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Scenario Note: Pathways towards Returning Warming to below 1.5°C by 2100

- Briefing Note to the Climate Institute -

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Summary

This briefing note provides information on illustrative emission pathways from the peer-reviewed literature that achieve limiting global-mean temperature increase to below 1.5°C by 2100. Two pathways are presented. Pathway A is a pathway that starts emission reductions immediately and already sees strong global emission reductions by 2020. Pathway B assumes that only limited emissions reductions are achieved by 2020 and then catches up significantly afterward. A short description of the pathways is followed by a discussion of the caveats.

This note is accompanied by a spreadsheet containing the emission data of the pathways presented here, both in terms of total CO_2 and total greenhouse gas emissions of the Kyoto-basket.

Contents

I. Pathway A

Pathway A is a stringent mitigation pathway that manages to return global-mean temperature rise to below 1.5°C by 2100 with about 66% probability. It is extracted from a recent peer-reviewed publication on relationships between climate mitigation costs and averted climate risks[1]. Pathway A assumes immediate, stringent action on all greenhouse gases from the Kyoto-basket[2] (Kyoto-GHG). Therefore, not only carbon-dioxide (CO_2) but also other gases like methane (CH_4) are reduced significantly throughout the entire century. Because no delay in globally coordinated action is assumed in this pathway, important emission reductions are already anticipated by 2020 in Pathway A. Global total Kyoto-GHG emissions roughly return to their 2000 value in 2020. Global emissions in this pathway thus peak significantly before the end of the current decade, and continue on a steep decline throughout the 21st century. Importantly, this scenario also assumes stringent reductions in CH_4, together with CO_2. Although the main driver for returning warming to below 1.5°C by 2100 are reductions in CO_2, higher CH_4 emissions might shift the probability of keeping warming to below 1.5°C by the end of the century from its initial value of 66% to about 50%.

Table 1: overview of emissions budgets over time of Pathway A

PATHWAY A: Emission budgets from 2000		
	Total CO_2 [$PgCO_2$]	*Kyoto-GHG [$PgCO_2e$]*
Until 2009	326	446
Until 2050	1103	1742
Until 2100	687	1798
Emission budgets from 2010		
Until 2050	777	1296
Until 2100	361	1352

Table 2: overview of methane emissions over time of Pathway A

PATHWAY A: Annual methane (CH_4) emissions over time		
	Total CH_4 [$MtCH_4/yr$]	*Total CH_4 [$PgCO_2e/yr$]*
In 2010	354	8.8
In 2020	334	8.3
In 2050	271	6.8
In 2100	167	4.2

CH_4 emissions are here translated in CO_2-equivalent emissions using a 100-year global-warming-potential value of 25.

[1] Reference: Rogelj, J., D. L. McCollum, A. Reisinger, M. Meinshausen & K. Riahi (2013) Probabilistic cost estimates for climate change mitigation. *Nature*, 493, 79-83, 10.1038/nature11787.

[2] Carbon-dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). NF_3 is not yet included in these calculations.

II. Pathway B

Pathway B is also a stringent mitigation pathway that manages to return global-mean temperature rise to below 1.5°C by 2100 with about 50% probability. The pathway has been published in the peer-reviewed literature as part of a study that aims at quantifying the window of emissions in 2020 through which emissions have to pass to limit warming to 1.5 or 2°C[3]. In contrast to Pathway A, Pathway B assumes only limited emission reductions by 2020, and emissions in 2020 are about 30% higher than they were in the year 2000. After 2020, however, globally stringent emission reductions are required in this path in order to keep emissions within a budget consistent with returning warming below 1.5°C in 2100. As in Pathway A, emission reductions in other Kyoto-GHGs, like CH_4, are assumed concurrently with reductions of CO_2. In general, Pathway B implies higher risks than Pathway A and this in various dimensions. Following a path like Pathway B would result in a higher dependency on the scaling up of key mitigation technologies, higher overall costs, higher pressure on future policy requirements, limitations on future societal choices, and increased climate risks[4].

Table 3: overview of emissions budgets over time of Pathway B

PATHWAY B: **Emission budgets from 2000**		
	Total CO_2 [$PgCO_2$]	*Kyoto-GHG [$PgCO_2e$]*
Until 2009	325	445
Until 2050	1259	1950
Until 2100	725	2006
Emission budgets from 2010		
Until 2050	935	1505
Until 2100	401	1561

Table 4: overview of methane emissions over time of Pathway B

PATHWAY B: **Annual methane (CH_4) emissions over time**		
	Total CH_4 [$MtCH_4/yr$]	*Total CH_4 [$PgCO_2e/yr$]*
In 2010	353	8.8
In 2020	387	9.7
In 2050	341	8.5
In 2100	253	6.3
CH_4 emissions are here translated in CO_2-equivalent emissions using a 100-year global-warming-potential value of 25.		

[3] Reference: Rogelj, J., D. L. McCollum, B. C. O'Neill & K. Riahi (2013) 2020 emissions levels required to limit warming to below 2°C. *Nature Clim. Change*, 3, 405-412, 10.1038/nclimate1758.

[4] For a more elaborate discussion, see Section 3.7 of reference: UNEP. 2012. The Emissions Gap Report 2012 - A UNEP Synthesis Report. 62. Nairobi, Kenya: UNEP, ISBN: 978-92-807-3303-7.

III. Important background notes

A. Climate model assumptions

The global-mean temperature outcome of both pathways is based on the assessment as described in the original papers of which the pathways were taken. Both publications use the reduced complexity carbon-cycle and climate model MAGICC in a probabilistic setup[5]. The model has been setup in a way such that it closely represents the uncertainty assessment of forcings and climate sensitivity[6] of the IPCC Fourth Assessment Report[7] (AR4). These assessments of uncertainties are subject to our current understanding and available knowledge of the climate system. It is both expected and desired that these assessments change over time as the state-of-the-art knowledge of the climate response to anthropogenic greenhouse gas emissions advances.

B. Scenario assumptions

The underlying assumptions in terms of population, economic and energy demand growth are important aspects of any emission scenario.. Both scenarios underlying Pathway A and B assume "middle-of-the-road" assumptions for socio-economic development from the scenario literature: population peaking at 9.7 billion later in the century (UN median projection[8]), and gross world product increasing more than seven-fold by 2100[9]. However, while population and economic growth are following intermediate trajectories for the future, energy demand is not. Both pathways require that measures on the supply side (renewable energy, bio-energy, carbon-capture and storage) are complemented by significant action on the demand side (energy efficiency measures).

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[5] References: Meinshausen, M., S. C. B. Raper & T. M. L. Wigley (2011) Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 – Part 1: Model description and calibration. *Atmos. Chem. Phys.*, 11, 1417-1456, 10.5194/acp-11-1417-2011.
Meinshausen, M., T. M. L. Wigley & S. C. B. Raper (2011) Emulating atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 – Part 2: Applications. *Atmos. Chem. Phys.*, 11, 1457-1471, 10.5194/acp-11-1457-2011.

[6] Reference: Rogelj, J., M. Meinshausen & R. Knutti (2012) Global warming under old and new scenarios using IPCC climate sensitivity range estimates. *Nature Clim. Change*, 2, 248-253, 10.1038/nclimate1385.

[7] Reference: IPCC. 2007. *Climate Change 2007: The Physical Science Basis.* Working Group I Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. 994. Cambridge, UK and New York, USA: Cambridge University Press

[8] Reference: UN. 2009. World Population Prospects: The 2008 Revision Population Database. New York: United Nations, Department of Economic and Social Affairs, Population Division <http://esa.un.org/wpp/>

[9] This is based on an updated IPCC SRES B2 scenario projection from the Global Energy Assessment, reference: Riahi, K., F. Dentener, D. Gielen, A. Grubler, J. Jewell, Z. Klimont, V. Krey, D. McCollum, S. Pachauri, S. Rao, B. van Ruijven, D. P. van Vuuren & C. Wilson. 2012. Chapter 17 - Energy Pathways for Sustainable Development. In *Global Energy Assessment - Toward a Sustainable Future*, 1203-1306. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, 9781 10700 5198 hardback 9780 52118 2935 paperback.

C. The importance of low energy demand

Lowering future energy demand is key to achieve stringent levels of climate protection (for example, see earlier published studies[1]). This insight has also been highlighted in the latest version of the UNEP Emissions Gap Report (section 3.6.4), the 2012 Global Energy Assessment[9], and the IPCC assessment on renewable energies[10]. The most important benefits of lower energy demand in 2°C-consistent pathways is that they reduce the pressure on single mitigation technologies. They thus provide more flexibility in terms of the extent to which each single mitigation needs to be scaled up to achieve the desired emissions reductions. For 1.5°C-consistent pathways lowering energy demand seems to be a pre-requisite. Only by significantly reducing energy demand over the course of the century, in combination with the implementation of a wide portfolio of mitigation technologies can emissions be reduced to a sufficient degree to limit warming to below 1.5°C in 2100.

In the scenarios presented here, ambitious improvements in energy efficiency are assumed at roughly double the global rate of what has been observed historically, in absence of targeted policies. Such ambitious energy efficiency improvements would be able to significantly reduce future energy demand. While being ambitious, energy efficiency improvements of similar stringency (in order to reduce energy demand) are part of the objectives of the United Nations Secretary-General's "Sustainable Energy for All" initiative[11]. It is important to note that energy efficiency improvements for reducing global energy demand are not only driven by climate protection concerns. As a matter of fact, economic and energy security concerns are equally strong motivations.

[10] Reference: Fischedick, M., R. Schaeffer, A. Adedoyin, M. Akai, T. Bruckner, L. Clarke, V. Krey, I. Savolainen, S. Teske, D. Ürge-Vorsatz & R. Wright. 2011. Mitigation Potential and Costs. In *IPCC Special Report on Renewable Energy Sources and Climate change Mitigation*, eds. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer & C. von Stechow. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press,

[11] See also: http://www.sustainableenergyforall.org/
A recent study has also shown the consistency of the three "Sustainable Energy for All" objectives with limiting warming below 2°C: Rogelj, J., D. L. McCollum & K. Riahi (2013) The UN's 'Sustainable Energy for All' initiative is compatible with a warming limit of 2°C. *Nature Clim. Change*, advance online publication, 10.1038/nclimate1806.

D. Budget comparison

In order to better understand the cumulative emission budgets implied by the two pathways described in this note, we here compare the budgets from both Pathway A and B with budgets consistent with 2°C. For this we use the 2°C check tool, developed by Malte Meinshausen[12].

Pathway A has a cumulative carbon dioxide emission budget of 1100 $PgCO_2$ between 2000 and 2049. This would be consistent with a 70% chance of staying below 2°C. Alternatively, Pathway A also has a cumulative total Kyoto-GHG emissions budget from 2000 to 2049 of 1728 $PgCO_2e$. This would be consistent with a 65% of staying below 2°C during the 21st century.

Pathway B has a cumulative carbon dioxide emission budget of 1259 $PgCO_2$ between 2000 and 2049. This would be consistent with a 62% chance of staying below 2°C. Alternatively, Pathway B also has a cumulative total Kyoto-GHG emissions budget from 2000 to 2049 of 1937 $PgCO_2e$. This would be consistent with a 54% of staying below 2°C during the 21st century.

When comparing these probabilities, some important issues have to be kept in mind:

1) An important aspect of the 1.5°C pathways presented in this note are the low emissions throughout the first half of the century, and the very low emissions in the second half of the century. The pathways in the Meinshausen *et al.* study (see footnote 12) do not assume such very low emission reductions in the second half of the century.
2) The MESSAGE model (underlying the pathways presented in this note) has a relatively large potential for negative emissions[13] by the end of the century[14]. In case these technologies would not scale up, or in case one would want to hedge against the risk that these technologies do not scale as projected, the budgets in the first half of the century would be smaller. Pathway B would not make it altogether.
3) The probabilities given above for CO_2-only budgets are, in this case, more comparable than the Kyoto-GHGs because Kyoto-GHGs by Meinshausen *et al.* were aggregated using the 100-year global warming potentials of the IPCC Second Assessment Report (in line with the 2002 UNFCCC guidelines), while the MESSAGE model reports its Kyoto-GHG emissions with the 100-year global warming potentials of the IPCC Fourth Assessment Report (which are higher for methane).

[12] This tool is freely available as supplementary material to the paper: Meinshausen, M., N. Meinshausen, W. Hare, S. C. B. Raper, K. Frieler, R. Knutti, D. J. Frame & M. R. Allen (2009) Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature*, 458, 1158-1162, 10.1038/nature08017.

[13] Negative emissions: the active removal of carbon-dioxide from the atmosphere, for example by combining bio-energy with carbon capture and storage.

[14] See also the accompanying excel sheet which shows that the 1.5°C consistent pathways presented in this note get to levels of about -7.5 $PgCO_2$ negative emissions through CCS by the end of the century.

E. Caveats and limitations

When making use of these pathways it is important to be aware of the caveats and limitations that are inherent to the studies underlying these pathways.

The 1.5°C pathways presented here are taken from the peer-reviewed scientific literature and their scientific soundness has therefore been vetted by the scientific community. However, both studies use one single integrated assessment modeling (IAM) framework: the MESSAGE modeling framework from the International Institute for Applied Systems Analysis[15] (IIASA), in Austria. While this is a very well established and well respected model (for example, it contributed to multiple IPCC assessments over the past couple of decades and lies at the basis of the Global Energy Assessment, published in 2012), important differences between IAM modeling frameworks can be observed. These differences can lead to differing results if the same question (in this case, limiting warming to below 1.5°C by 2100) were to be studied by other models.

Besides the structure of the model, an important difference between IAM frameworks can lie in the amount and potential of available mitigation technologies. Variations in these technologies could result in differing emission trajectories over time, and also differing shares of emissions in CO_2 versus other Kyoto-GHGs, like CH_4. The pathways presented in this note should therefore be used as illustrative pathways towards limiting warming below 1.5°C, and definitely not as the one and only solution to achieve such a target. The most robust features of the pathways are the cumulative emissions over the entire century (the emissions budget).

[15] http://www.iiasa.ac.at/

IV. Pathways

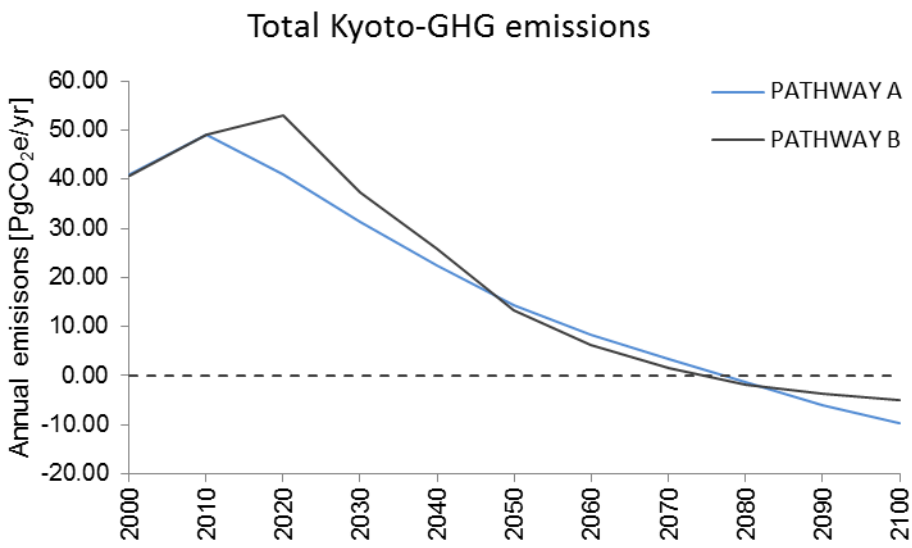

Figure 1: Total annual Kyoto-GHG emission trajectories over the 21st century for Pathways A and B. Note that the Kyoto-GHG emission budget (the area under the curve) is significantly smaller for Pathway A relative to Pathway B, resulting in a higher probability of returning warming to below 1.5°C by 2100.

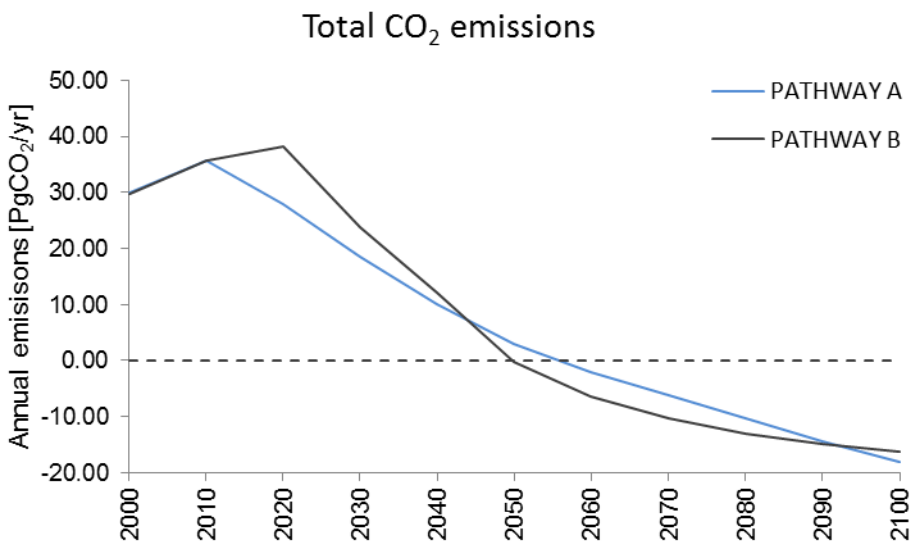

Figure 2: Total annual carbon dioxide (CO_2) emission trajectories over the 21st century for Pathways A and B.