an associated global emission envelope over time (usually to 2100) can be defined. Within this envelope at each time period emissions are allocated to regions/countries in such a way that their per-capita emissions converge to emissions which equal the global per-capita emission target in the convergence year. The path towards convergence can be linear or non-linear.[73]
- South-African Proposal – The South African regime is based on the development of an index, which will be applied to the mitigation burden and split among countries. This index, however, is based on pre-determined factors: historical responsibility and capability, adjusted by a sustainable development index. Historical responsibility and capabilty are calculated in the same way than in other equity regimesn, and the sustainable development index is derived from the human development index (HDI). Since the HDI is a composite statistic of life expectancy, education and per capita income, the main idea is to create an altered version of the HDI supressing the GDP factor, as it is already taken into account in the previous step. This metric is then a combination of life expectancy at birth and expected years of schooling indicators.[74]

Building on a range of methodologies and equity criteria put forward by the scientific community and Parties for sharing the burden of reducing emissions, the PRIMAP equity tool also offers a modality that allows users to emulate equity regimes based on various equity criteria – and for each criterion a range of possible empirical metrics to quantify them is available. The equity criteria selected and the different empirical metrics available to evaluate them in the Equity Tool are:

Historical Responsibility: this remains the main argument often used by many developing countries that the greenhouse gas problem is primarily caused by emissions from industrialized countries. The metrics used as a proxy for historical responsibility in this exercise are based on per capita cumulative emissions i.e. the quotient of cumulative emissions for each country and its cumulative population within the pre-set time frame:

73 Agarwal and Narain (1991), Meyer (2000)

74 Winkler et al (2013)

- Cumulative greenhouse gases emissions per capita, excluding deforestation emissions: starting and end years for accounting cumulative emissions are flexible
- Cumulative greenhouse gases emissions per capita, including deforestation emissions: starting and end years for accounting cumulative emissions are flexible

Capacity to mitigate: the overall capacity to mitigate in a country is often related to a country's wealth or degree of development, as these relate to the country's ability to pay for and implement measures to reduce greenhouse gases emissions. Metrics available to evaluate this criterion are:

- GDP Purchasing Power Parity (PPP) per capita
- Human Development Index (HDI) at a certain year

Potential to mitigate is a measure of the actual room for improvement existing in a country. Among proposals that consider potential as a criteria are the Triptych methodology[75] and the South North Proposal. The following intensities can be used to estimate a country's potential to mitigate:

- Emissions intensity: Energy related greenhouse gas emissions per unit of GDP
- Emissions per capita: Total national greenhouse gas emissions per capita, including deforestation emissions.
- Carbon intensity: greenhouse gas emissions per unit of energy production

Weights can be attributed to each one of the criteria selected. This means that allocation regimes based on only one of the criteria, e.g. responsibility, or based on more than one criterion, and assuming either equal or different weighting among the different criteria can be studied. For each criterion, one or a set of empirical measures to evaluate them can be selected, also with dif-

75 The Triptych methodology contains elements of cost–effectiveness in that those with high specific emissions (i.e. high potential for reductions) have to reduce more. It was used as a basis to share the emissions reductions of the first commitment period for the Kyoto Protocol within the EU.

ferent weights. Such an approach allows for full flexibility of assumptions in regard to criteria and metrics.

Another important feature of the tool is that is that it allows for the calculation of **ranges of responsibilities** for countries, based on the different indicators. To calculate ranges, (1) **random weights** are attributed to each indicator and measure, (2) resulting emissions pathways calculated and finally (3) calculations are repeated multiple times to define a range of possible pathways. Such an approach allows capturing the full range of emissions allowances of a country and to determine how different criteria and metrics influence its outcome.

Index Calculation: The selected quantitative measures are weighted, normalized and added, to obtain an interim index. The split of the mitigation burden is calculated proportionally to a final index, which is obtained by normalizing and weighting the interim index by the population share of each country. To avoid using projections, we calculated the index based on the last common historical year shared between all selected metrics, which was 2010. The index is calculated for as many countries as possible, which is the number of common countries available for all selected metrics.

Because the index is the result of the normalization of variables, we investigated the presence of extreme countries in each one of the metrics and excluded those countries (potentially a different set of countries at each iteration of the model) to avoid the over or under-estimation of countries' share of responsibility.

Global mitigation burden: Equity methodologies often fit global emissions to levels that are in line with temperature targets. The two target scenarios investigated in this report are the Paris Agreement 1.5°C and the Cancun Agreements 2°C pathways.

Based on the selected low-carbon scenario, an emissions mitigation burden is calculated as the difference between global business-as-usual emissions (here, RCP8.5) and an emissions trajectory that avoids the worst effects of global warming (here consistent with the Paris Agreement 1.5°C and the Cancun Agreements 2°C scenarios).

Calculation of emissions allowances: The index calculated using the methodology described above is then used to split the mitigation burden across countries, in such way that the country's index share of the sum of all indices will be proportional to its share of the mitigation burden. Countries with high indices will be attributed a high share of the mitigation burden and vice-versa. The share of the global mitigation burden of a country is subsequently subtracted from this country's business-as-usual emissions to obtain its final emissions allocations.[76]

Provided that the LULUCF sector does not represent a large share of national emissions for Germany, the assessment of fairness of all commitments was done against emissions allowances excl. land-use, land-use change and forestry (LULUCF) emissions. This is due to two main reasons. First, emissions projections in the LULUCF sector are generally highly doubtful and would add a considerable amount of uncertainty to the overall assessment. Second, while the LULUCF sector requires important emissions reductions (and increasing sinks), a pathway towards 1.5°C requires decarbonisation of the world energy system. The use of sinks to achieve targets may mask e.g. an increase in emissions from the energy and industrial sectors which would be inconsistent with a low carbon, transformational pathway towards 1.5°C goal. Real, substantial reductions in emissions from all sectors need to be made by all countries to set the world on a pathway towards a decarbonised economy. **The emissions allowance ranges presented in this report constitute the 20th to 80th percentile of the overall range, which is consistent with IPCC AR5 methodology.**[77]

Emissions levels within the equity range that guarantees the target scenario is met: The goal of the present analysis is to evaluate a range of responsibility for the countries of interest. Given the large variability of equity proposals, criteria and metrics, we can have wildly different outcomes for a country leading to very wide equity ranges. However, even if all outcomes behind the equity ranges were in line with the target scenario in question, if all countries would meet reductions in line with the top of the ranges, the resulting global emissions

76 Such an approach allows for attribution of negative emissions allocations.

77 Höhne et al (2014)

would be far higher than the emissions levels in that scenario. It is therefore crucial to determine the maximum level of emissions within countries' equity ranges, which when aggregated, would result in the target scenario. This level is determined as follows:

- Calculate emissions levels consistent with:
  - **a global equity best case scenario:** where all countries choose to reduce emissions to the very bottom of their range, which is numerically equivalent to the total of the minima of all countries' equity ranges, and necessarily below the target scenario.
  - **a global equity worst case scenario:** where all countries choose to reduce emissions only to the top of their equity range, which is numerically equivalent to the total of the maxima of all countries' equity ranges, and necessarily below the target scenario.
  - The global equity best case scenario and the global equity worst case scenario points result in a global equity range.
- In a next step the Paris Agreement 1.5°C (or Cancun Agreements 2°C) pathway is then overlaid with the global equity range to determine the intersection between global equity scenarios and the target scenario. We calculate what is the relative level of that intersection.
- Apply that relative level to all countries' equity ranges (including Germany).

Detailed results for the different equity approaches are shown in the following table.

Emissions reduction ranges for PA 1.5°C pathways for Germany based on a range of equity approaches for all GHG emissions, without Land use, land-use change and forestry. Table 9

Reduction below 1990 levels		2030	2040	2050
Historical responsibility	Max	-61%	-98%	-139%
	Mean	-88%	-147%	-212%
	Min	-113%	-192%	-279%
Capability	Max	-67%	-110%	-157%
	Mean	-91%	-153%	-221%
	Min	-106%	-180%	-261%
Responsibility/Capability	Max	-63%	-103%	-146%
	Mean	-117%	-197%	-286%
	Min	-152%	-259%	-378%
South African Proposal	Max	-57%	-73%	-88%
	Mean	-96%	-148%	-200%
	Min	-149%	-254%	-370%
Per capita convergence	Max	-57%	-72%	-88%
	Mean	-83%	-112%	-135%
	Min	-113%	-164%	-213%
South-North Proposal	Max	-78%	-102%	-124%
	Mean	-90%	-123%	-152%
	Min	-113%	-164%	-213%
Green Development Rigths	Max	-60%	-96%	-130%
	Mean	-71%	-109%	-149%
	Min	-83%	-134%	-193%

Climate Analytics, own calculations

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In partnership with key players in the field of politics, economics, science and civil society, Agora Verkehrswende aims to lay the necessary foundations for a comprehensive climate protection strategy for the German transport sector, with the ultimate goal of complete decarbonisation by 2050. For this purpose we elaborate the knowledge base of climate protection strategies and support their implementation.

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