Working Paper Sustainability and Innovation
No. S 22/2018

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The EU long-term strategy to reduce GHG emissions in light of the Paris Agreement and the IPCC Special Report on 1.5°C

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Abstract

The European Commission's long-term Strategic Vision "A clean planet for all" and the In-Depth Analysis supporting it were released on 28 November, 2018. The Commission claims that an 80% reduction of the EU's GHG emissions by 2050 can be taken as being in line with the Paris Agreement's long-term temperature goal (LTTG). This is shown to be questionable due to the Commission's relabelling of the former "hold-below-2°C" pathways associated with the 2010 Cancun Agreements as "well-below 2°C" pathways. Those "hold-below-2°C" pathways had a 66% chance of limiting warming to 2°C and were further characterised by a peak warming of around 1.7-1.8°C.

By contrast, the actual Paris long-term temperature goal is, by design, a strengthening of the former "hold-below-2°C" goal. In this paper, strong arguments are provided that this implies achieving a *lower* peak warming and a *higher probability* of limiting warming to 2°C. Further, the "hold-below-2°C" pathways do *not* provide guidance in terms of lowering peak warming and increasing the probability of limiting warming to 1.5°C, an integral part of the Paris LTTG (unless with negative emissions at a scale the IPCC Special Report on 1.5°C does not deem feasible). At the same time, the IPCC SR1.5 is very clear about the increases in climate risks between 1.5°C and 2°C, which relates 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 lower limit to peak warming.

Despite the shortcoming with regard to interpreting "well-below-2°C", the EU Strategic Vision is a clear shift away from the lower end of the former "80-95%" reduction target by 2050 towards achieving net-zero greenhouse gas emissions in 2050. This is based on the In-Depth Analysis, which shows that a greenhouse gas emission reduction of 90% by 2050 compared to 1990 is necessary to keep 1.5°C in range, while limiting negative emissions even calls for net-zero greenhouse gas emissions in 2050. Hence, the "net-zero greenhouse gas emissions in 2050" target chosen in the Strategic Vision is a reasonable choice in light of the Paris Agreement and the IPCC Special Report on 1.5°C, but 80% reduction by 2050 is not. Thus, the lower end of the current "80-95%" EU target is insufficient.

Disclaimer

This paper has been commissioned by the German Environment Agency (Umweltbundesamt, UBA) under contract 3717 41 1020. The views expressed in this paper do not necessarily comply with those of UBA and remain the authors' responsibility.

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List of abbreviations

BECCS	Bioenergy with carbon capture and storage
CDR	Carbon dioxide removal
COP	Conference of the Parties to the UNFCCC
EU	European Union
GHG	Greenhouse gas emissions
IPCC	Intergovernmental Panel on Climate Change
IPCC SR1.5	The IPCC's Special Report on Global Warming of 1.5°C
LTTG	Long-term temperature goal
LTS	Long-term strategy
LULUCF	Land use, land use change and forestry
PA	Paris Agreement
SPM	Summary for Policy Makers
UNFCCC	United Nations Framework Convention on Climate Change

1 Summary of the main findings

The European Commission's long-term Strategic Vision "A Clean Planet for All" (the "Strategic Vision") [1] and the In-Depth Analysis supporting it (the "In-Depth Analysis") [2] were released on 28 November, 2018. Fraunhofer ISI and Climate Analytics have assessed the scientific basis behind the Strategic Vision and in particular the discussion of the required level of ambition in Section 1 and Section 7 of the In-Depth Analysis.

Central findings with regard to the interpretation of the *long-term temperature goal (LTTG)* in the Paris Agreement:

- Recent studies on the LTTG in the Paris Agreement ("hold well below 2°C … limit … to 1.5°C") all indicate that it represents a strengthening of the previous Cancun Agreements temperature goal ("hold warming below 2°C")
- Mitigation pathways informing the implementation of the Paris Agreement should therefore
  - Have a lower peak warming and higher probability to hold warming below 2°C, compared to "hold below 2°C" pathways that typically peaked at 1.7-1.8°C warming, held warming below 2°C with an at least 66% probability, and approached 1.5°C warming by 2100 with a 50% or lower probability
  - Have a clear link to limiting temperature increase to 1.5°C with a higher probability than "hold below 2°C" pathways.
- The IPCC Special Report on 1.5°C [3] in evaluating 1.5°C compatible mitigation pathways followed the above considerations in selecting pathways with no or low (<0.1°C) overshoot of 1.5ºC. These pathways having a peak warming of 1.6°C, below that of the "hold below 2°C" pathways and with a higher probability limiting warming to 1.5°C or below by 2100.
- Consequently, mitigation pathways in the category of those that were previously used to inform the "hold below 2°C" goal cannot inform implementation of the Paris Agreement, including not by simply re-labeling these to "well below 2°C"
- The IPCC Special Report on 1.5°C [3] currently provides the awaited, best available science for operationalising the LTTG and defining the global goals mentioned in Article 4.1 consistent with this strengthened goal

Central findings with regard to the ambition of the EU long-term strategy:

- The central scenario and information on sector transformations in the Strategic Vision is built around achieving net-zero greenhouse gas emissions for the EU

by 2050. The Strategic Vision argues this is consistent with a 1.5°C limit and as such would be consistent with the Paris Agreement LTTG. However, the In-Depth Analysis and the scenario methodology reflected in Figures 2 and 4 of the Strategic Vision have two problems that are inconsistent with the Paris Agreement LTTG:

(1) Elements of Figures 2 and 4 in the Strategic Vision refer to “well below 2°C”, but the Analysis and the associated 80% reductions by 2050 for the EU represent essentially a re-labeling of scenarios previously used to inform the former 2°C goal (Cancun Goal). The scenarios used to underpin 80% by 2050 are therefore not consistent with “well below 2°C”, 1.5°C and the Paris Agreement.

(2) These elements and the In-Depth Analysis distinguish between the Comission terms as “hold well below 2°C” and 1.5°C pathways without integrating these in one long-term temperature goal, which would be needed to be consistent with the PA, as explained above.

- In view of the Paris LTTG, the pathways need to be categorized differently, distinguishing between those consistent with the Paris LTTG (no or low overshoot 1.5°C scenarios) and those consistent with the former “hold below 2°C”goal, which may include high overshoots of 1.5°C. This clearly fosters the Commission’s suggestion to head for net-zero greenhouse gas emissions in 2050 and this can provide guidance for enhancing ambition for near-term targets, incl. the EU NDC.
- When considered altogether, the In-Depth Analysis covers the most relevant topics for resetting ambition, a perspective on below-2°C and 1.5°C pathways (with a questionable interpretation of the former), cost-effective and equity-based approaches, precautionary approaches with regard to limiting the need for negative emissions as well as vulnerability to climate change.
- However, with regard to equity-based effort-sharing approaches, transparency of the In-Depth Analysis needs to be increased by adding more information on the ranges of equity-based effort-sharing and their relevance for the EU’s long-term target. Moreover, the discussion of negative emissions lacks quantitative information about the implications for the EU.
- In its Strategic Vision, the Commission focuses on a reconsideration of the EU’s long-term target, which is necessary, but not sufficient. According to the provisionally agreed text of the Governance Regulation remaining carbon budgets associated with the Paris LTTG and hence also short- and mid-term targets have to be considered as well, which is not the case in the In-Depth Analysis.

In summary, the Commission's claim that an 80% reduction of the EU's GHG emissions by 2050 can be taken as in line with the Paris LTTG is questionable, due to the Commission's re-labelling of the former "hold-below-2°C" pathways associated with the 2010 Cancun Agreements as "well-below 2°C" pathways. Those "hold-below-2°C" pathways[1] had a 66% chance of limiting warming to 2°C and were further characterised by a peak warming of around 1.7-1.8°C.

In contrast, the findings above imply that the Paris LTTG requires achieving a *lower* peak warming and a *higher probability* of limiting warming to 2°C. Further, the "hold-below-2°C" pathways do *not* provide guidance in terms of lowering peak warming and increasing the probability of limiting warming to 1.5°C, an integral part of the Paris LTTG (unless with negative emissions at a scale the IPCC Special Report on 1.5°C does not deem feasible). At the same time, the IPCC SR1.5 is very clear about the increases in climate risks between 1.5°C and 2°C, which relates 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 lower limit to peak warming.

Despite the shortcoming with regard to interpreting "well-below-2°C", the EU Strategic Vision is a clear shift away from the lower end of the former "80-95%" reduction target by 2050 towards achieving net-zero greenhouse gas emissions in 2050. This is based on the In-Depth Analysis, which shows that a greenhouse gas emission reduction of 90% by 2050 compared to 1990 is necessary to keep 1.5°C in range, while limiting negative emissions even calls for net-zero greenhouse gas emissions in 2050. Hence, the "net-zero greenhouse gas emissions in 2050" target chosen in the Strategic Vision is a reasonable choice in light of the Paris Agreement and the IPCC Special Report on 1.5°C, but 80% reduction by 2050 is not. Thus, the lower end of the current "80-95%" EU target is insufficient.

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1 Note that this formulation used by the Commission - " to limit global warming to 2°C within the 21st century" is logically not the same as "to hold global warming below 2°C" as it allows for warming to equal, or even exceed 2°C before returning to, or below, 2°C by 2100. At footnote 16 in the main report it is noted "While there is no official definition of 'well below' 2°C, studies typically refer to pathways with a >66% chance of keeping global warming below 2°C. The *average* temperature change expected in such pathways is therefore lower – typically 1.7-1.8°C in 2100."

2 Background and objectives

The European Commission is currently preparing a new long-term strategy (LTS) to reduce greenhouse gas emissions (GHG) that is meant to update the Low-Carbon Roadmap 2050 published in 2011 with regard to recent developments, in particular the objectives of the Paris Agreement and its implications, but also the implications of IPCC Special Report on 1.5°C (from here on IPCC SR1.5) [3]. On November 28, 2018, the Commission released its long-term Strategic Vision “A clean planet for all” (from here on the Strategic Vision) [1] and the In-Depth Analysis in support of the Strategic Vision (from here on the In-Depth Analysis) [2]. These documents imply an interpretation of the Paris Agreement’s long-term temperature goal (PA LTTG) as consisting of two separate targets, namely (1) a particular interpretation of holding global warming “well-below 2°C” and (2) “pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels”. This has far-reaching implications including that a global GHG reduction by 50% by 2050 compared to 1990 and a reduction of the EU’s GHG emissions of 80% by 2050 compared to 1990 could be seen as in line with limiting global warming to "well-below 2°C". The German Environmental Agency has asked Fraunhofer ISI and Climate Analytics to assess the scientific basis for the implications.

2.1 Objectives

This paper contextualizes the content of the the Strategic Vision and the In-Depth Analysis, based on the scientific literature. On the one hand, the paper provides an overview of the scientific discourse about the Paris targets and the underlying global scenarios, in particular with regard to the chances of limiting global warming to a certain temperature level and the associated carbon budget and negative emissions. On the other hand, the paper assesses in detail the interpretations and assumptions of the the Vision and the In-Depth Analysis, and their implications, in particular in the context of global mitigation effort-sharing approaches.

3 Interpreting global mitigation pathways in light of the Paris Agreement long-term temperature goal

In this section, we present the current scientific basis on the interpretation of the Paris Agreement.

3.1 Interpretation and operationalization of the Paris Agreement's long-term temperature goal

Article 2.1 defines the PA LTTG as "[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, recognizing that this would significantly reduce the risks and impacts of climate change". Note that the Paris Agreement itself also clearly refers to one and only one long-term temperature goal (LTTG)[2].

Article 4.1 of the Paris Agreement is designed to operationalize the LTTG [4]. The emissions goals specified in Article 4 – to peak global emissions "as soon as possible", followed by "rapid reductions thereafter", and to reach a balance between anthropogenic sources and sinks of greenhouse gases emissions in the second half of this century – are to be determined "according to best available science" so as to be consistent with the LTTG.[3] In this context it is to be noted that the IPCC SR1.5 currently provides the awaited, best available science for operationalising the LTTG and defining the global goals mentioned in Article 4.1 consistent with this. It is important to further note that, by construction and its relationship to Article 2.1, Article 4.1 is not a standalone goal or set of goals, but is to be quantified in view of Article 2.1.

3.1.1 Development of long-term temperature goal

The Cancun "hold below 2°C" goal has often been assessed in the scientific literature, including the IPCC Fifth Assessment Report Synthesis [5], to meaning a 'likely' probability (greater than 66%) of holding the increase in global mean temperature increase below 2°C above pre-industrial levels over the 21st century. Such "hold below 2°C" pathways have a median peak 21st century warming of, at most, around 1.8°C. In this light the Paris Agreement LTTG, with its reference to "well below 2°C" and 1.5°C limit, explicitly and intentionally represents a strengthening [6]–[11] of the goal in the 2010 Cancun Agreements [12] to hold the increase in global average temperature below 2°C above preindustrial levels.

UNFCCC COP16 also agreed the adequacy of the long-term goal would be reviewed periodically. Owing in large part to concerns of many vulnerable countries

2 Art. 4 says "In order to achieve the long-term temperature goal set out in Article 2 […]", UNFCCC (2015) FCCC/CP/2015/L.9/Rev.1

3 https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

the Cancun Agreements adopted at UNFCCC COP16 recognized the need to consider "strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5 °C". The first periodic review, known as the 2013-2015 review was mandated to consider this[4]. UNFCCC COP18 established the Structured Expert Dialogues (SED) on the 2013-2015 Review [13], with the results of the SED leading to the strengthening of the global goal in Decision 10/CP.21 and to the PA LTTG mentioned above [4], [14].

The core scientific basis for mitigation pathways that underpinned the Cancun Agreements and subsequent literature, and the work of the SED on the 2013-2015 Review of the adequacy of the long-term goal (all preceding the Paris Agreement) systematically characterized the Cancun "hold below 2°C" global goal using pathways that limited warming to below 2°C with a chance of *at least* 66%, or "*likely*" in IPCC terms [15]. The decision to strengthen the long-term goal therefore has to be seen with reference to this context, which frames the negotiations over the ambition elements of the Paris Agreement. The Paris Agreement LTTG strengthens the former Cancun temperature goal by referring to holding warming "well below 2°C" and, in this context, pursuing efforts to limit warming to 1.5°C. It therefore signals that warming needs to be held to a lower level than in the former (Cancun) goal, and hence increase both margin and likelihood by which warming is to be kept below 2°C compared to merely "hold below 2°C" [4]. The reference to the 1.5°C limit is embedded in Article 2.1 and is an integral part of it, providing a clear reference point and also to the point of "recognizing that this [limit] would significantly reduce the risks and impacts of climate change".

3.1.2 Scientific literature on Paris Agreement long-term temperature goal

A review of the recent literature shows two broad categories of reflections on PA Article 2. Whereas papers published in political science and international law journals generally emphasize the strengthening of the global goal as explained above [6]–[10], [14], [16]–[18], or merely quote Article 2 without evaluation [19], this is generally not linked to a quantitative perspective on mitigation pathways and targets and there is no mention of pathway characteristics such as probabilities of achieving a temperature limit, or level of peak warming reached over the 21st

4 https://unfccc.int/topics/science/workstreams/periodic-review/what-was-the-2013-2015-review-frequently-asked-questions-faq

century. An overarching observations from this category of literature [8]–[10] is that to comply with the Paris Agreement, global mitigation pathways need to provide a real perspective to limiting temperature increase to 1.5°C.

In a second category of literature, papers in climate-science and energy-related journals generally look at quantitative implications of the PA, but generally these papers do not explicitly evaluate the PA. This is highly problematic, as scientific assessments linked to the PA need to be explicit about the interpretations of the agreement they adopt [20]. Implicit assumptions about potential interpretations of the PA in the scientific literature would be policy prescriptive in a non-transparent way about the PA's nature.

Mostly these papers draw from emissions scenarios assessed in IPCC's pre-Paris Fifth Assessment Report [21] from 2014, which is also the case for UNEP's series of Emissions Gap Reports [22] that supported the UNFCCC process in the Cancun-to-Paris period 2010-2015. One broad group of these papers evaluates the former "hold below 2°C" and 1.5°C limit alongside each other [23]–[27] and if there is a mention of "hold well below 2°C", then this is by re-labelling scenarios previously used to assess the former "hold below 2°C" goal as "hold well below 2°C". This is indeed what the Strategic Vision (Figures 2 and 4) and the In-Depth Analysis do (see Section 4 below). Such an approach represents a questionable interpretation of "hold well below 2°C", and fails to provide a simultaneous perspective on well-below 2°C and 1.5°C. It is therefore not compatible with the PA and should not be used to guide policy action towards achieving its goals.

Another group of papers in this literature category ignores the 1.5°C limit all together [28], [29], while also continuing to refer to scenarios in the literature that predate the PA and focus on the former "hold below 2°C" of the Cancun Agreements. The "hold below 2°C" pathways in this literature do not provide a perspective to limiting temperature increase to 1.5°C (see above), with 2030 levels that are far above those in 1.5°C pathways, as shown in IPCC SR1.5, so that 1.5°C would be out of reach, unless extreme Carbon Dioxide Removal levels are achieved by 2050 that the Special Report does not deem feasible for technical, economic and sustainability reasons [3].

Finally, a range of publications bring together an evaluation of the process that led to the Paris Agreement with quantitative aspects [4], [11], [30], [31], and while again not always resolving the "well below 2°C" issue, at least include the 1.5°C long term temperature limit as an integral part of the LTTG.

3.1.3 Mitigation pathways to inform implementation of long-term temperature goal

The most comprehensive and up-to-date assessment of mitigation pathways is the recent IPCC Special Report on 1.5°C (SR1.5). Its Summary for Policy Makers (SPM) [3] established 1.5°C mitigation pathways as being pathways with no- or limited-overshoot. These pathways limit median global warming to 1.5°C throughout the 21st century without exceeding that level ("no-overshoot"), or 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"). With a peak warming of at most 1.6ºC these pathways meet several tests with reference to the LTTG:

- Whereas the "hold below 2ºC" pathways peaked warming at up to 1.8°C, these pathways in IPCC SR1.5 SPM peak warming at a significantly lower level (1.5-1.6°C)
- While "hold below 2°C" pathways kept warming below 2°C with a least 66% probability, these pathways in the SR1.5 SPM increase the probability to at least 86%
- These SR1.5 SPM pathways limit warming by 2100 to below 1.5°C with a probability greater than 50%

Hence these pathways can be said to hold warming "well below 2°C" and limit warming to 1.5°C. In these 1.5°C mitigation pathways, total greenhouse gas emissions peak around 2020 and decrease rapidly to global zero around 2070. These pathways are compatible with interpretations of the PA LTTG in its Article 2.1 and can be used for operationalising Article 4.1 as described above.

Although the IPCC SR1.5 also assesses other pathways, these lead to higher warming levels. These include pathways that hold warming below 2°C with 66% chance, i.e. "hold below" 2°C with peak warming levels up to 1.8°C and do no retain a line of sight towards "pursuing" the limiting warming to 1.5°C. The IPCC SR1.5 provides an assessment of these pathways for purposes of comparison and consistency and does not establish linkages with the PA LTTG. At the same time, the IPCC SR1.5 is very clear about the increases in climate risks between 1.5°C and 2°C, which relates to the clause of the LTTG that recognizes that holding warming well below 2°C and limiting it to 1.5°C significantly reduces the risks and impacts of climate change.

Finally, we note the IPCC SR1.5 category of "high-overshoot" pathways returning warming to 1.5°C by 2100 after peak warming up to 1.9°C is also not consistent

with the LTTG requirement, and these would be associated with climate risks, impacts and damages closer to those associated with warming of 2°C than with 1.5°C. The peak warming levels in these pathways cannot be construed as holding warming well below 2°C. Indeed, IPCC SR1.5 SPM concludes: “Future climate-related risks depend on the rate, peak and duration of warming. In the aggregate they are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (e.g., about 2°C) (*high confidence*).” In addition, as IPCC WR1.5 shows, the peak warming of these pathways, as well as the peak warming of 1.7-1.8°C in the “hold below 2°C” pathways does not provide a real perspective on achieving the 1.5°C limit, because these high peak levels will likely preclude dropping back down to 1.5°C: “Reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR at rates and volumes that might not be achievable given considerable implementation challenges”.

In summary, the IPCC SR1.5 is the most authoritative scientific assessment on relevant for the PA LTTG to date. It establishes the feasibility of pathways limiting warming to 1.5°C that are compatible with interpretations of the PA LTTG to account for a strengthening of the former (Cancun) goal. It provides comprehensive information on the key characteristics of such pathways, e.g. 2030 emission levels, that can guide policy processes.

3.2 Characterization of global mitigation pathways

Global mitigation pathways need to be evaluated against PA Article 2 and can then be used to inform the operationalization in accordance with Article 4, for example in NDCs and LTS. We discuss here the mitigation pathway categories from IPCC SR1.5. In general, global total greenhouse gas emissions typically peak by 2020 and then decline rapidly. Total global CO_2 emissions reach zero around 2050 for the 1.5°C compatible pathways and by around 2080 for the “hold below 2°C” pathways. Table 1 summarizes key benchmarks for these categories from IPCC SR1.5 (Chapter 2 and annex).

Table 1: Selected pathway characteristics from IPCC Special Report on 1.5°C focused on global emissions and climate-projections.

IPCC SR1.5 pathway category	Peak warming (°C above pre-industrial)	Probability <2°C at time of peak warming (%)	GHG emissions 2030 (% below 2010)	GHG emissions 2050 (% below 2010)	Year of zero GHG	Year of zero CO_2	Cumulative CO_2 emissions 2016-2100 ($GtCO_2$)
No-overshoot 1.5°C ("hold well below 2°C, limit to 1.5°C")[5]	1.5°C (1.4-1.5°C)	95% (93-96%)	58% (56-69%)	94% (92-95%)	2044 or later	2037-2054	150 (5-260)
Low-overshoot 1.5°C ("hold well below 2°C, limit to 1.5°C")[6]	1.6°C (1.5-1.6°C)	90% (86-93%)	41% (37-49%)	85% (78-90%)	2061-2080	2047-2055	260 (130-790)
Hold below 2°C – return to 1.5°C by 2100 ("hold below 2°C")[7]	1.7°C (1.6-1.9°C)	82% (66-89%)	19% (3-28%)	83% (76-88%)	2058-2067*	2049-2059	340 (90-820)
Hold below 2°C ("hold below 2°C")[8]	1.7°C (1.5-1.8°C)	74% (66-88%)	24% (15-35%)	65% (57-72%)	2099 or later	2065-2095	880 (190-1420)

Values represent median across pathways in each category. Ranges represent interquartiles (50% range). Note GHG Emissions are aggregated with GWP-100 values from IPCC Fourth Assessment Report (AR4). Values in this table were taken from Table 2.4 in Chapter 2 and Table 2.A.12 in Chapter 2 Annex, except for GHG emissions in 2030 and 2050, which were calculated from the IPCC SR1.5 scenario database https://data.ene.iiasa.ac.at/iamc-1.5c-explorer (accessed 22 October, 2018).

*It may seem counter-intuitive that these pathways with a high peak level of warming have an earlier year of zero emissions than others. This is related to the additional effort needed to bring warming down from the peak level to 1.5°C by 2100, which requires substantially more Carbon Dioxide Removal, leading to total greenhouse emission reaching zero shorter after CO_2 emissions reach zero than in other pathway categories.

One of the key characteristics of all these pathways is the deployment of Carbon Dioxide Removal (CDR). As IPCC SR1.5 explains, this is required to both compensate for past emissions and for future remaining CO_2 and non-CO_2 emissions

5 IPCC SR15 label is "1.5°C-no-OS"

6 IPCC SR15 label is "1.5°C-low-OS"

7 IPCC SR15 label is "1.5°C-high-OS"

8 IPCC SR15 label is "Lower-2°C"

in (sub)sectors where scientific literature shows zero emissions will not be feasible (e.g. agriculture). The amount of negative emissions varies strongly across pathways: within a pathway category more CDR is required if emissions reductions are less rapid immediately after emissions peak in 2020. The main approaches in the underlying models to achieve CDR are afforestation/reforestation and bioenergy with carbon capture and storage (BECCS). Although IPCCSR1.5 also assessed the potential of CDR in terms of economic, technical, social and sustainability concerns, these mitigation pathways have not been filtered to exclude pathways exceeding those potentials, although in general the no- and low-overshoot have lower reliance on CDR than high-overshoot pathways.

4 Assessing the interpretation of the Paris long-term temperature goal in the Strategic Vision and In-Depth Analysis

The literature and global pathways overview in the preceding section will be used to put in context the global pathways referred to in the Strategic Vision and the In-Depth Analysis. The In-Depth Analysis writes in its section 7.3 (footnotes removed, bold print added):

"Many recent studies have examined cost effective global pathways to **well below 2°C** and report results at global level. A small number of studies report results at regional level for different world regions including the EU. These tend to confirm that **reducing EU domestic greenhouse gas emissions by at least 80% below 1990 levels** would still be **consistent with a global pathway for keeping warming well below 2°C**.

For instance the Horizon 2020 projects LIMITS and AMPERE examined different scenarios, comparing multiple models operated by different teams around the world. A 2018 summary by the Netherlands Environment Assessment Agency, which selects only scenarios that have **66% likelihood or more to limit global warming to 2°C** and where global cost-optimal mitigation begins in 2020 or later, finds the average reduction for the EU, including the LULUCF sector, to be 74% below 2010 levels which is around 78% below 1990 levels.

This finding is also supported by analysis conducted by the Netherlands Environmental Assessment Agency and JRC for this report. **Pathways keeping global warming by 2100 compared to pre-industrial below 2°C with a probability of at least 66% see EU reduce GHG emissions, including LULUCF,**

by 76% to 84% below 1990 levels in 2050 the more ambitious pathway being associated with a scenario that limits technology options related to CCS. ”

As in part of the literature assessed in the preceding section, these are all references to mitigation pathways that previously were associated with the former “hold below 2°C” goal and no argumentation is provided why these pathways would now be consistent with “well below 2°C”. A brief clarification is provided in footnote 16:

“While there is no official definition of ‘well below’ 2°C, studies typically refer to pathways with a >66% chance of keeping global warming below 2°C. The average temperature change expected in such pathways is therefore lower – typically 1.7-1.8°C in 2100.”

This footnote does not provide further information or references to “studies” and is not consistent with our literature analysis in Section 3. It seems clear that what are labelled “well below 2°C” pathways in the Strategic Vision and In-Depth Analysis are pathways previously used to inform the former “hold below 2°C” goal. This is confirmed by other indicators characterizing the pathways in the In-Depth Analysis, such as “zero net GHG emissions by the end of the century” (Page 15 of In-Depth Analysis, to compare with Table 1 of this paper).

The In-Depth Analysis Sections 1.1 and 7.3 mention 1.5°C pathways, referring to IPCC SR 1.5 no- and low-overshoot pathways, that seem consistent with those mentioned in the preceding section, but puts these in a separate category distinct from what they call “well below 2°C” (pathways consistent with the former “hold below 2°C” goal). In this context it does correctly refer to the need for early zero emissions and subsequent negative emissions, for instance on page 16 (footnotes removed):

“Limiting global warming to 1.5°C requires even greater, and more urgent, action. In a 1.5°C world, typical projections reach net zero GHG emissions by 2070, and become negative afterwards (Figure 2). In such scenarios, global CO_2 emissions would have to become net zero already by 2050, as confirmed by the IPCC.”

5 Assessing the Commission's conclusions on Paris-compatible emission pathways for the EU

In Section 7.3 of the In-Depth Analysis supporting the EU's Strategic Vision [2], a meaningful EU contribution to the Paris Agreement's temperature objectives is discussed. Based on this, the Commission's Strategic Vision [1] assesses all the scenarios of the In-Depth Analysis [2] as "in-line with the Paris Agreement" and, in particular, labels the scenarios with 80% GHG reduction in 2050 as "well below 2°C scenarios". In the following, we assess the underlying statements in Section 7.3 of the In-Depth Analysis [2] with regard to the corresponding assumptions and implications in the context of the scientific literature cited but also additional references. We do not assess the scenarios of the In-Depth Analysis itself.

5.1 Implications of global cost-effective pathways

A central statement of the In-Depth Analysis [2] in Section 7.3 is that global cost-effective mitigation pathways that include regional coverage of the EU "tend to confirm that reducing EU domestic greenhouse gas emissions by at least 80% below 1990 levels would still be consistent with a global pathway for keeping warming well below 2°C". The In-Depth Analysis here refers to the results of the AMPERE and the LIMITS projects (Kriegler et al. 2014, Riahi et al. 2015) and a report not publicly available yet [34].[9] The AMPERE and the LIMITS projects were carried out in the run-up to COP21 in Paris. Hence, they were therefore informing the negotiations in Paris, but not aware of the LTTG formulated in the PA as adopted and later on ratified and entered into force. In particular, the projects included scenarios with a 66% chance of limiting global warming to 2°C during the 21st century (no overshoot), but did not explicitly label them as "well-below 2°C", which is the interpretation of the In-Depth Analysis based on other scientific literature (see Section 4). For those scenarios with a 66% chance for 2°C and ambitious action after 2020 only, the mean reduction of GHG emissions in the EU in 2050 is indeed close to 80% compared to 1990.

The LIMITS and AMPERE projects are the latest global scenario analyses that have already published also detailed regional data for the EU. In particular, the scenario analyses that contributed to the scenario database for the IPCC SR1.5 (https://data.ene.iiasa.ac.at/iamc-1.5c-explorer) have only published data for the OECD90 + EU so far. For the OECD90 + EU, GHG emissions in the cost-effective

9 On 3 December 2018, this PBL report was not available on PBL's website yet.

global scenarios with a 66% chance to limit global warming to 2°C are on average reduced by 75 % in 2050 compared to 2010. If as a proxy indicator the same rate is applied to the EU, this is consistent with an 80% reduction target compared to 1990. For 1.5°C, GHG emissions of OECD90 + EU are on average reduced by 90% in 2050 compared to 2010. This in turn is in line with the statements of the In-Depth Analysis for the EU's GHG emission reductions in 1.5°C pathways based on [34], which finds a reduction of 91% by 2050 compared to 1990.

With regard to reaching the target of net-zero GHG emissions included in Article 4 of the PA and the implied need for negative emissions, the In-Depth Analysis refers to a recent meta-analysis by van Soest et al. [35]. The In-Depth Analysis states that in global cost-effective pathways "the EU is typically not the first large emitter to achieve net zero emissions" because its potential for negative emissions based on land use is limited due to its relatively small size. The In-Depth Analysis does not explicitly mention a point in time for reaching net-zero GHG emissions in the EU with regard to what they define as the well-below 2°C pathways. As the global section refers to global net-zero emissions at the end of the 21st century and "the EU is typically not the first large emitter to achieve net zero emissions", one can implicitly assume that the net-zero target is not taken into account here. There are two issues with this: on the one hand, reaching net-zero GHG emissions in the second half of the 21st century is a target of the PA itself. So it needs to be addressed in any case to be in line with the PA. On the other hand, van Soest et al. [35] make clear that there is an issue with data harmonization, in particular with regard to LULUCF data, as LULUCF emissions reported to the UNFCCC are typically lower than those assumed in global integrated assessment models. Taking this into account, van Soest et al. find an earlier date for net-zero GHG emissions: 2080 for the EU in scenarios with 66% chance for 2°C. There is no data for the 1.5°C-consistent pathways in [35], but the In-Depth Analysis [2] itself states that 1.5°C-consistent pathways with limited negative emissions show net-zero GHG emissions in the EU by 2050**.**

5.2 Wider considerations including equity-based effort-sharing and the need for negative emissions

The In-Depth Analysis [2] mainly focuses on cost-effective global pathways to reach the specific interpretation of the PA LTTG (shown to be questionable in Section 2) and their implications for an adequate level of ambition of the EU. In addition, the In-Depth Analysis also addresses equity-based effort-sharing approaches. There is a wide range of such approaches in the scientific literature as

well as in the political debate about a fair global effort-sharing. Here, the In-Depth Analysis mainly refers to Robiou du Pont et al. [36]. Based on this, the In-Depth Analysis provides another argument that a reduction of GHG emissions by 80% in 2050 compared to 1990 is in line with a 66% chance for 2°C, as Robiou du Pont et al. find a reduction of the EU's GHG emissions in 2050 by 75% compared to 1990 for an approach based on convergence of per-capita emissions, while the reduction amounts to 90% compared to 1990 for 1.5°C-consistent pathways.

However, while for the 1.5°C pathways the In-Depth Analysis [2] also mentions approaches that take into account different GDP levels (equity criterion "capability") and historic emissions (equity criterion "responsibility"), this is not the case for the pathways that reach 2°C with 66% chance. Our evaluation of the existing approaches in Wachsmuth et al. [37] shows that for these approaches emissions allowances for the EU may well become strongly negative in 2050 even for the pathways that reach 2°C with 66% chance depending on the details of the chosen effort-sharing approach. Thus, an equity point of view on pathways that reach 2°C with 66% chance does not justify a focus on an 80% reduction for 2050. In this regard, an important issue is whether a chosen emission reduction target is to be satisfied domestically only, or whether mechanisms for international cooperation may be taken into account. Conceptually, domestic targets are to be reached without any international offsetting approach. Politically, this is in line with the PA's Article 6, which prescribes the role of cooperative approaches to serve only for a total rise of ambition globally.

The In-Depth Analysis provides several other arguments for not sticking to the lower level of ambition of an 80% reduction for the 2050 target. The main arguments are:

- Demonstration of leadership in the context of equity considerations: From a global leadership perspective, there are strong arguments that the highly-developed world regions such as the EU should demonstrate how to achieve net-zero emissions first (cf [38]).
- Risk of lock-ins: a lower ambition early on may put a 1.5°C pathway out of range by leading to investments in long-living carbon-intensive infrastructure, such as an energy-intensive building stock.
- A precautionary approach, in particular with regard to a lower reliance on negative emission technologies, vulnerability to climate change as well as uncertainties about the remaining carbon budgets associated with the PA LTTG

Consistent with the global findings in IPCC SR1.5 [39], Esmeijer et al. [34] find – according to the In-Depth Analysis [2] – that reaching net-zero GHG emissions

by 2050 reduces the need for negative emission in the second half of the 21st century substantially. This is also supported by the recent carbon budget analysis of Duscha et al. [40] for the EU, which shows that in the existing global and EU pathways ambition can be increased with regard to demand-side mitigation so that additional cumulative savings are in the same order of magnitude as the negative emissions in those pathways.

The Commission's In-Depth Analysis addresses the annual negative emissions required in 2050 and qualitatively discusses negative emissions required after 2050. However, there is no quantitative information on the total negative emissions required in the course of the 21st century, which is an important gap to judge the feasibility to provide those negative emissions. With regard to the required negative emissions in the EU, Duscha et al. [40] find that in global scenarios that reach 2°C with a 66% chance, the cumulative emission reductions by CCS for the EU vary widely ranging between 17 and 145 Gt CO_2e, depending on the 2050 reductions but also on the global distribution of negative emissions. Moreover, Ohlendorf et al. [41] compare global cost-effective 1.5°C pathways for the EU to a pathway based on the EU's current 2030 and 2050 GHG reduction target. They find that the EU would require negative emissions between 43 and 57 Gt CO_2e to stay within its carbon budget corresponding to the global cost-effective 1.5°C pathway. Furthermore, they argue that based on current expectations, neither LULUCF nor BECCS are in any way likely to provide that amount of negative emissions. These findings suggest that a precautionary approach with regard to negative emissions is indeed appropriate.

5.3 Summary of the findings with regard to the Commission's Strategic Vision and the In-Depth Analysis

In summary, the Commission's claim that an 80% reduction of the EU's GHG emissions by 2050 can be taken as in line with the Paris LTTG is questionable, due to the Commission's re-labelling of the former "hold-below-2°C" pathways associated with the 2010 Cancun Agreements as "well-below 2°C" pathways. Despite the shortcoming with regard to interpreting "well-below-2°C", the EU Strategic Vision is a clear shift away from the lower end of the former "80-95%" reduction target by 2050 towards achieving net-zero greenhouse gas emissions in 2050. This is based on the In-Depth Analysis, which shows that a greenhouse gas emission reduction of 90% by 2050 compared to 1990 is necessary to keep 1.5°C in range, while limiting negative emissions even calls for net-zero greenhouse gas emissions in 2050. Hence, the "net-zero greenhouse gas emissions in

2050" target chosen in the Strategic Vision is a reasonable choice in light of the Paris Agreement and the IPCC Special Report on 1.5°C, but 80% reduction by 2050 is not. Thus, the lower end of the current "80-95%" EU target is insufficient.

Moreover, for compatibility with the Paris LTTG, a reconsideration of the EU long-term target is necessary, but not sufficient. Also the remaining carbon budgets associated with the LTTG and hence also mid-term targets have to be assessed in the context of a fair global effort sharing. This is not the case in the In-Depth Analysis, which is conflict with the requirements under Article 15 of the provisionally agreed text of the Governance Regulation [42], which demands that the Commission's analysis covers "the implications of the scenarios (…) on the remaining global and Union carbon budget in order to inform a discussion about cost efficiency, effectiveness and fairness of greenhouse gas emission reduction".

6 Literature

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Karlsruhe 2018