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Uncertainty in an Emissions Constrained World: Method Overview and Data Revision

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Uncertainty in an Emissions-Constrained World: Method Overview and Data Revision

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Contents

Abstract

The study by Jonas *et al.* (2014) has received interest, notably by the Austrian Climate Research Programme [ACRP], regarding the use of the results at national scales. Jonas *et al.* discuss diagnostic (retrospective: looking back in time) and prognostic (prospective: looking forward in time) uncertainty in an emissions-temperature-uncertainty framework that allows any country to understand its near-term mitigation and adaptation efforts in a globally consistent and long-term context which includes all countries and stipulates global warming to range between 2 and 4 °C. To achieve this understanding, the study established national linear emission target paths (e.g., from 1990 to 2050) that are globally consistent. In this systems context, cumulative emissions until 2050 are constrained and globally binding but are uncertain (i.e., they can be estimated only imprecisely); and whether or not compliance with an agreed temperature target in 2050 and beyond will be achieved is also uncertain. In a nutshell, the emissions-temperature-uncertainty framework can be used to monitor a country's performance - past as well as prospective achievements - in complying with a future warming target in a quantified uncertainty-risk context.

Our working paper (i) recalls the background of the study by Jonas *et al.* in a condensed but comprehensive manner; and (ii) provides a detailed description of the study's input and output data which have been updated in the meantime. The paper uses Austria as a case country, while placing it in a European and global context.

Acknowledgments

The authors are grateful to the Austrian Climate Research Programme [ACRP] for financing this working paper. The paper is part of the ClimTrans2050 project: *Open Source Model for Analysing Austria's Transition to a Low Carbon Society by 2050 - A Research Plan* (ACRP7: KR14AC7K11796)[1].

The authors thank Anna Shchiptsova for intermittent data collection and assemblage.

[1] The official website of the ClimTrans2050 project is made available by the Austrian Institute for Economic Research (project leader) at https://climtrans2050.wifo.ac.at/tiki-index.php
The involvement of IIASA's Advanced Systems Analysis Program in the ClimTrans2050 project is summarized at
http://www.iiasa.ac.at/web/home/research/researchPrograms/AdvancedSystemsAnalysis/climtrans2050.html

About the Authors

Matthias Jonas is a senior research scholar with IIASA's Advanced Systems Analysis (ASA) Program. His interests are in environmental science, and in the development of systems analytical models and tools to address issues of global, universal and regional change, including surprises, and their potential implications for decision and policymakers.

Piotr Żebrowski joined IIASA's Advanced Systems Analysis (ASA) Program as a research assistant in February 2015. His current research focus is on diagnostic uncertainty of greenhouse gas inventories, uncertainty propagation in climate models and on retrospective learning.

Uncertainty in an Emissions-Constrained World: Method Overview and Data Revision

Matthias Jonas and Piotr Żebrowski

I. Overview

1. Purpose

The study by Jonas *et al.* (2014) has received interest, notably by the Austrian Climate Research Programme [ACRP], regarding the use of the results at national scales. This paper:

i) recalls the background of the study by Jonas *et al.* in a condensed but comprehensive manner; and

ii) provides a detailed description of the study's input and output data which have been updated in the meantime.

The paper also makes use of Austria as a case country, while placing it in a European and global context.

2. Background

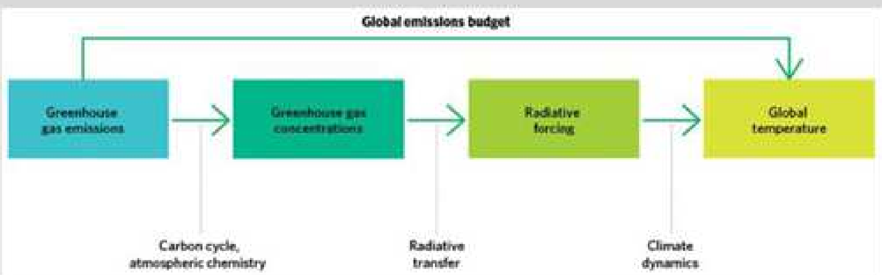
Since their inception, climate treaty negotiations have set out to stabilize the Earth's climate by implementing mechanisms that reduce global greenhouse gas [GHG] emissions and lead to sustainable management of the atmosphere at a 'safe' steady-state level (assumed to be characterized by an increase in global average temperature of not more than 2 °C above preindustrial levels). In recent years, international climate policy has been increasingly focusing on limiting temperature rise (Rogelj *et al*. 2011). The idea of limiting cumulative global GHG emissions by adhering to a long-term global warming target was first discussed publicly by policymakers at the 2009 United Nations climate change conference in Copenhagen. It appears to be a promising and robust methodology (Allen *et al*. 2009; Matthews *et al.* 2009; Meinshausen *et al*. 2009; WBGU 2009; Zickfeld *et al*. 2009; Raupach *et al*. 2011a; cf. also Box 1). To comply with it, the emissions reductions required from the fossil-fuel and land use/land-use change [LUC] sector are daunting: 50%–85% below the 1990 global annual emissions, with even greater reductions for industrialized countries (Fisher *et al*. 2007; Jonas *et al*. 2010, 2014). The underlying assumptions are equally daunting: terrestrial or oceanic sinks continuing to offset fossil-fuel and LUC emissions before achieving an emissions balance that goes beyond CO_2-C (i.e., CO_2-equivalents also including CH_4, N_2O, etc.), with no systemic surprises occurring during the transition process. In particular, net emissions from LUC activities will need to be reduced linearly to zero by 2050. That is, it is assumed that deforestation and other LU mismanagement will cease and that net emissions balance.

Box 1: Relationship between greenhouse gas [GHG] emissions and global surface temperature. Source: Raupach *et al.* (2011b; adapted).

The magnitude of an increase in global surface temperature is not determined by emissions in any one year, but by the concentration of GHGs in the atmosphere which, in turn, is the net outcome of total emissions and removals of GHGs to and from the atmosphere over an extended period.

Global emission budgets estimate the total amount of (net) GHG emissions that will result in a given temperature increase, within a probability range. This is why cumulative emissions (e.g., between today and 2050) are perceived as a good predictor for this temperature increase (e.g., in 2050 and beyond). That is, the emissions budget approach allows linking cumulative emissions of GHGs directly to temperature, without determining atmospheric concentrations of GHGs and their radiative forcing as intermediary observables (see figure below). The relationship between cumulative emissions and temperature is expressed as a probability, to reflect uncertainty of the climate response to a given amount of GHG emissions.

While global emission budgets identify the overall limit on global emissions, they do not prescribe the timing of peak emissions or the rate at which emissions must be reduced, so long as the overall budget is not breached. There will be a number of trajectories that could lead to the budgeted level of cumulative emissions and the related (but uncertain because trajectory-dependent) temperature increase over time. Because the emissions budget is ultimately fixed, however, delays in reducing emissions must be compensated with more rapid GHG emission reductions in future years.



In their study Jonas *et al.* (2014)[2] use an emissions-temperature-uncertainty [ETU] framework as a basis to discuss diagnostic (retrospective: looking back in time) and prognostic (prospective: looking forward in time) uncertainty. The ETU framework allows any country to understand its near-term mitigation and adaptation efforts in a globally consistent and long-term context which includes all countries and stipulates global warming to range between 2 and 4 °C. To achieve this understanding, national emission target paths, linear in time, were established (from 1990 to 2050 or,

[2] Cf. also http://pure.iiasa.ac.at/10910/

alternatively, from 2000 to 2050) that are globally consistent. In this systems context, cumulative emissions until 2050 are constrained and globally binding but are uncertain (i.e., they can be estimated only imprecisely); and whether or not compliance with an agreed temperature target in 2050 and beyond will be achieved is also uncertain. In a nutshell, the ETU framework can be used to monitor a country's performance - past as well as prospective achievements - in complying with a future warming target in a quantified uncertainty-risk context (cf. Box 2). The authors' objective, in particular, was to understand the relevance of diagnostic and prognostic uncertainty in this global emissions-temperature setting and across temporal scales. Although the mode of bridging uncertainty across temporal scales still relies on discrete points in time ('today' and 2050) and is not yet continuous, the authors' study provides a valuable first step toward that objective.

Box 2: Output features of Jonas *et al.*'s (2014) ETU framework.

> The output of the ETU framework provides national linear target paths for emissions, which are consistently embedded globally,
>
> – for two temporal (predictor) regimes: 1990–2050 and 2000–2050;
> – for CO_2 and all six Kyoto GHGs (cumulative);
> – for individual spheres: technosphere and land use / land-use change;
> – for three 2050 temperature targets: 2, 3 and 4 °C; and
> – which allow monitoring Austria's performance—past (with and without embodied emissions) as well as projected achievements—in complying with these warming targets;
>
> while accounting for both **diagnostic uncertainty** (which relates to the risk that true GHG emissions are greater than inventoried emission estimates reported in a specified year) and **prognostic uncertainty** (which relates to the risk that an agreed 2050 temperature target is exceeded).

3. Overview of the ETU framework

Table 1 compiles an overview of relevant information on the basic features that underlie the Jonas *et al.* study. This overview was not part of the study because of space limitations imposed by the publisher. The overview goes beyond Tables S1 and S2 in the electronic supplementary material to Jonas *et al.*, which summarize data, techniques, and models used in the study.

Table 2 lists five advancements, which are considered important and which were not covered by Jonas *et al.* at the time. These are:

1. Extending the diagnostic period of the ETU framework.

2. Introducing additional norms for referencing GHG emissions.

3. Introducing additional models/scenarios.

4. Introducing additional start years.

5. Introducing additional principles for reducing GHG emissions.

Table 1: Overview of the Emissions-Temperature-Uncertainty (ETU) framework (Jonas *et al.* 2014).

Basic feature	Description
Scientific reference	M Jonas, G Marland, V Krey, F Wagner & Z. Nahorski, 2014: Uncertainty in an emissions-constrained world. *Clim. Change*, **124**(3), 459–476, doi: 10.1007/s10584-014-1103-6.
Financial support	ACRP (3rd Call 2010: K10AC1K00057)
Objective	The incentive behind developing the ETU framework was to provide an overview of how to perceive uncertainty regarding constraining global warming in a systems context. The framework allows understanding of uncertainty across temporal scales and of how to reconcile short-term GHG emission commitments with long-term efforts to meet global temperature targets in 2050 and beyond.
Ad uncertainty: Diagnostic uncertainty and risk	Diagnostic uncertainty is the uncertainty contained in inventoried emission estimates and relates to the risk that true GHG emissions are greater than inventoried emission estimates reported in a specified year.
Ad uncertainty: Prognostic uncertainty and risk	Prognostic uncertainty refers to cumulative emissions between a start year and a future target year and relates to the risk that an agreed temperature target is exceeded.
Scientific pillar	The ETU framework builds on the contraction and convergence (C&C) approach (GCI 2012) resulting from cumulative emissions that are constrained. The ETU framework expands this approach by taking diagnostic and prognostic uncertainty on board. The strength of the cumulative-emissions based C&C approach is that it can be used to shortcut the serial logic 'GHG emissions → GHG concentrations → global temperature increase'. Cumulative emissions (here as of 2000 until 2050) have been shown to be a good predictor for the expected temperature rise in the future (here in 2050 and beyond).
Assumptions I	Emission targets derived for 2050 are exclusively available for technospheric emissions. The imperative for net emissions from LU activities is that these will be reduced linearly to zero by 2050. It is presupposed that deforestation and other LU mismanagement will cease and that net emissions balance.
Assumptions II	The hidden assumptions are that: (i) the remainder of the biosphere (including oceans) stays in or returns to an emissions balance; (ii) this return, which refers to CO_2-C, implies in turn that emissions and removals of CH_4, N_2O, etc. also return to an emissions balance; and (iii) these returns happen without any unforeseen systemic surprises of the terrestrial biosphere.

Table 1: Continued.

Basic feature	Description
Assumptions III	Additional assumptions exist when making the step from a 2 °C global warming target to global warming targets of 3 and 4 °C; namely that (i) the risk of overshooting is comparatively stable and independent of the particular warming situation, equilibrium or transient, when going from, e.g., 2 to 3 °C; and (ii) deviations from this assumption are minor compared to the considerable change in risk when going from, e.g., 2 to 3 °C under either warming scenario, equilibrium or transient.
Data availability	All input and output data pertinent to Jonas *et al.* (2014) are available at http://pure.iiasa.ac.at/10910/. Note: The revised data are made available below in Part II.
Thematic scope	GHG emissions: CO_2 and CO_2-eq (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 combined)
Thematic resolution	Technosphere, land use/land-use change, and trade (embodied emissions)
Spatial scope	Global
Spatial resolution	Country
Temporal scope	1990–2100
Temporal resolution	Annual
Ad temporal: Start years for accumulating GHG emissions	1990 and 2000
Ad temporal: Periods for accumulating GHG emissions	1990–2050 and 2000–2050
Ad temporal: Period for calculating the risk of exceeding 2050 global warming targets (based on multi-emission-climate-change-model scenarios)	2000–2050
Ad temporal: Diagnostic period (data-wise)	1990–2008/09
Ad temporal: Prognostic period (data-wise)	2008/09-2100
Ad temporal: Monitoring periods (to monitor both reported data and scenarios vis-à-vis linear GHG emission target paths)	1990–2050 and 2000–2050
Ad temporal: Period for comparative, long-term global warming scenarios	2000–2100
2050 temperature (global warming) targets	2, 3 and 4 °C

Table 1: Continued.

Basic feature	Description
GHG emissions over time (standard)	Without and with uncertainty by country: National linear target paths for emissions, which are consistently embedded globally, - for two temporal (predictor) regimes: 1990–2050 and 2000–2050; - for CO_2 and all six Kyoto GHGs (cumulative); - for individual spheres: technosphere and land use/land-use change; - for three global warming targets: 2, 3 and 4 °C; and - which allow monitoring Austria's performance - past (with and without embodied emissions) as well as projected achievements - in complying with these warming targets.
Units	Emissions, emissions per capita, emissions per GDP (the ETU framework allows translating between these units)
Consistency	National linear target paths for emissions are consistently embedded in the global context (summing over all countries' national target paths yields the global emissions target path).
Monitoring	National linear target paths for emissions serving as reference in monitoring the performance of countries - past as well as prospective achievements - in complying with a future warming target in a quantified uncertainty-risk context.
Monitored models / scenarios:	1. GAINS model: Mode of application: Two-points-in-time approach applied at country scale between reference year (1990) and target year (2020) to construct linear target paths for emissions; Output/use: Potential emissions reduction by (Annex I) country achievable between 2010–2020 (with reference to 1990) by means of available mitigation measures, and associated costs. 2. Long-tern scenarios: Mode of application: Forward-looking, medium to long-range scenarios for the 21st century from large-scale energy-economic and integrated assessment models; Output/use: Emissions (CO_2-eq, CO_2, CH_4, N_2O, F-Gases) and GDP by world region (resolving large countries) in 5 and 10-year steps until 2100, and atmospheric CO_2 concentrations in 2100.

Table 2: List of output features, which are considered important but which were not covered by Jonas *et al.* (2014).

Advancements not realized at the time	**Description**
1. Extending the diagnostic period of the ETU framework	Going beyond 2008/09, the current diagnostic period of the ETU framework
2. Introducing additional norms for referencing GHG emissions	Referencing GHG emissions by norms other than per-capita or per GDP; e.g., per ha
3. Introducing additional models/scenarios/new emissions reductions targets and policies	To expand monitoring, making use of additional global as well as national models/scenarios Already realized for Austria: Austria's targeted and projected emissions as specified under Austria's energy strategy (for 2020) and in Austria's climate protection report (for 2030) (BMWFJ/LFUW 2010; UBA 2011) are compared against Austria's national linear target path for emissions (for 1990–2050).
4. Introducing additional start years	Considering start years other than 1990 and 2000 for accumulating GHG emissions
5. Introducing additional principles for reducing GHG emissions	Follow emission-reduction principles other than the principle of equality, which leads to a universally, globally applicable emissions equity target in 2050; e.g., a blend of a future in which the present distribution of emissions is maintained with a future in which cumulative emissions are distributed equally on a per-capita basis.

This paper explores the following advancements:

Ad 1. Extending the diagnostic period of the ETU framework: Estimates of global and national GHG emissions and auxiliary data on population and economic activity (both being the dominant factors influencing GHG emissions) are up to date as of 2015. (For details and periods covered by the data see Part II of this paper).

Ad 3. Introducing additional models/scenarios/new emissions reduction targets and policies: we compare targets of different international GHG emissions reduction agreements/treaties (cf. Appendix A) against target paths which are linear in time and obtained by means of the ETU framework. We also analyze scenarios of future global and EU-27 emissions published by the International Energy Agency [IEA] and Austria's projected emissions under already implemented and additional mitigation measures (for details see also Appendices C and D).

Ad 4. Introducing additional start years: in addition to 1990 and 2000 the year 2010 was also considered as (i) start year for accounting cumulative GHG emissions and (ii) base year as reference for reduction targets for the year 2050 (cf. Part III of this paper).

4. Austria in the ETU framework (prior to data revision)

A comprehensive overview of Austria as a case study in the context of the ETU framework was presented at a workshop hosted by the ACRP in 2015[3]. The overview was given in the form of a poster (cf. Figure 1). Relevant data backing up the poster are summarized in Tables 3 and 4.

The poster relies on the data from Jonas *et al.* (2014). Although the data had not yet been updated at the time, the poster's overview remains pertinent. Austria's 2050 emissions outlook will not change in principal, although it will become more severe, as demonstrated in Section 10.

Starting from the international GHG emissions context described in Sections 2 and 3 and assuming that all countries will meet the 2 °C temperature target in 2050, Austria would have to reduce its per-capita emissions (excluding emissions from LUC activities) until 2050 by 71% relative to 1990 and 77% relative to 2000, respectively. The universally valid, 2050 global emissions equity [GEE] targets would be 3.0 and 2.3 t CO_2-equivalent per capita (CO_2-eq/cap). These GEE targets would, according to current knowledge, ensure that the risk of exceeding the 2050 temperature target of 2 °C will stay below 50% (cf. Table 3 and Table 4).

Table 3: Interpretation of the 2050 GEE targets in accordance with the expected global warming in 2050 and beyond, to be read as follows: universally valid 2050 GEE targets of 3.0 and 2.3 t CO_2-eq/cap, respectively - which can be considered as the end points of linear emission reduction paths between 1990–2050 and 2000–2050, respectively - are believed to ensure that the risk of exceeding the 2050 temperature target of 2 °C will stay below 50%. For a more detailed, quantified uncertainty–risk interpretation cf. Jonas *et al.* (2014: Table 1).

Target paths	2050 Global emission targets	Compliance with temperature targets in 2050 (risk of exceedance < 50%)			
	t CO_2-eq/cap	2 °C	2 – 3 °C	3 – 4 °C	≥ 4 °C
1990–2050	3.0	X			
	4.1		X		
	5.2			X	
	6.4				X
2000–2050	2.3	X			
	3.7		X		
	5.1			X	
	6.5				X

[3] ClimTrans2050 project: https://climtrans2050.wifo.ac.at/tiki-index.php

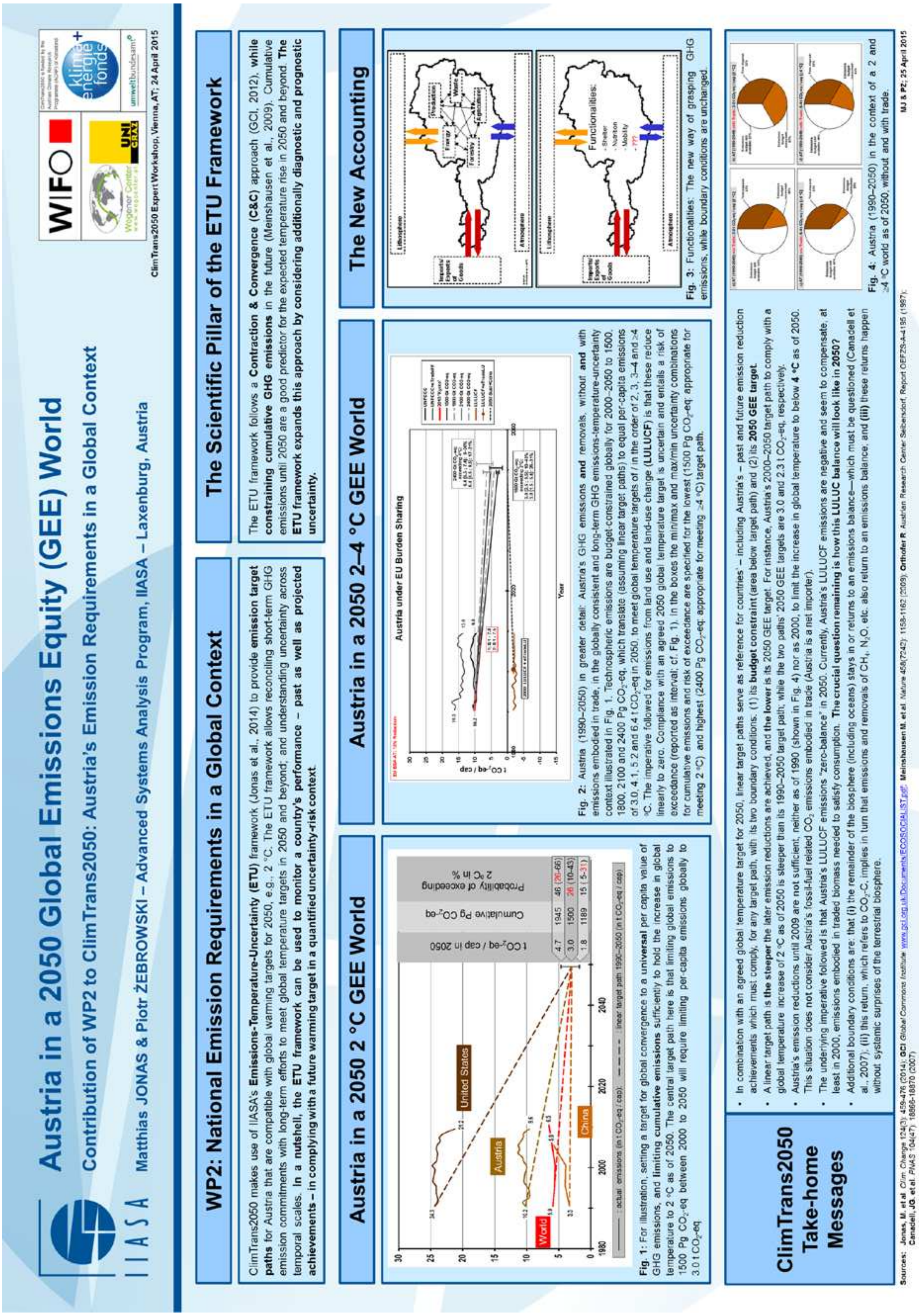


Fig. 1: Austria in the ETU framework.

Table 4: Austria's emissions in 1990, without and with trade, and in a constrained emissions context for 1990–2050 and 2000–2050, respectively.

<table>
<tr><th rowspan="3">Sector</th><th rowspan="2">1990 Per-capita emissions w/o trade</th><th rowspan="2">1990 Per-capita emissions with trade</th><th rowspan="2">1990–2009 Cumulative Emissions w/o trade</th><th rowspan="2">1990–2009 Cumulative Emissions with trade</th><th colspan="4">2050 Global emissions equity targets [in t CO_2-eq/cap]</th></tr>
<tr><th>3.0</th><th>4.1</th><th>5.2</th><th>6.4</th></tr>
<tr><th>t CO_2-eq/cap</th><th>t CO_2-eq/cap</th><th>Tg CO_2</th><th>Tg CO_2</th><th colspan="4">1990–2050 emission reduction w/o trade [and cumulative emissions]
% / cap [t CO_2-eq] | % / cap [t CO_2-eq] | % / cap [t CO_2-eq] | % / cap [t CO_2-eq]</th></tr>
<tr><td>Technosphere</td><td>10.2[a]</td><td>16.3[b]</td><td>1666[a]</td><td>2328[b]</td><td>71 [3489][c]</td><td>60 [3753][c]</td><td>48 [4016][c]</td><td>37 [4280][c]</td></tr>
<tr><td rowspan="2">LUC</td><td rowspan="2">-1.8[a]</td><td rowspan="2">unknown[d]</td><td rowspan="2">-351[a]</td><td rowspan="2">unknown[d]</td><td colspan="4">Imperative: Net emissions from LUC reduce linearly to zero until 2050!</td></tr>
<tr><td>[-610][a]</td><td>[-610][a]</td><td>[-610][a]</td><td>[-610][a]</td></tr>
<tr><th rowspan="3">Sector</th><th rowspan="2">2000 Per-capita emissions w/o trade</th><th rowspan="2">2000 Per-capita emissions with trade</th><th rowspan="2">2000–2009 Cumulative Emissions w/o trade</th><th rowspan="2">2000–2009 Cumulative Emissions with trade</th><th colspan="4">2050 Global emissions equity target [in t CO_2-eq/cap]</th></tr>
<tr><th>2.3</th><th>3.7</th><th>5.1</th><th>6.5</th></tr>
<tr><th>t CO_2-eq/cap</th><th>t CO_2-eq/cap</th><th>Tg CO_2</th><th>Tg CO_2</th><th colspan="4">2000–2050 emission reduction w/o trade [and cumulative emissions]
% / cap [t CO_2-eq] | % / cap [t CO_2-eq] | % / cap [t CO_2-eq] | % / cap [t CO_2-eq]</th></tr>
<tr><td>Technosphere</td><td>10.0[a]</td><td>13.3[b]</td><td>871[a]</td><td>1165[b]</td><td>77 [2552][c]</td><td>63 [2886][c]</td><td>49 [3184][c]</td><td>36 [3500][c]</td></tr>
<tr><td rowspan="2">LUC</td><td rowspan="2">-2.2[a]</td><td rowspan="2">-1.9[e]</td><td rowspan="2">-178[a]</td><td rowspan="2">unknown[d]</td><td colspan="4">Imperative: Net emissions from LUC reduce linearly to zero until 2050!</td></tr>
<tr><td>[-437][a]</td><td>[-437][a]</td><td>[-437][a]</td><td>[-437][a]</td></tr>
</table>

[a] UNFCCC; [b] UNFCCC + CICERO / GCP; [c] Jonas *et al.* (2014) + IIASA / POP; [d] unknown to the ETU framework which requires a globally consistent approach; [e] UNFCCC + IFF / WHRC

It is important to note that the 2050 GEE targets come with the condition that Austria's cumulative GHG emissions are limited until 2050; that is, limited to 3489 t CO_2-eq with 1990 as start year and to 2552 t CO_2-eq with 2000 as start year. However, by 2009 Austria had already consumed 48% of the 1990 allowance (and 33% of the available time) and 34% of the 2000 allowance (and 20% of the available time) - not accounting for embodied carbon emissions contained in trade (cf. also Figure 1).

II. Data supporting the ETU framework

Here we give a description of the revised and expanded dataset supporting the ETU framework. The dataset supporting the ETU framework (referred further as the **ETU dataset**) is organized in the form of an Excel workbook and consists of the three main parts:

1. Input data containing global and national estimates of GHG emissions together with auxiliary data (Section 5);
2. Worksheets facilitating the use of the ETU framework and the calculations of reduction targets (Section 6);
3. Compilation of projections of future GHG emissions obtained with the use of widely recognized models, whose output we compare against reduction targets obtained by means of the ETU framework (Section 7).

The complete ETU dataset is available at http://pure.iiasa.ac.at/13295/

5. Description of the input data

In this section we describe the input data required to calculate emissions reductions targets with the use of the ETU framework. In the ETU dataset the name of each worksheet contains the information on the data source as well as the period of time covered by the dataset (otherwise it is given in the description of the data; cf. Table 5).

Table 5: List of worksheets: Input data required for calculating emissions reduction targets for use in the ETU framework.

Worksheet no.	Worksheet name	Data description	Spatial and temporal resolution
1	CDIAC[4] Global 1959–2011	Estimates global CO_2 emissions from burning of fossil fuels (solid, liquid, gaseous), cement manufacture and gas flaring (in Mt C/yr).	global/ annual
2	CDIAC[2] Nations 1751–2011	Estimates national CO_2 emissions from burning of fossil fuels (solid, liquid, gaseous), cement manufacture and gas flaring (in kt C/yr).	national/ annual
3 - 24	CDIAC[2] Nations 1990, … , CDIAC Nations 2011	National CO_2 emissions from fossil-fuel burning, cement manufacture and gas flaring, extracted from WS 2 (CDIAC Nations 1751-2011) for each individual year in the period 1990–2011 (in kt C/yr).	national/ 1990, …, 2011
25	GCP[5] CO2 Transfer 1990–2013	CO_2 emissions from fossil-fuel use embodied in international trade, calculated as a difference between emissions from production of goods on a given territory and emissions embodied in the goods consumed on this territory (in Mt C/yr).	national/ annual
26	GCP[3] Global 1959–2013	Estimates carbon emissions and removals for elements of the global carbon cycle: fossil-fuel burning, land use, atmospheric increase, ocean sink, land sink and other sinks/sources (in Pg C/yr).	global/ national
27a, 27b	WHRC[6] LU 1850–2005 and WHRC LU 1850–2010	Estimates annual carbon fluxes to the atmosphere resulting from land-use change (in Tg C/yr).	regional/ annual
28	WRI[7] LUCF 1990–2011	Net CO_2 emissions due to land-use changes and forestry (in Tg CO_2 / yr).	national/ annual
29	IFF[8] HANPP agr 1986–2007	Estimates human appropriation of net primary production (HANPP) resulting from agricultural activity on the territory of a given country. HANPP is defined as the difference between the NPP of potential vegetation and the amount of NPP that remains in the ecosystem after harvest (in tons of dry matter biomass / year: t DM / yr).	national/ annual
30	IFF[6] eHANPP agr 1986–2007	Estimates HANPP embodied in agricultural products consumed on the territory of a given country (in tons of dry matter biomass / year: t DM / yr).	national/ annual

[4] Carbon Dioxide Information Analysis Center: http://cdiac.ornl.gov/trends/emis/overview_2011.html

[5] Global Carbon Project: http://www.globalcarbonproject.org/carbonbudget/14/data.htm

[6] The data are from R.A. Houghton (2011; pers. comm.) from the Woods Hole Research Center.

[7] World Resources Institute: http://cait2.wri.org/

[8] The data are from K.-H. Erb (2015; pers. comm.) from the Vienna-based Institute of Social Ecology, Faculty of Interdisciplinary Studies (IFF) of the Alpen Adria University Klagenfurt.

31	IFF[6] HANPP forestry 1997–2007	Estimates HANPP resulting from forestry activity on the territory of a given country (in tons of dry matter biomass / year: t DM / yr).	national/ annual
32	IFF[6] eHANPP forestry 1997–2007	Estimates forestry HANPP embodied in the goods consumed on the territory of a given country (in tons of dry matter biomass / year: t DM / yr).	national/ annual
33	IFF[6] HANPP Trade 1997–2007	Difference between eHANPP and territorial HANPP. This difference is equal to the difference between imported and exported NPP and is used as a proxy for the transfers of land-use emissions due to international trade (in tons of dry matter biomass / year: t DM / yr).	national/ annual
34	EPA[9] Non-CO2 1990–2030	Historical emissions of non-CO_2 greenhouse gases (for 1990–2010) and projections of future emissions (for 2015 – 2030) (in Mt CO_2-eq / yr).	national/ 5 year steps
35	UNFCCC[10] CO2-eq 1990–2012	Estimates total GHG emissions (excluding LULUCF emissions) reported by Annex I countries to the UNFCCC (in Gg CO_2-eq / yr).	national/ annual
36	UNFCCC[8] CO2 1990–2012	Estimates total CO_2 emissions (excluding LULUCF emissions) reported by Annex I countries to the UNFCCC (in Gg CO_2 / yr).	national/ annual
37	UNFCCC[8] LULUCF 1990–2012	Estimates total GHG emissions for Land Use, Land-use Change and Forestry (LULUCF) reported by Annex I countries to the UNFCCC (in Gg CO_2-eq / yr).	national/ annual
38	UNFCCC[8] POP 1990–2012	Population of Annex I countries reported to the UNFCCC (in 1000 cap).	national/ annual
39	UNFCCC[8] GDP 1990–2012	Gross domestic product (GDP) of Annex I countries reported to the UNFCCC (in billions USD).	national/ annual
40	Non-Annex I CO2-eq	UNFCCC[8] data on the total annual GHG emissions, by way of example for three big non-Annex I countries: Brazil, China, and India. Data gathered over the period 1990 – 2005 (in Gg CO_2-eq / yr).	national/ annual (irregular reporting)
41	UN POP[11] 1950–2015	Population estimates by the UN Population Division (in 1000 cap).	national/ annual
42a–42e	UN POP[9] prob projections (median, 80 and 95 quantiles)	Probabilistic projections of future population dynamics for 2015–2100 (probabilistic fertility rate, constant mortality rate) by the UN Population division (in 1000 cap).	national/ 5-year steps
43	IIASA[12] POP 2008–2100	Probabilistic projections of future population (probabilistic fertility and mortality rates) published by IIASA in 2007 (in million cap).	global, big regions/ annual

[9] Environmental Protection Agency: http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html

[10] UN Framework Convention for Climate Change: http://unfccc.int/di/FlexibleQueries.do

[11] UN Population Division: http://esa.un.org/unpd/wpp/DVD/

[12] IIASA's World Population Program: http://www.iiasa.ac.at/Research/POP/proj07/index.html

6. Application of the ETU framework — data compilations and calculations

Below we describe the part of ETU dataset that implements the ETU framework itself. Each worksheet in this part contains a logically closed part of analysis allowing the derivation of global emissions reductions targets for the year 2050, while satisfying GEE requirements (cf. worksheets 45–48). Global emissions equity in 2050 means equal per-capita emissions for every human living in 2050. Next, the GEE targets are translated to national reduction targets that are globally consistent (worksheets 51–53). Finally, in worksheets 54–56, we demonstrate the ETU framework potential to produce comprehensive and insightful results on global, regional and national levels (the latter two by way of example for EU-27 and Austria). Table 6 below presents the purpose of each worksheet in the discussed part of ETU dataset and provides a short description of its contents. Further details can be found in the worksheets themselves. Results obtained in worksheets 54–56 are also described and commented in more detail in Sections 8–10.

Table 6: List of worksheets implementing the ETU framework.

Worksheet no.	Worksheet name	Content description and purpose
44	Global total emissions 1990–2013	Summary of global GHG emissions with split to sources: CO_2 emissions from fossil fuel burning and land use, non-CO_2 gases, and other emissions. Categories summarized as technospheric emissions, land-use emissions and total emissions. These summaries describe initial conditions (starting points) for the emissions reduction paths that are derived in further ETU worksheets.
45	1500 Gt budget	The notion of cumulative GHG emissions over a certain period of time lays the foundations of the ETU framework, as it is considered to be a good predictor for the future stabilization level of global warming - see work by Meinshausen *et al.* 2009. Using this work we are able to relate the budget of global cumulative GHG emissions for 2000–2050 to a risk of exceeding a 2 °C warming target. In this worksheet we analyze global emissions reductions targets (together with their uncertainties) corresponding to the 1500 Gt CO_2-eq budget of global cumulative emissions for 2000–2050. The worksheet contains: 1) An assessment of the uncertainty in the risk of exceeding the 2 °C warming target. For a sharp cumulative emissions value (with minimum uncertainty in emissions) we find the range of risk of overshooting the 2 °C warming (with maximum uncertainty in risk). We call it min/max uncertainty. Similarly, we calculate this the other way around: max/min uncertainty. That is, we find the range of cumulative emissions (maximum uncertainty in emissions) associated with the sharp level of risk of exceeding the 2 °C warming target (minimum uncertainty in risk). 2) Translation of risks of exceeding 2 °C warming into the risks of exceeding 3 °C and 4 °C warming targets 3) Calculations of global GHG emissions target in 2050 for linear reductions starting in 1990, 2000, and 2050 that satisfy 1500 Gt CO_2-eq emissions budget for the period 2000–2050

		4) Calculations of GEE targets for 2050. Confidence intervals are given for per-capita linear reductions targets corresponding to start years and budgets mentioned above.
46	1800 Gt Budget	Analysis as in worksheet 45 but for a cumulative GHG emissions budget of 1800 Gt CO_2-eq for 2000–2050.
47	2100 Gt Budget	Analysis as in worksheet 45 but for a cumulative GHG emissions budget of 2100 Gt CO_2-eq for 2000–2050.
48	2400 Gt Budget	Analysis as in worksheet 45 but for a cumulative GHG emissions budget of 2400 Gt CO_2-eq for 2000–2050.
49	2 °C to 3 °C Conversion	The work of Meinshausen 2005 provides unsharp relationships between CO_2 stabilization levels and risks of overshooting 2 °C, 3 °C, and 4 °C warming targets. These relationships are of the form of S-shape belts (cf. Figs. 32 and 33c–33d). Using these relationships it is possible to convert (in an approximate manner) the risk of exceeding the 2 °C warming target into the risk of overshooting the 3 °C or 4 °C warming targets. This worksheet facilitates translation of risks of exceeding the 2 °C warming target into risks of exceeding the 3 °C warming target. It contains: 1) Approximation of unsharp dependences between CO_2 stabilization level and risks of overshooting 2 °C and 3 °C warming targets. Each S-shaped belt is approximated by piecewise linear functions (for median risks and boundaries of the belt). 2) Analysis of uncertainty of these approximations 3) Translation of the risk of exceeding the 2 °C warming into the risk of exceeding the 3 °C warming target 4) Analysis of uncertainty of this translation.
50	2 °C to 4 °C Conversion	This worksheet facilitates translation of risks of exceeding the 2 °C warming target into risks of exceeding the 4 °C warming target (as in worksheet 49).
51	GEE as of 1990	This worksheet summarizes global and national emissions reductions targets for the year 2050 assuming: (i) linear reductions of per-capita emissions starting in 1990; (ii) a cumulative GHG emissions budget of 1500 Gt CO_2-eq for 2000–2050; and (iii) global equity in terms of per-capita emissions in 2050. Contents of the worksheet: 1) 2050 target of global GHG emissions for linear reductions starting in 1990 2) GEE target for 2050 per capita emissions (with 95% confidence interval) 3) Summary of 1990 emissions for Annex B countries 4) Reduction rates of per-capita emissions for Annex B countries to meet GEE targets in 2050. NOTE: Calculations of GEE targets in this worksheet are similar to those in worksheets 45–48 but use the IIASA projections of world population in 2050 (instead of the newest UN Population Division projections, which are as much as 1 billion higher).
52	GEE as of 2000	This worksheet summarizes global and GEE per-capita emission reduction targets for 2050 if reductions had started in the year 2000. All calculations resemble those in Worksheet 51 but with 2000 as start year. In addition, this worksheet contains calculations of "undershooting" - that is, corrections of nominal reduction targets to account for diagnostic uncertainty in emission estimates. Diagnostic uncertainty relates to the risk that true GHG emissions are greater than inventoried emission estimates reported in 2050.

53	GEE as of 2010	This worksheet repeats calculations made in worksheet 51 but with 2010 as the start year.
54	World summary	This worksheet summarizes historical GHG emissions, linear reduction target paths and projections of future GHG emissions derived by means of widely recognized models external to the ETU framework. The worksheet contains: 1) Data on global emissions for 1990, 2000 and 2010 (i.e., the considered start years of reductions) 2) Summary of global emission reductions targets for different 2000–2050 emission budgets and start years (based on targets calculated in worksheets 45–48) 3) Compilation of per-capita and total emissions, linear reduction target paths with different start years (1990, 2000 and 2010) and projections of future emissions obtained by means of widely recognized external models.
55	EU-27 summary	This worksheet summarizes the emissions of EU-27 (without Malta or Cyprus). It contains: 1) Data on EU-27 emissions (without Malta or Cyprus) for 1990, 2000 and 2010 (i.e., the considered start years of reductions) 2) Summary of EU-27 emission reduction targets for different 2000–2050 emission budgets and start years for emission reduction efforts 3) Reduction targets declared in international agreements (Kyoto Protocol, post-Kyoto pledges, effort sharing targets; cf. Appendix A) 4) Compilation of per capita and total emissions, linear reduction target paths obtained using ETU framework and scenarios of future emissions generated by external models (see also Appendices B and C).
56	Austria summary	Summary of Austria's historical GHG emissions, 2050 targets, international obligations and projections of future emissions. The worksheet contains: 1) Data on Austria's emissions for 1990, 2000 and 2010 (i.e., considered start years of reductions). 2) Summary of Austria's emission reductions targets for different 2000–2050 emission budgets and start years for reduction efforts. 3) Reduction targets declared in international agreements (Kyoto Protocol, EU burden-sharing and effort-sharing targets). 4) Compilation of per-capita and total emissions, reduction target paths and scenarios for future emissions (cf. Appendix D). 5) Projections of Austria's CO_2 emissions resulting from energy-related functionalities (cf. Appendix E).

7. Emissions reduction targets of international agreements and illustrative mid-term and long-term GHG emissions scenarios

The last part of the ETU dataset begins with a summary of reduction/limitation targets of the parties to the Kyoto Protocol as well as EU member states' targets for the post-Kyoto period. This is followed by a compilation of example scenarios of future GHG emissions generated by means of large-scale, energy-economic and integrated assessment models. These targets and scenarios are compared against linear target paths obtained by applying the ETU method.

Table 7: List of worksheets containing reduction targets declared in the international agreements and scenarios of future emissions.

Worksheet no.	Worksheet name	Content description
57	Kyoto + EU Targets	Compilation of 1) emission limitation/reduction commitments of countries included in Annex B to the Kyoto Protocol; 2) common EU reduction pledges for the post-Kyoto period; and 3) reduction obligations of EU countries for the Burden Sharing and Effort Sharing mechanisms.
58	SRREN[13] 2000–2100	Database containing scenarios of emission reductions generated by the large-scale, energy-economic, and integrated assessment models.
59	SRREN Extract	Three ambitious emission reduction scenarios extracted from the SRREN database which stabilize $CO_{2\text{-eq}}$ concentrations around 450 ppmv by the end of the century (i.e., they are compatible with the 2 °C warming target).
60	GAINS Interface	Projections of general macroeconomic drivers for Annex I countries generated by the GAINS[14] model.
61	GAINS Baseline Em	Baseline projections of GHG emissions for Annex I countries generated by the GAINS model.
62	Con_NO-NO	Analysis of conservative pledges of Annex I countries in absence of Emissions Trading (ET) and Clean Development Mechanisms (CMD). Reduction targets and corresponding costs were taken from GAINS' Mitigation Efforts Calculator (MEC)[15]. The worksheet also contains targets corrected for diagnostic uncertainty (undershooting) and corresponding additional costs of mitigations.
63	Opt_NO-NO	Analysis of optimistic pledges of Annex I countries in absence of ET and no CMD. (Calculations analogous to those made in worksheet 62.)
64	Con_Yes-Yes	Analysis of conservative pledges of Annex I countries assuming availability of ET and CMD. (Calculations analogous to those made in worksheet 62.)
65	Opt_Yes-Yes	Analysis of optimistic pledges of Annex I countries assuming availability of ET and CMD. (Calculations analogous to those made in worksheet 62.)

[13] Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN): http://srren.ipcc-wg3.de/report . Scenarios from the SRREN database are available at http://www.iiasa.ac.at/web-apps/tnt/SrRenDb.

[14] GAINS: http://gains.iiasa.ac.at/models/index.html

[15] MEC: http://gains.iiasa.ac.at/MEC/

66	GAINS Interface (WEO_2009)	Projections of general macroeconomic drivers for Annex I countries generated by the GAINS model for IEA's World Energy Outlook (WEO[16]) baseline scenario from 2009.
67	GAINS Baseline Em (WEO 2009)	Projections of GHG emissions for Annex I countries generated by the GAINS model for WEO's 2009 baseline scenario.
68	GAINS Interface (ECLIPSE)	Projections of general macroeconomic drivers for Annex I countries generated by GAINS model for the new ECLIPSE baseline scenario from 2015.
69	GAINS Baseline Em (ECLIPSE)	Projections of GHG emissions for Annex I countries generated by the GAINS model for the ECLIPSE baseline scenario.

III. Results

This part of the paper contains results of analyses performed with the use of the ETU framework and the updated ETU dataset described in Sections 5–7. The results presented below update and extend those of Jonas *et al.* 2014.

8. Global emission reduction targets in the ETU framework

Results presented in this section were derived in worksheets 45–48 (emissions reduction targets and their uncertainties) and in worksheet 54 (summary of historical emissions, reduction targets and scenarios of future emissions).

The derivation of reduction targets for global GHG emissions is based on the concept of constrained cumulative emissions until 2050. Meinshausen *et al.* 2009 (and authors of other papers) showed that the cumulative emissions over a specified period of time, here 2000–2050, rather than emissions in any individual year during this time, are a good predictor of the stabilization level of global warming in 2050 and beyond (relative to the pre-industrial level). It is also possible to relate the budget of cumulative emissions to the risk of overshooting an agreed warming target. The ETU methodology builds on this option (for details cf. Jonas *et al.* 2014). In this paper we analyze targets and their uncertainties corresponding to four cumulative GHG emissions budgets for the period 2000–2050, namely 1500, 1800, 2100 and 2400 Gt CO_2-eq.

Table 8 summarizes - based on the default climate sensitivity distribution used in Meinshausen *et al.* 2009 - the risks (henceforth referred to as reference risks) of overshooting warming targets of 2, 3 and 4 °C for each of these budgets. However, the risk of exceeding the warming target varies, depending on the actual trajectory (scenario) of future emissions that satisfy the cumulative emissions constraint. The range of these risks reflects our uncertainty in the risk of overshooting the warming target given the

[16] IEA World Energy Outlook 2009: http://www.worldenergyoutlook.org/weo2009/

constrained emissions budget. This type of uncertainty we call min/max, for in this case the emissions budget takes on a sharp value (minimum uncertainty) while the risk related to this budget is maximally uncertain.

Table 8: Risk (in %) of overshooting a warming target corresponding to a global emissions budget for 2000–2050 ranging between 1500 and 2400 Pg CO_2-eq. The min/max risk range (in %) is given in brackets whenever it could be meaningfully translated from the risk of exceeding the 2 °C warming target.

Warming target in °C	Risk of overshooting the global warming target for cumulative emission constraints for 2000–2050 ranging between 1500 to 2400 Pg CO_2-eq			
	1500 Pg CO_2-eq: Risk in %	1800 Pg CO_2-eq: Risk in %	2100 Pg CO_2-eq: Risk in %	2400 Pg CO_2-eq: Risk in %
2	26 [10 – 43]	38 [20 – 58]	57 [35 – 76]	76 [53 – 90]
3	9	15 [5 – 26]	23 [11 – 40]	38 [19 – 66]
4	3	6	11 [4 – 21]	19 [8 – 36]

The fact that for different budgets risk ranges overlap is yet another source of uncertainty, as each agreed risk of exceeding the target is in accordance with a range of emissions budgets (although they are not all equally likely). This type of uncertainty we examine by using a max/min approach - that is, by finding the range of cumulative emissions for which the arbitrarily fixed risk level is attainable. In this case the cumulative emissions budget constraint (or equivalently, emission targets in 2050 for linear reductions; cf. Table 9a.) is maximally uncertain, in contrast to a minimally uncertain risk level. In the ideal case this risk level takes on a sharp value. However, this risk may only be specified approximately in the form of a narrow interval (cf. Table 9b). This unsharpness in the risk is a consequence of the lower bound for cumulative emission budgets used in Meinshausen *et al.* 2009 or is caused by the uncertainty in translating the risk of overshooting the 2 °C target to that of overshooting a higher warming target.

Table 9 is to be read in the following way. Assume that we require global cumulative emissions in the period 2000–2050 to satisfy a budget of 1800 Gt CO_2-eq. If the constant-rate reductions had started in 2000 the target emissions in the year 2050 would have been 32.8 Gt CO_2-eq. The reference risk of exceeding the 2 °C warming target corresponding to this target for emissions in 2050 is 38% (cf. Table 8). Under assumption that emissions are reduced linearly (i.e. with constant rate) this risk is attainable with emissions in 2050 ranging from 15.8 to 46.8 Gt CO_2-eq. The 2050 emissions targets in this range correspond also to the risk of overshooting the 3°C warming target ranging from 12 to 17% (with a 15 % reference risk of not meeting the 3 °C target; cf. Table 8). This unsharpness in risk is due to the approximate translation of risk of exceeding 2 °C to that of overshooting 3 °C.

Table 9: Max/min uncertainty analysis of linear reductions targets for 2050. Negative emissions denote removals of GHGs from the atmosphere).

a)	**Emission reduction targets in 2050 (and max/min uncertainties; in Gt CO_2-eq) satisfying global emission constraints for 2000–2050 ranging between 1500 and 2400 Gt CO_2-eq**			
Start year	**1500 Gt CO_2-eq**	**1800 Gt CO_2-eq**	**2100 Gt CO_2-eq**	**2400 Gt CO_2-eq**
1990	25.5 [15.1 – 40.3]	35.5 [21.3 – 47.1]	45.5 [35.3 – 57.8]	55.5 [45.8 – 70.7]
2000	20.8 [8.4 – 38.6]	32.8 [15.8 – 46.8]	44.8 [32.6 – 59.6]	56.8 [45.2 – 57.1]
2010	5.5 [-10.1 – 27.7]	20.5 [-0.8 – 37.9]	35.5 [20.2 – 54.0]	50.5 [35.9 – 73.3]
b)	**Risk (and uncertainties; in %) for which max/min uncertainty intervals of emission reduction targets in 2050 were calculated**			
Warming target	**1500 Gt CO_2-eq**	**1800 Gt CO_2-eq**	**2100 Gt CO_2-eq**	**2400 Gt CO_2-eq**
2 °C	26 [26 – 31]	38	57	76
3 °C	9 [7 – 14]	15 [12 – 17]	23 [21 – 26]	38 [34% – 41%]
4 °C	3 [2 – 6]	6 [5 – 8]	11 [9 – 13]	19 [17 – 21]

The guiding principle of the ETU framework for deriving per-capita reduction targets for 2050 is global emissions equity [GEE], which means that in 2050 (and beyond) the amount of GHG emissions required to support the well-being of every individual will be common for everyone, regardless of age, income or nationality. We find the per-capita GEE emission targets by dividing the required level of global GHG emissions in 2050 by the estimate of world population in 2050. This procedure introduces yet another source of uncertainty of GEE targets since estimates of future world populations are themselves uncertain. Table 10 summarizes the per-capita GEE targets corresponding to the four global cumulative emission constraints considered in this study.

Table 10: GEE targets and uncertainties (in t CO_2-eq / cap). Negative emissions denote removals of GHGs from the atmosphere).

Start year	(i) Per-capita emission targets (in t CO_2-eq / cap) for 2050 satisfying global emission constraints for 2000–2050 ranging between 1500 and 2400 Gt CO_2 (ii) Range of targets (in t CO_2-eq / cap) due to the uncertainty in 2050 population values (95% confidence interval) (iii) Range of targets (in t CO_2-eq / cap) for median population in 2050 due to max/min uncertainty (iv) Uncertainty range combining ii + iii (in t CO_2-eq / cap)			
	1500	**1800**	**2100**	**2400**
1990	**2.6** [2.5 – 3.8] [1.6 – 4.1] [1.5 – 4.3]	**3.6** [3.5 – 3.8] [2.2 – 4.8] [2.1 – 5.1]	**4.7** [4.5 – 4.9] [3.6 – 5.9] [3.5 – 6.2]	**5.7** [5.4 – 6.0] [4.7 – 7.3] [4.5 – 7.6]
2000	**2.1** [2.0 – 2.2] [0.9 – 4.0] [0.8 – 4.2]	**3.4** [3.2 – 3.5] [1.6 – 4.8] [1.5 – 5.0]	**4.6** [4.4 – 4.8] [3.3 – 6.1] [3.2 – 6.4]	**5.8** [5.6 – 6.1] 4.6 – 7.7] [4.4 – 8.1]
2010	**0.6** [0.5 – 0.6] [-1.0 – 2.9] [-1.0 – 3.0]	**2.1** [2.0 – 2.2] [-0.1 – 3.9] [-0.1 – 4.1]	**3.6** [3.5 – 3.8] [2.1 – 5.6] [2.0 – 5.8]	**5.2** [5.0 – 5.4] [3.7 – 7.5] [3.5 – 7.9]

We demonstrate how Table 10 is to be read by continuing the example related to the budget of 1800 Gt CO_2-eq (see example of interpreting Table 9). According to Table 9a target emissions in 2050 for reductions starting in 2000 are 32.8 Gt CO_2-eq. By dividing this target by the median of the 2050 population distribution we obtain a GEE target of 3.4 t CO_2-eq/cap. Taking into account only the uncertainty of population in 2050 (95% confidence interval) the GEE target ranges between 3.2 and 3.5 t CO_2-eq/cap. On the other hand, ignoring the uncertainty of the 2050 population estimate we obtain the max/min uncertainty interval between 1.6 and 4.8 t CO_2-eq/cap for GEE targets by dividing max/min uncertainty range of 2050 global emissions target (see Table 9a) by the median of population estimates. Combining these two uncertainties (i.e., the most stringent reductions target is divided by the upper 95% quantile of the 2050 population estimate and *vice versa*) yields a range of 2050 GEE emissions targets between 1.5 t CO_2-eq/cap and 5.0 t CO_2-eq/cap.

Table 11 is an extract of Tables 8–10. It summarizes global 2050 targets for total and per-capita emissions assuming linear reductions starting in 1990, 2000, and 2010. For each period 1990–2050, 2000–2050, and 2010–2050 we list targets corresponding to 2000–2050 global cumulative GHG emissions budgets ranging between 1500 and 2400 Gt CO_2-eq. We also indicate which warming target is likely to be achieved for a given reduction target. Figures 2–5 visualize target paths for linear reductions mentioned above (for detailed descriptions of Figs. 2–5 see end of this section).

Table 11: Summary of results presented in Tables 8–10. 2050 global emissions targets for linear reductions starting in 1990, 2000, and 2010 are given together with the indication of the most likely level of global warming they would achieve.

Period	Budget of global cumulative GHG emissions	2050 global emission targets		Compliance with temperature targets in 2050 (risk of exceedance < 50%)			
	Gt CO_2-eq	Gt CO_2-eq	t CO_2-eq/cap	2 ºC	3 ºC	3–4 ºC	≥ 4 ºC
1990–2050	1890	25.5	2.6	X			
	2190	35.5	3.6		X		
	2490	45.5	4.7			X	
	2790	55.5	5.7				X
2000–2050	1500	20.8	2.1	X			
	1800	32.8	3.4		X		
	2100	44.8	4.6			X	
	2400	56.8	5.8				X
2010–2050	1070	5.5	0.6	X			
	1370	20.5	2.1		X		
	1670	35.5	3.6			X	
	1970	50.5	5.2				X

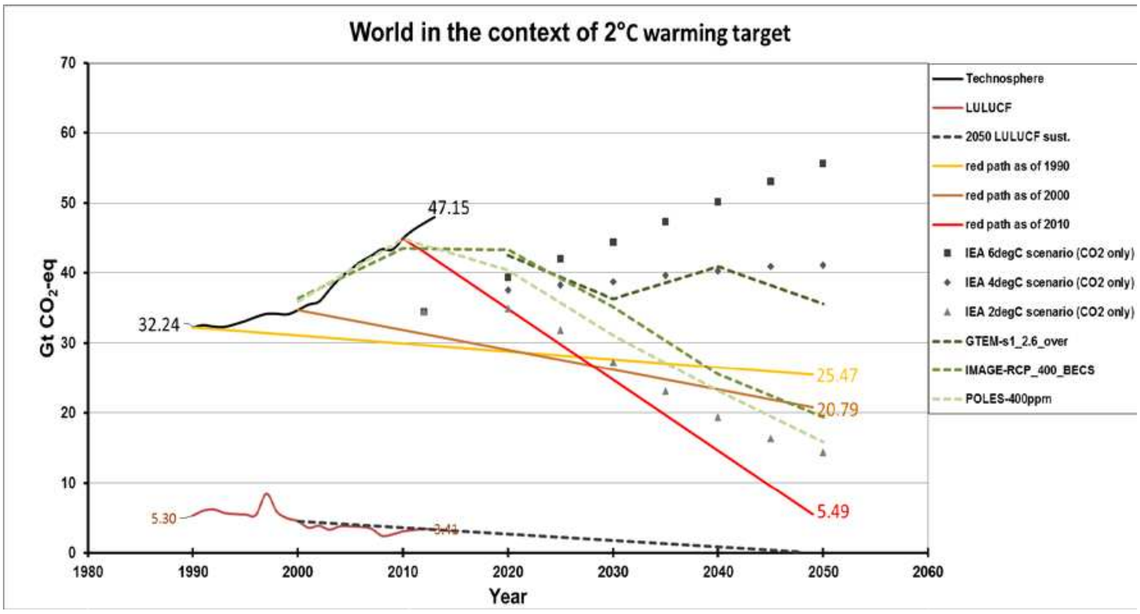


Fig. 2a: Historical global technospheric and land-use related GHG emissions, linear reduction target paths likely to secure a 2 °C warming target, and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq).

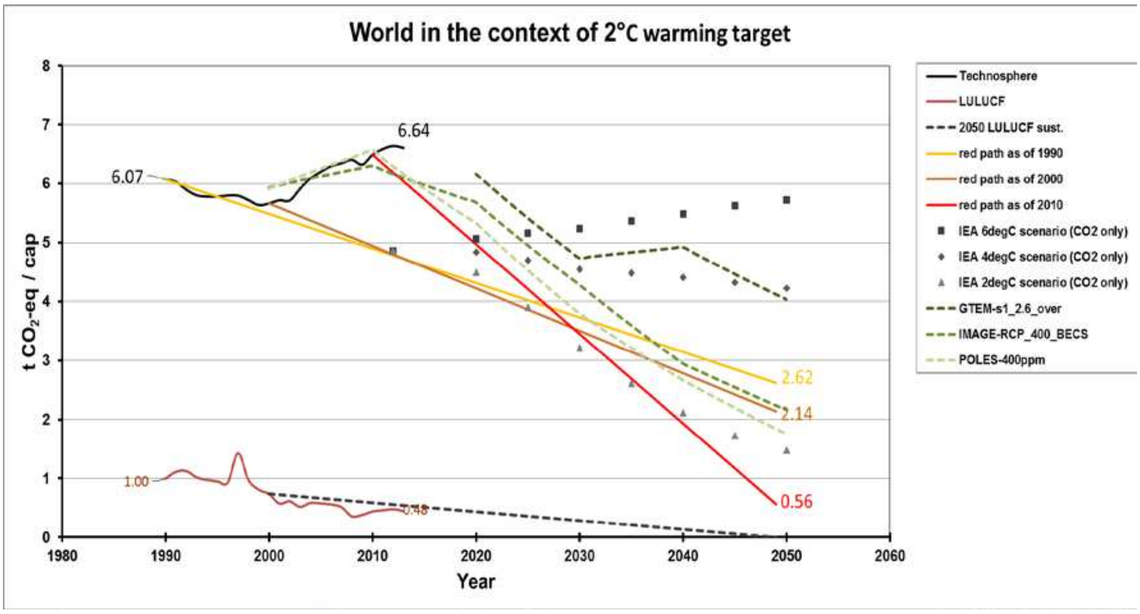


Fig. 2b: Historical global per-capita emissions from the technospheric and land-use sector, linear reduction target paths likely to secure a 2 °C warming target and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq/cap).

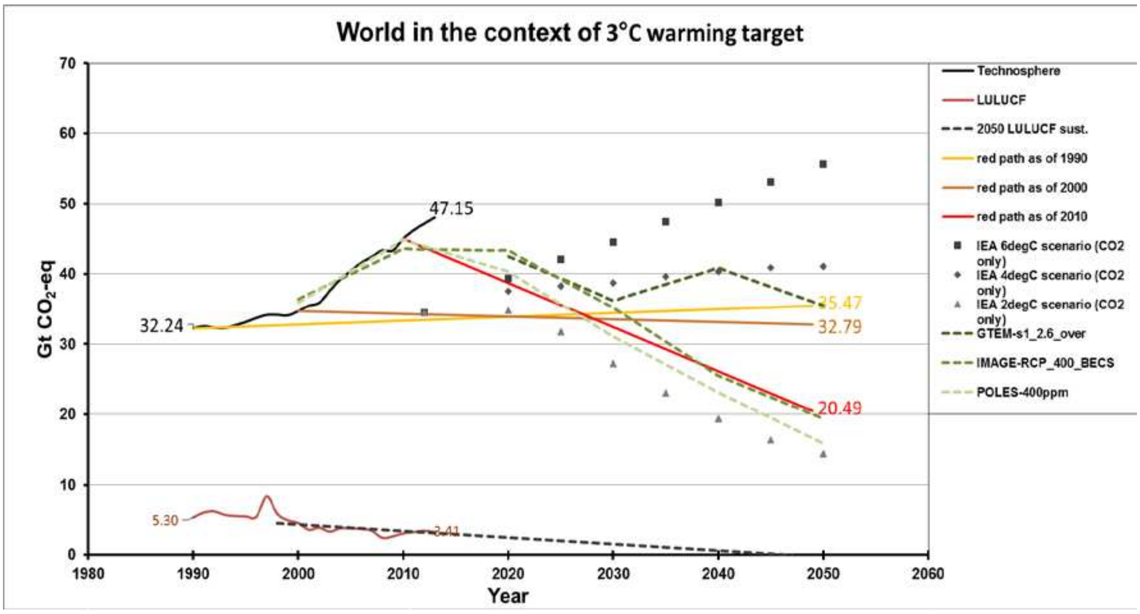


Fig. 3a: Historical global technospheric and land-use related GHG emissions, linear reduction target paths likely to secure a 3 °C warming target, and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq).

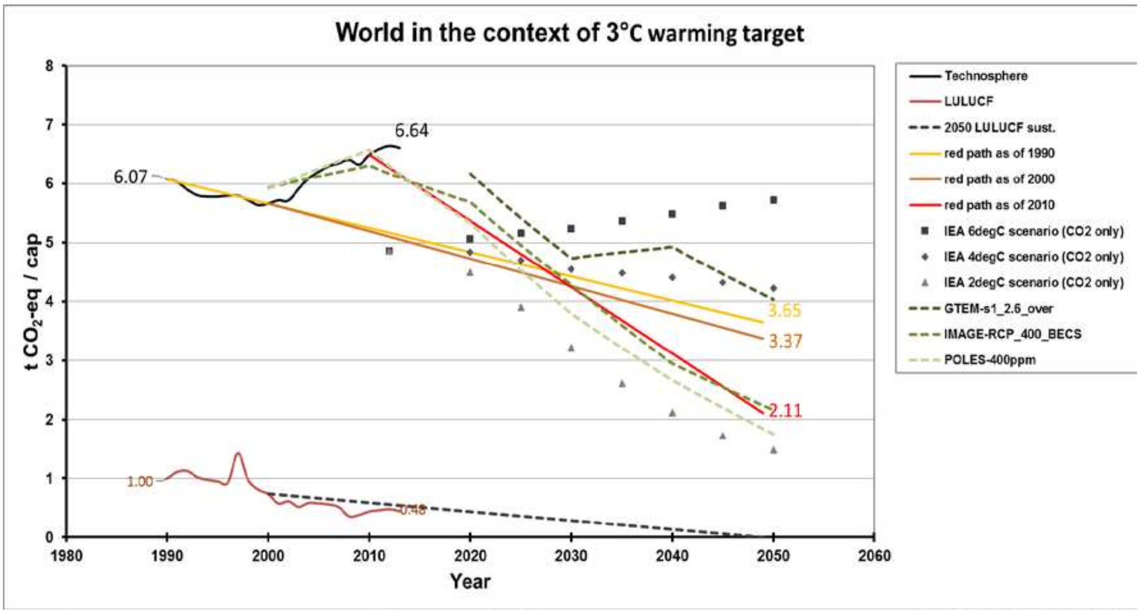


Fig. 3b: Historical global per capita emissions from the technospheric and land-use sector, linear reduction target paths likely to secure a 3 °C warming target, and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq/cap).

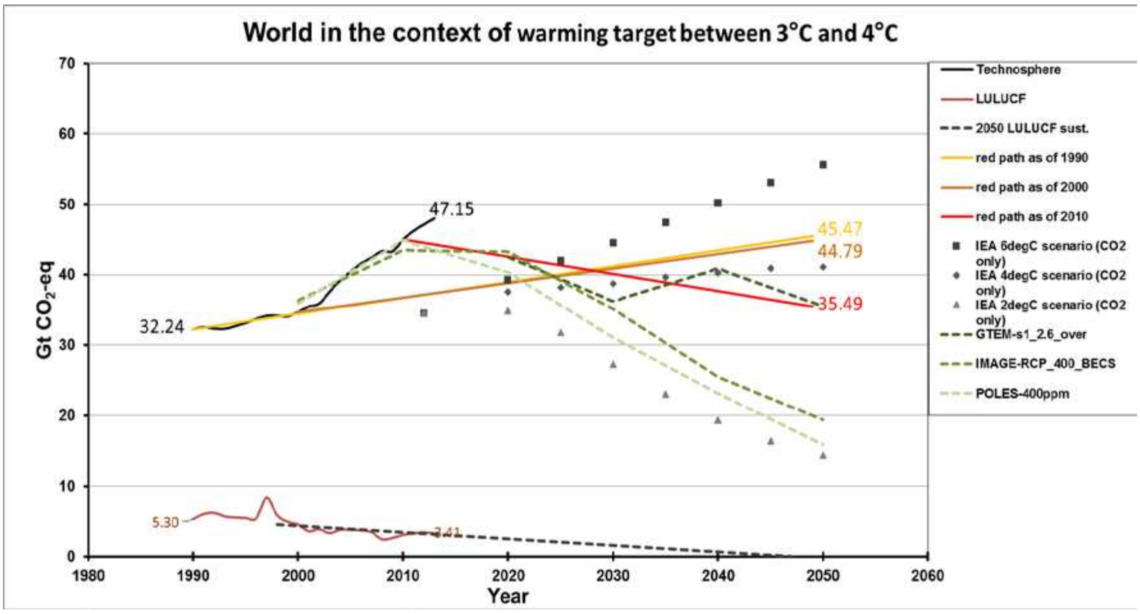


Fig. 4a: Historical global technospheric and land-use related GHG emissions, linear reduction target paths likely to secure a warming target between 3 °C and 4 °C, and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq).

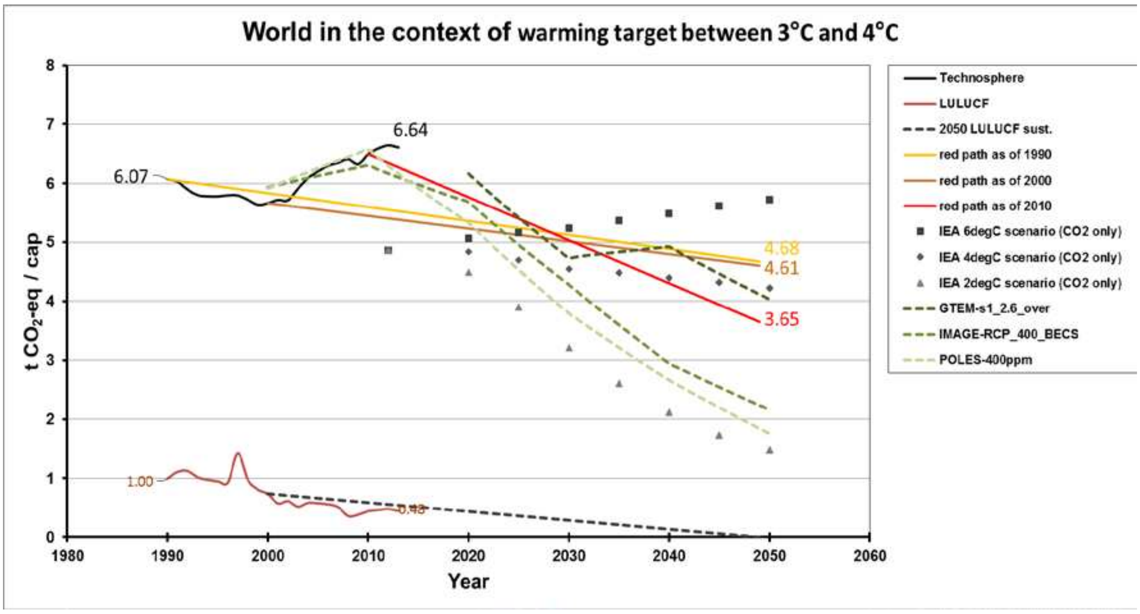


Fig. 4b: Historical global per capita emissions from the technospheric and land-use sector, linear reduction target paths likely to secure warming target between 3 °C and 4 °C, and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq/cap).

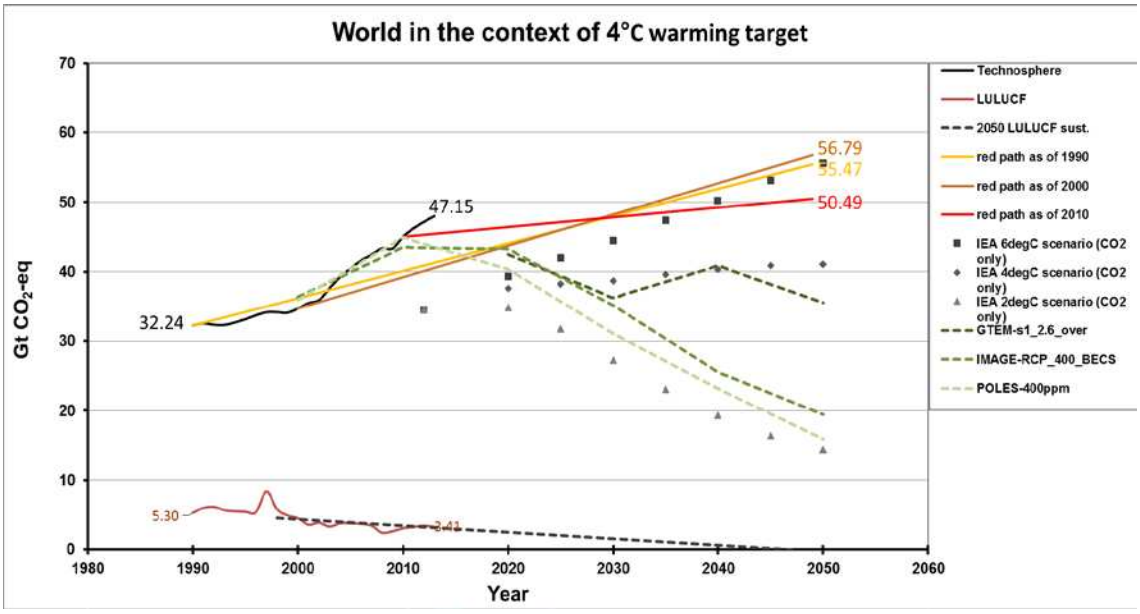


Fig. 5a: Historical global technospheric and land-use related GHG emissions, linear reduction target paths likely to secure a 4 °C warming target, and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq).

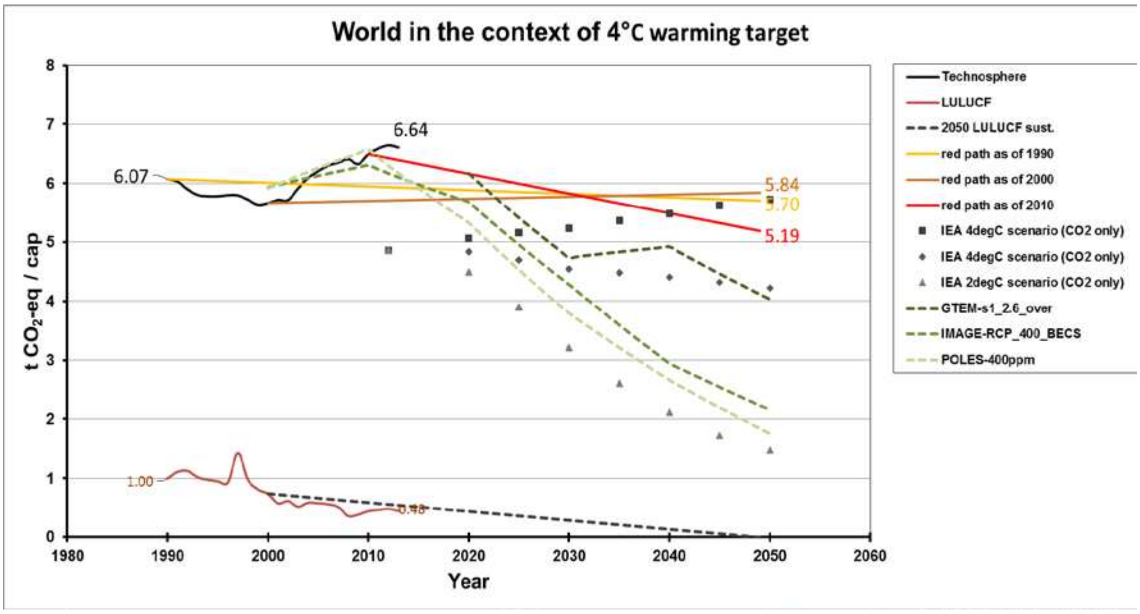


Fig. 5b: Historical global per capita emissions from the technospheric and land-use sector, linear reduction target paths likely to secure a 4 °C warming target and future emissions scenarios generated by models external to the ETU framework (in Gt CO_2-eq/cap).

Figures 3–5 show historical global GHG emissions from both the technosphere (thick black line) and the land-use sector (thick brown line). While land-use related emissions seem to follow the linear reduction path towards sustainable land-use (grey dashed line) required by the ETU framework, technospheric emissions - both total and per-capita - have risen sharply since the beginning of the 21st century. Two decades of delays in undertaking serious mitigation efforts have resulted in reduction targets that are becoming increasingly challenging to meet, which is clearly visible in the increasing slopes of the linear reduction target paths obtained by means of the ETU framework (yellow, orange and red lines). The reduction paths starting in 2010 are considerably steeper than the others, as a result of rapidly depleting 2000–2050 emissions budgets over the last decade.

The linear reduction target paths are compared against model-generated emissions projections. These are ambitious reduction scenarios (dark, medium and light green dashed lines, respectively; for details see Appendix B) generated by means of the GTEM, IMAGE and POLES models. Using linear target paths as a reference one can clearly see that all three scenarios lead to a warming between 2 and 3 °C.

We also plot the projections of CO_2-only emissions related to energy production, published by the IEA for three case scenarios and claimed to lead to 2, 4 and 6 °C warming levels (light, medium, and dark olive dotted lines, respectively; cf. Appendix C). In comparing these projections with linear target paths we conclude that IEA's 4 and 6 °C scenarios agree with the findings of the ETU framework, but even the most stringent 2 °C scenario is rather likely to lead to 3 °C warming instead.

9. The EU in the ETU framework

This section demonstrates how the ETU framework operates on the regional level. In Table 12 we present the levels of per-capita emissions by start year and reduction required in order to meet GEE targets in 2050, which by definition are universal. The reduction requirements are split with reference to both the technosphere and the land-use change sector. Reduction targets for the technosphere are calculated with respect to per-capita emissions without taking international trade into account (i.e., without emissions embodied in the goods consumed on the EU-27 territory which were produced outside its borders). While international trade has no impact on deriving GEE targets (as its balance is zero on the global scale), taking it into consideration on the regional or national level may result in even more stringent reduction targets for net importers such as the EU-27. The ETU framework requires (as applied here) that land-use change emissions on any considered area are reduced linearly to zero - that is, in 2050 sustainable land use will be achieved both globally and locally.

Figures 6–9 show historical emissions of the EU-27: technospheric emissions without international trade (thick black line) and with international trade taken into account (thin black line). The sum of technospheric emissions of EU member countries has decreased over the last two decades; however, the part of emissions embodied in products imported to the EU has increased from about 0.7 Gt CO_2-eq in 1990 to over 1 Gt CO_2-eq in 2012. On the other hand, international trade has only a small impact on the EU-27's emissions related to the land-use sector. This is evident when one compares these emissions with and without international trade taken into account (dotted and solid brown lines, respectively). Both lines follow the reduction path towards sustainable land-use in 2050.

Reductions declared in the Kyoto Protocol, pledges for the post-Kyoto period and targets for the EU's Effort Sharing (implementing the Climate and Energy Package) are marked with dark blue, dark and light olive, and light blue dashed lines, respectively (cf. Appendix A). Comparing them with the linear reduction target paths of the ETU framework corresponding to the global constraints considered in this study (yellow, orange and red solid lines) we can conclude that the mitigation policies mentioned above are insufficient and do not comply with the 3 °C warming target (cf. Figs. 8 and 9).

We also compare IEA's CO_2-only projections of the EU's future emissions against the ETU linear target paths and deduce that both the 2 and 4 °C scenario may fail to secure their declared warming targets (cf. Figs. 6 and 9).

Table 12: EU-27: Per-capita emissions in 1990, 2000 and 2010 and emission reductions needed to meet GEE targets in 2050.

Sector	**1990 Per-capita emissions w/o trade**	**1990 Per-capita emissions with trade**	**2050 Global emissions equity targets [in t CO_2-eq/cap]**			
			2.6	**3.6**	**4.7**	**5.7**
			1990–2050 emission reduction w/o trade			
	t CO_2-eq/cap	**t CO_2-eq/cap**	**% / cap**	**% / cap**	**% / cap**	**% / cap**
Techno-sphere	10.2	13.5	78	69	61	52
LUC	-1. 3	unknown	100% (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			
Sector	**2000 Per-capita emissions w/o trade**	**2000 Per-capita emissions with trade**	**2050 Global emissions equity target [in t CO_2-eq/cap]**			
			2.1	**3.4**	**4.6**	**5.8**
			2000–2050 emission reduction w/o trade			
	t CO_2-eq/cap	**t CO_2-eq/cap**	**% / cap**	**% / cap**	**% / cap**	**% / cap**
Techno-sphere	10.6	12.3	80	68	56	45
LUC	-0.6	-0.5	100% (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			

Sector	2010 Per-capita emissions w/o trade	2010 Per-capita emissions with trade	2050 Global emissions equity target [in t CO_2-eq/cap]			
			0.6	2.1	3.6	5.2
			2010–2050 emission reduction w/o trade			
	t CO_2-eq/cap	t CO_2-eq/cap	% / cap	% / cap	% / cap	% / cap
Techno-sphere	9.4	11.5	94	78	61	45
LUC	-0.6	unknown	100% (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			

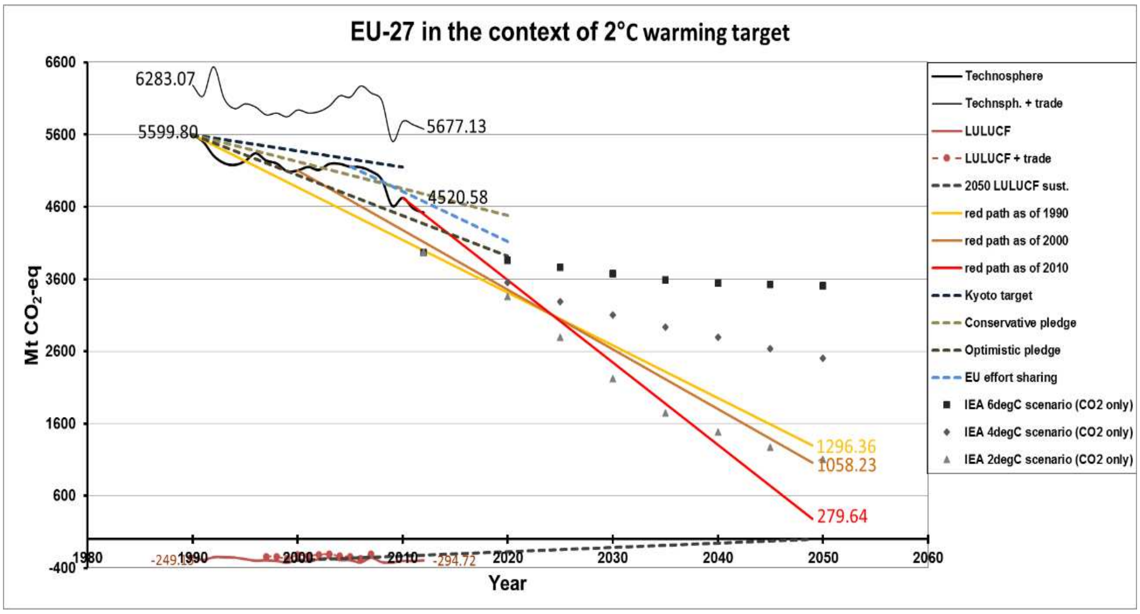


Fig. 6a: Historical technospheric and land-use related GHG emissions of the EU-27, linear reduction target paths likely to secure a 2 °C warming target, intended reductions for mitigation efforts and future emissions scenarios (in Mt CO_2-eq).

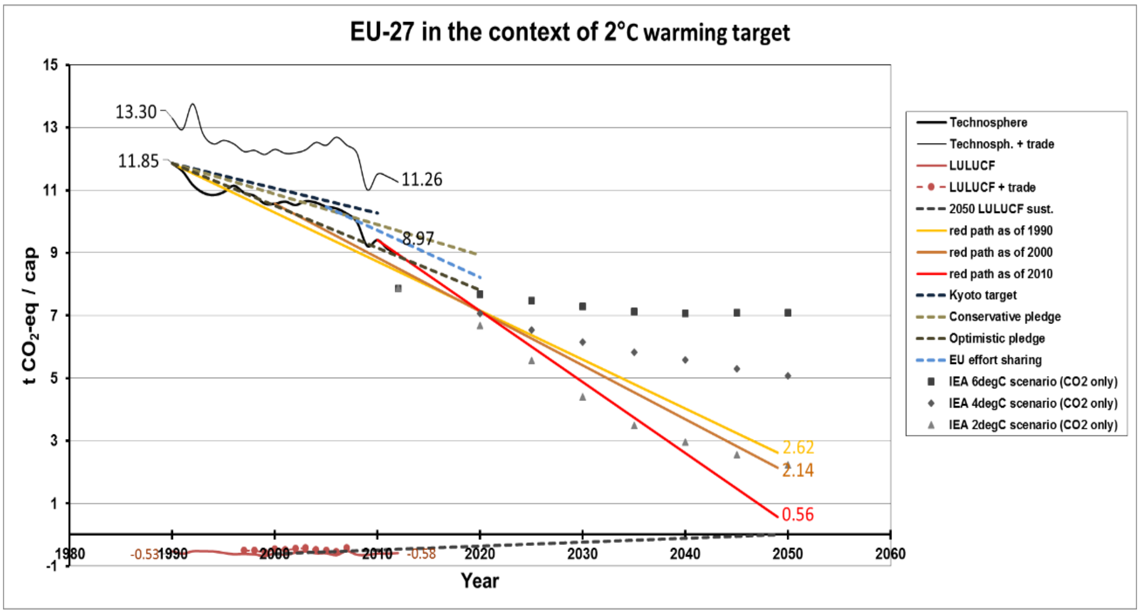


Fig. 6b: Historical per capita emissions of EU-27 from the technospheric and land-use sector, linear reduction target paths likely to secure a 2 °C warming target, intended reductions for mitigation efforts and future emissions scenarios (in Mt CO_2-eq/cap).

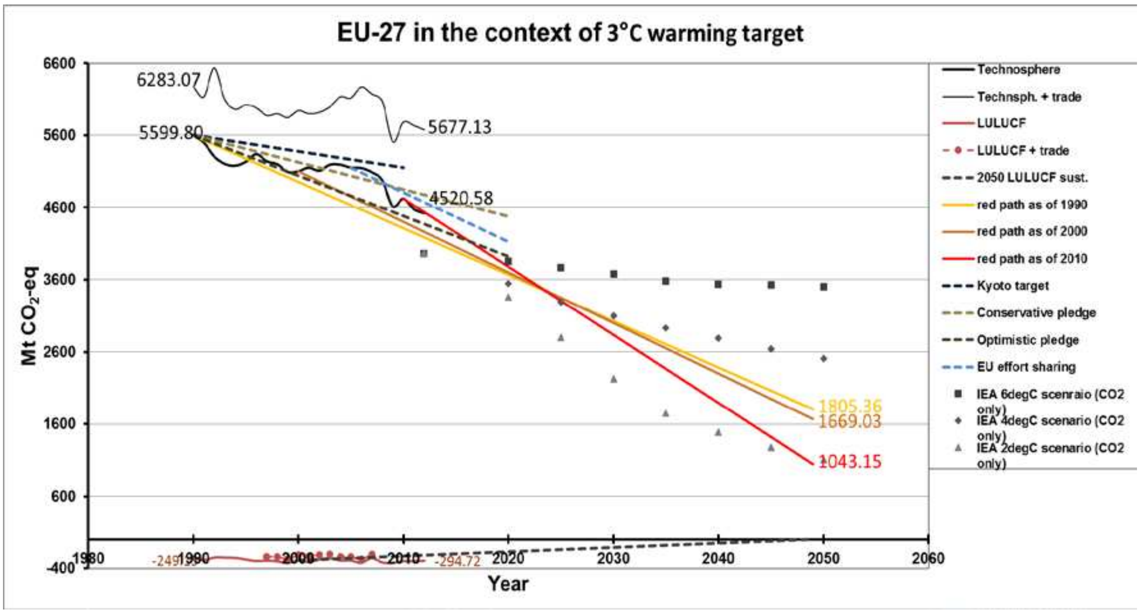


Fig. 7a: Historical technospheric and land-use related GHG emissions of EU-27, linear reduction target paths likely to secure a 3 °C warming target, intended reductions for mitigation efforts and future emissions scenarios (in Mt CO_2-eq).

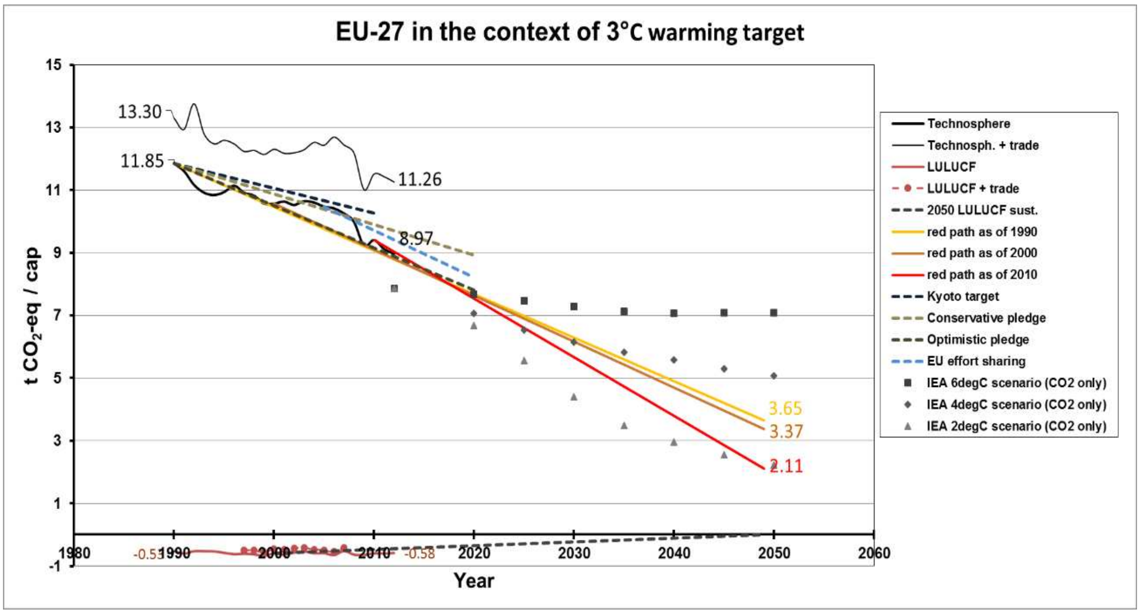


Fig. 7b: Historical per capita emissions of EU-27 from the technospheric and land-use sector, linear reduction target paths likely to secure a 3 °C warming target, intended reductions for mitigation efforts and future emissions scenarios (in Mt CO_2-eq/cap).

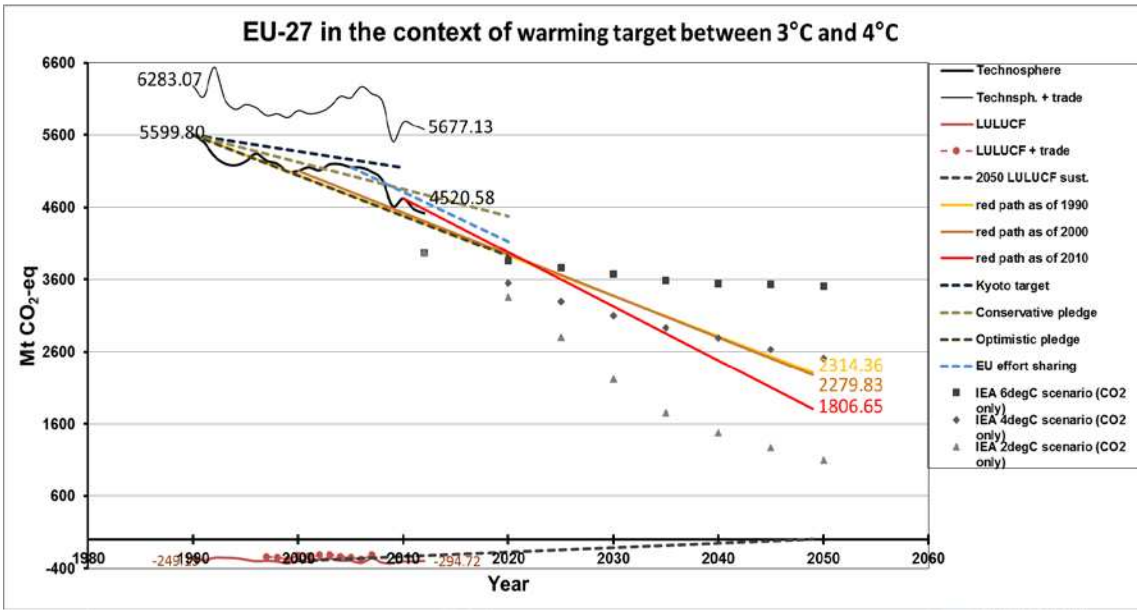


Fig. 8a: Historical technospheric and land-use related GHG emissions of EU-27, linear reduction target paths likely to secure a warming target between 3 °C and 4 °C, intended reductions for mitigation efforts, and future emissions scenarios (in Mt CO_2-eq).

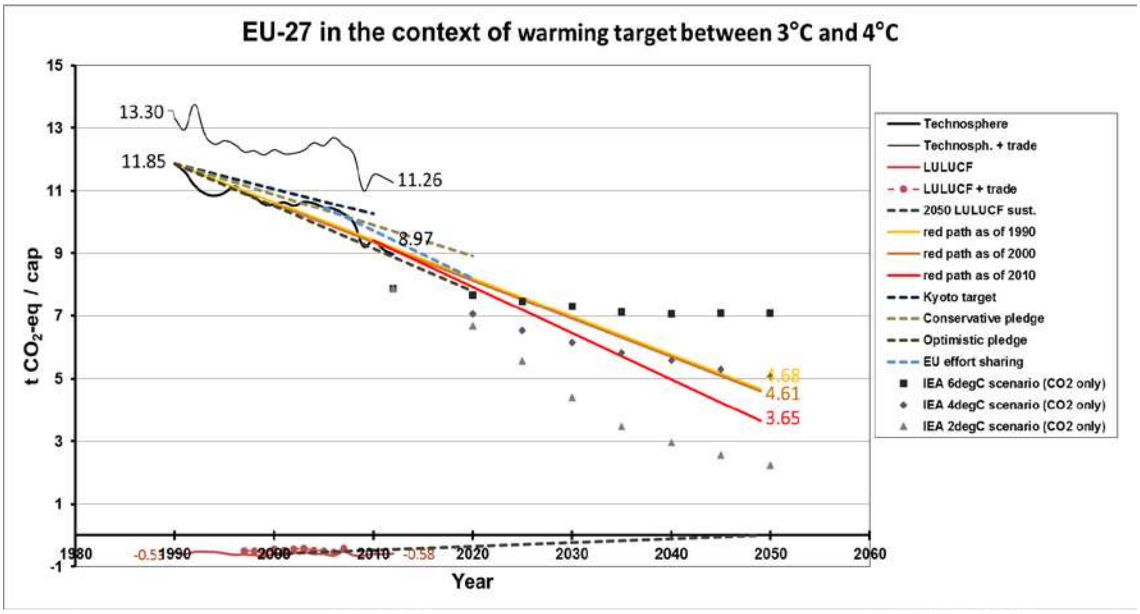


Fig. 8b: Historical per capita emissions of EU-27 from the technospheric and land-use sector, linear reduction target paths likely to secure a warming target between 3 °C and 4 °C, intended reductions for mitigation efforts, and future emissions scenarios (in Mt CO_2-eq/cap).

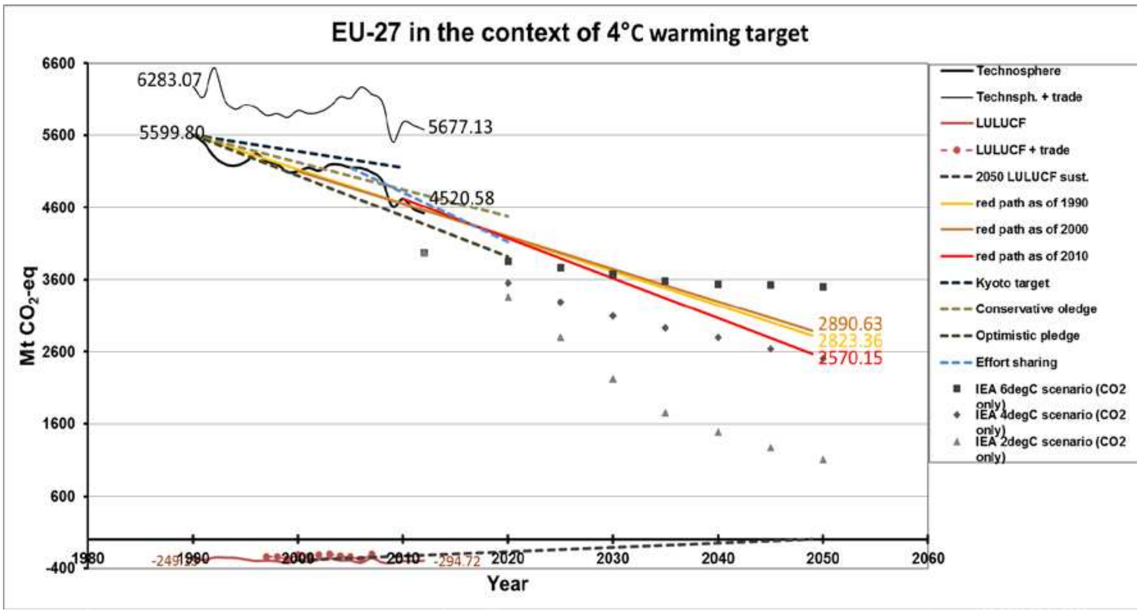


Fig. 9a: Historical technospheric and land-use related GHG emissions of EU-27, linear reduction target paths likely to secure a 4 °C warming target, intended reductions for mitigation efforts, and future emissions scenarios (in Mt CO_2-eq).

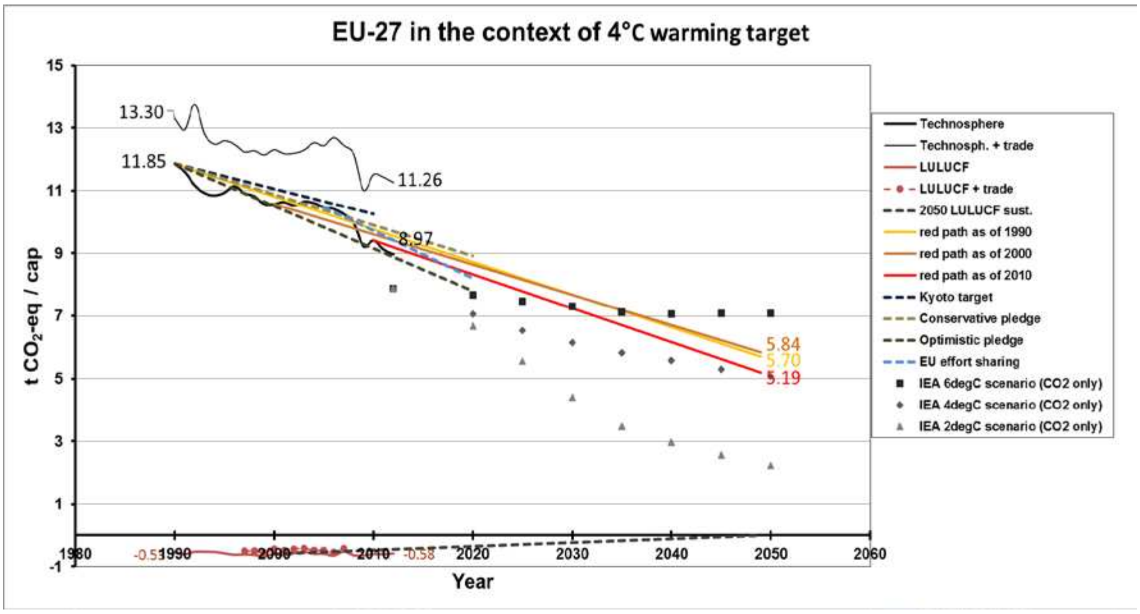


Fig. 9b: Historical per capita emissions of EU-27 from the technospheric and land-use sector, linear reduction target paths likely to secure a 4 °C warming target, intended reductions for mitigation efforts, and future emissions scenarios (in Mt CO_2-eq/cap).

10. Austria in the ETU framework

In this section we present results of applying the ETU framework on the national level. We have chosen Austria as a working example.

Table 13 summarizes Austria's per-capita emissions in the years 1990, 2000, and 2010 which we consider as start years for reduction efforts. We also give levels of emission reductions required to achieve universal GEE targets in 2050. The reduction requirements are specified for the technospheric and land-use sectors and were calculated with respect to start year emissions without taking international trade into account.

Figures 10a–13a present the technospheric part of Austria's emissions. The thick black line represents the GHG emissions from the technosphere that occurred within Austria only, while the thin black line represents Austria's technosphere emissions with international trade taken into account (i.e., emissions that occurred outside Austria's territory that resulted from the production and transport of goods consumed in Austria). Austria's technospheric emissions exhibit a decreasing trend over the last decade with a relatively stable share of emissions embodied in international trade.

Dark blue and gray dashed lines denote emissions reduction targets to which Austria agreed in the Kyoto Protocol and the Burden Sharing mechanism, respectively. Austria's targets within the Effort Sharing mechanism implementing EU's Climate and Energy Package are marked with a light blue dashed line (cf. Appendix A). All these short-term mitigation efforts follow linear reduction paths leading to a warming target of around 4 °C (cf. Fig. 13).

We also analyze Austria's projections of future GHG emissions assuming implementation of already existing mitigation measures ("with existing measures" or WEM scenario; light olive symbols) and additional planned measures ("with additional measures" or WAM scenario; dark olive symbols). For a description of these scenarios see Appendix D. Comparing these emissions projections with the ETU target paths, we can conclude that even the more ambitious WAM scenario is hardly sufficient to generate reductions corresponding to the 4 °C warming target (cf. Fig. 13).

Figures 10b–13b present a simplified view of Austria's technospheric emissions and reduction targets but also show historical per-capita emissions from the land-use sector, both with and without international trade taken into account (dotted and solid brown lines, respectively). Austria's territory has been a sink over the last two decades considered in this study. Evidently, international trade has minimal effect on that picture. The ETU framework requires land-use related emissions to be zero in 2050, thus being a sink puts Austria on the safe side of that requirement. However, the strength of Austria's sink has decreased over the last decade and is approaching zero emissions much faster than the target path for land-use emissions assumed by ETU framework (dark grey dashed line in Figs. 10b–13b).

In summary, meeting the reduction target corresponding to a 2 °C warming will be an immense challenge for Austria since none of the analyzed policies or scenarios comply with this target. Simply maintaining the reduction rates assigned to Austria in the Burden Sharing or Effort Sharing mechanisms in the future, or relying on currently planned or implemented mitigation measures, instead puts Austria on a track towards a global warming of >4 °C.

Table 13: Austria's per-capita emissions of Austria in 1990, 2000 and 2010 and emissions reductions needed to meet GEE targets in 2050.

Sector	1990 Per-capita emissions w/o trade	1990 Per-capita emissions with trade	2050 Global emissions equity targets [in t CO_2-eq/cap]			
			2.6	3.6	4.7	5.7
			1990–2050 emission reduction w/o trade			
	t CO_2-eq/cap	t CO_2-eq/cap	% / cap	% / cap	% / cap	% / cap
Techno-sphere	10.2	13.5	74	64	54	44
LUC	-1.3	unknown	100% (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			

Sector	2000 Per-capita emissions w/o trade	2000 Per-capita emissions with trade	2050 Global emissions equity target [in t CO_2-eq/cap]			
			2.1	3.4	4.6	5.8
			2000–2050 emission reduction w/o trade			
	t CO_2-eq/cap	t CO_2-eq/cap	% / cap	% / cap	% / cap	% / cap
Techno-sphere	10.0	13.5	79	66	54	42
LUC	-1.9	-1.8	100% (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			
Sector	**2010 Per-capita emissions w/o trade**	**2010 Per-capita emissions with trade**	**2050 Global emissions equity target [in t CO_2-eq/cap]**			
			0.6	**2.1**	**3.6**	**5.2**
			2010–2050 emission reduction w/o trade			
	t CO_2-eq/cap	**t CO_2-eq/cap**	**% / cap**	**% / cap**	**% / cap**	**% / cap**
Techno-sphere	10.1	13.3	94	79	64	49
LUC	-0.5	unknown	100% (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			

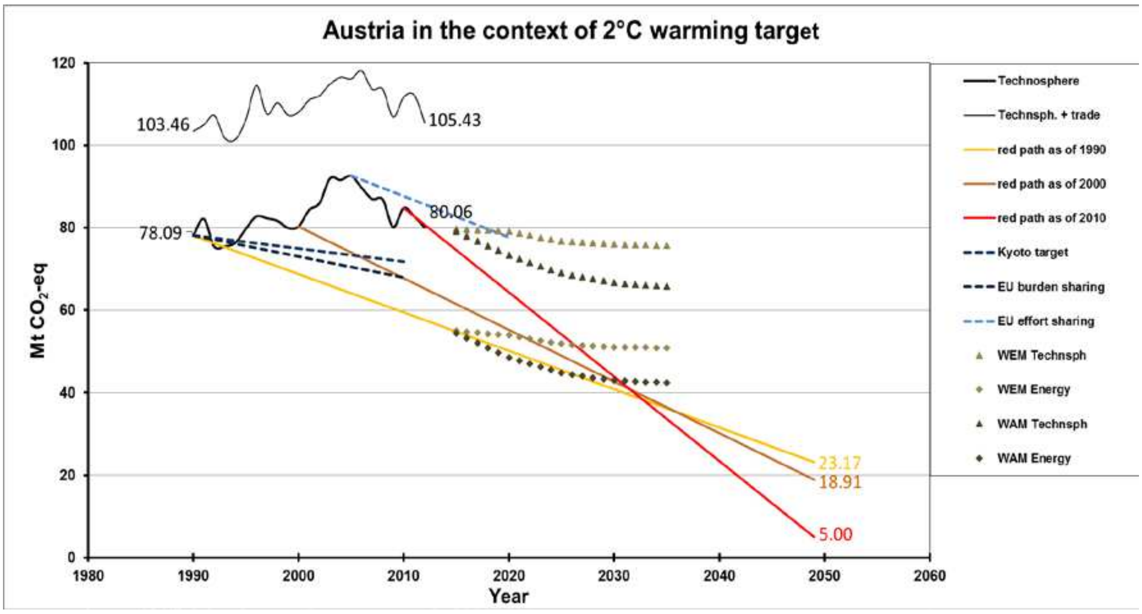


Fig. 10a: Analysis of technosphere emissions of Austria: historical GHG emissions, linear reduction target paths complying with a 2 °C warming target, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq).

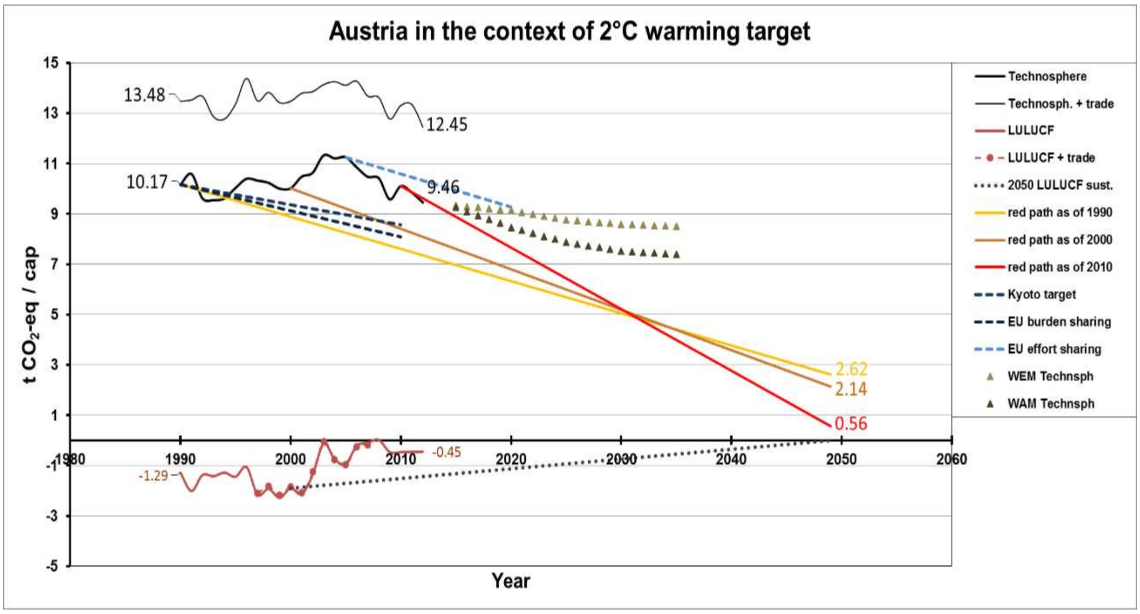


Fig. 10b: Historical per capita GHG emissions of Austria from the technospheric and land-use sector, linear reduction target paths complying with a 2 °C warming target, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq/cap).

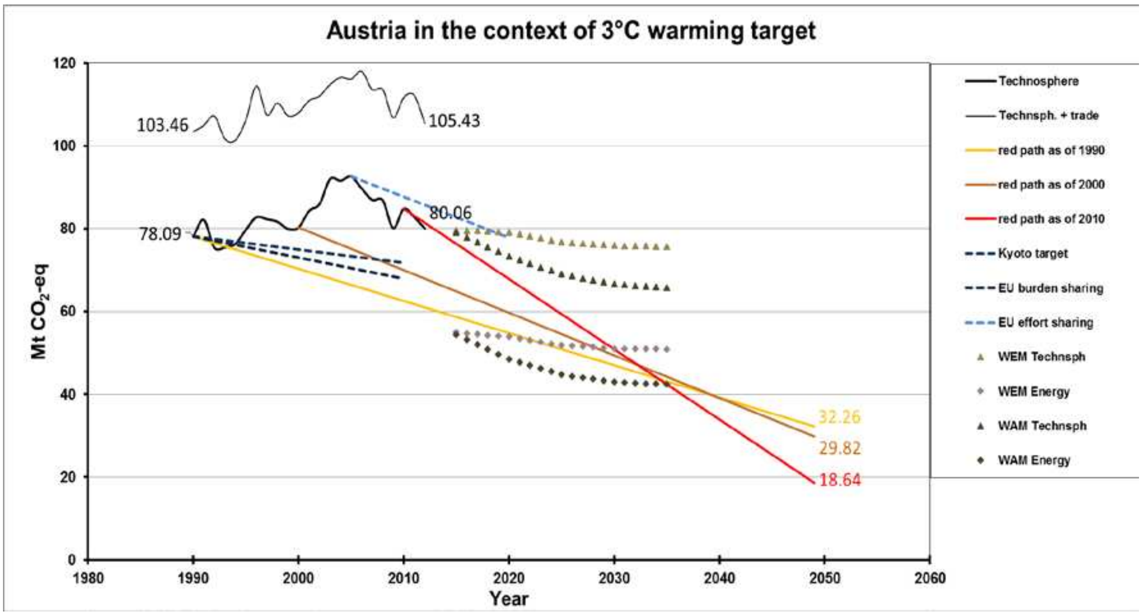


Fig. 11a: Analysis of technosphere emissions of Austria: historical GHG emissions, linear reduction target paths complying with a 3°C warming target, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq).

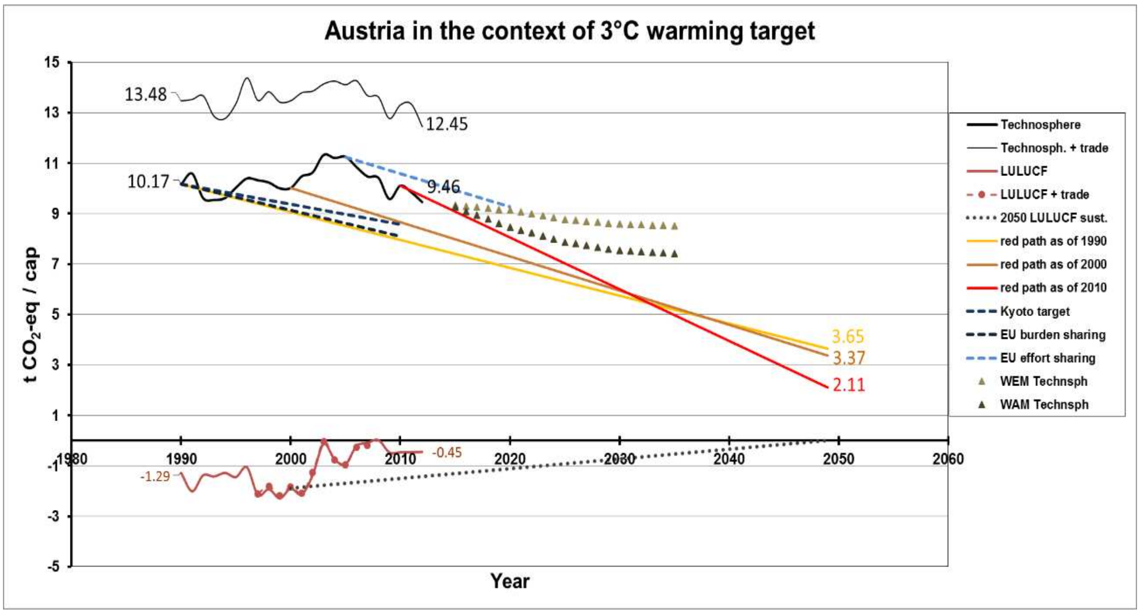


Fig. 11b: Historical per capita GHG emissions of Austria from the technospheric and land-use sector, linear reduction target paths complying with a 3 °C warming target, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq/cap).

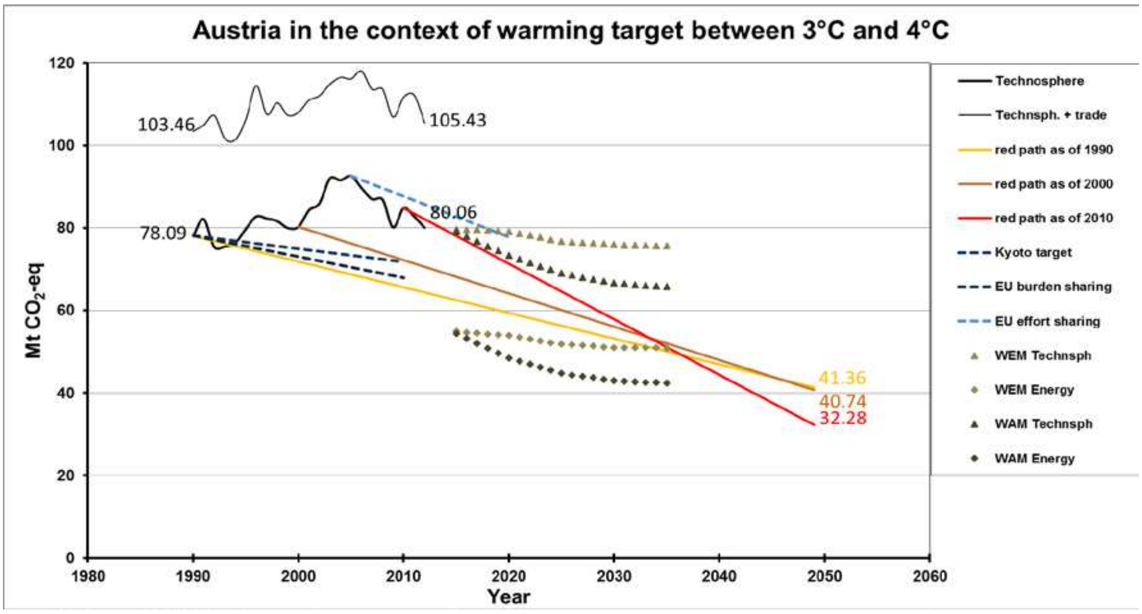


Fig. 12a: Analysis of technosphere emissions of Austria: historical GHG emissions, linear reduction target paths complying with a warming target between 3 °C and 4 °C, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq).

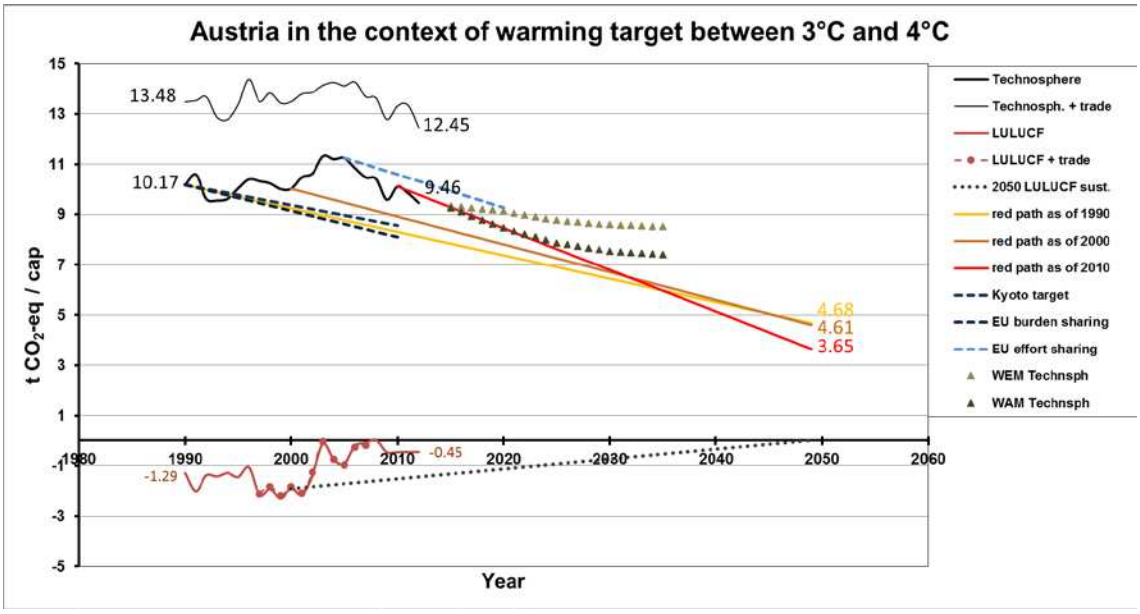


Fig. 12b: Historical per capita GHG emissions of Austria from the technospheric and land-use sector, linear reduction target paths complying with a warming target between 3 °C and 4 °C, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq/cap).

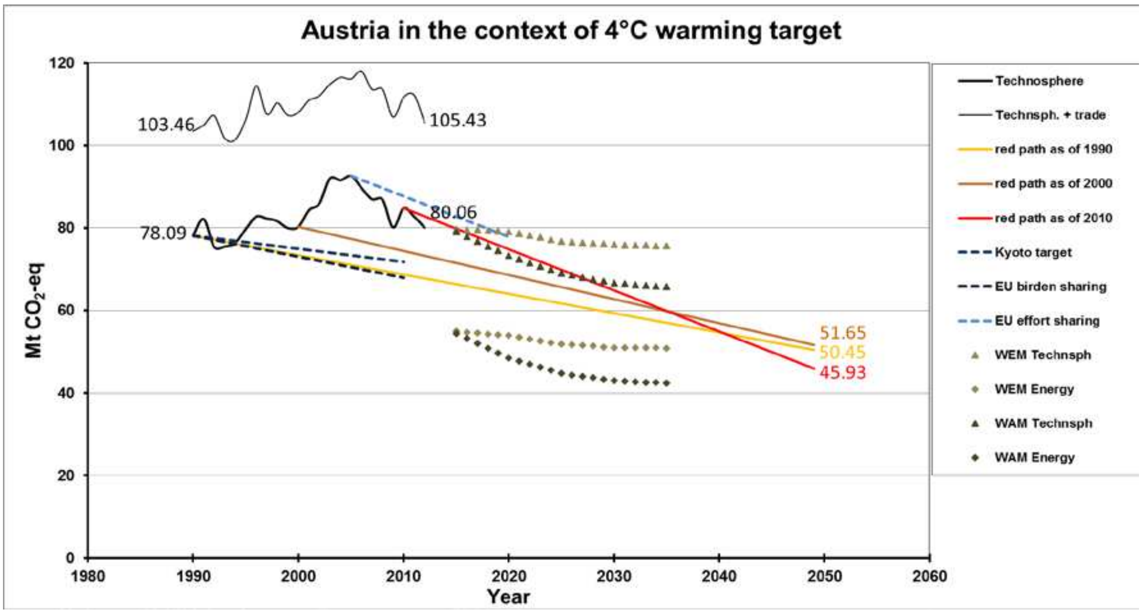


Fig. 13a: Analysis of the technosphere emissions of Austria: historical GHG emissions, linear reduction target paths complying with a 4 °C warming target, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq).

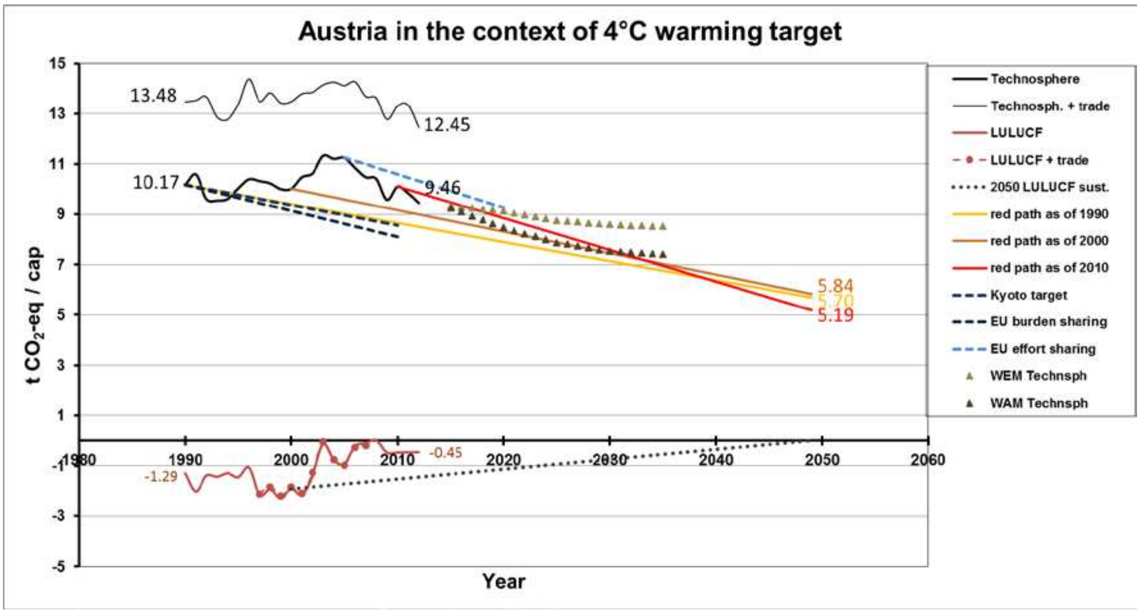


Fig. 13b: Historical per capita GHG emissions of Austria from the technospheric and land-use sector, linear reduction target paths complying with a 4 °C warming target, intended reductions for mitigation efforts, and projections of future emissions (in Mt CO_2-eq/cap).

IV. Summary

In this paper we revise and extend the results of Jonas *et al.* 2014, in which the ETU framework was introduced.

In Part I we provide a condensed, yet comprehensive overview of the ETU framework including its background, assumptions and basic features. We briefly discuss potential directions of further development of the ETU framework.

One way of upgrading the ETU framework is to extend its diagnostic period by updating and expanding the dataset which facilitates its application. Part II of this paper serves as a detailed documentation of these new input data. It also provides technical descriptions of the calculation steps required to obtain emissions reduction targets by means of the ETU framework.

In Part III we repeat the analysis of global emission reduction targets that was described first in the work of Jonas *et al.* 2014. We present revised reduction target paths starting in the years 1990 and 2000 that were calculated using the updated dataset described in Part II. We also establish reduction targets for emission cuts starting in 2010. We describe how to calculate global emissions equity targets. We also discuss the uncertainty in these targets. The analysis of the targets for emission reductions starting in 2010 reinforce the findings of previous studies, namely that delaying mitigation results in more stringent reduction requirements until 2050.

We demonstrate how the ETU framework can be applied to find globally consistent emission reduction targets on the regional and national levels using the EU-27 and Austria as examples. The EU has managed to reduce its GHG emissions over the last two decades; however, future mid-term reduction targets and policies are not sufficient to secure the 2 °C warming target. Austria is also facing severe emissions cuts. Its GHG emissions over the last two decades were relatively stable with a slight decrease in recent years. Nevertheless, the lack of serious mitigation efforts in the past have resulted in dramatically stringent reduction targets - from 10 t CO_2-eq/cap in 2010 to just 0.6 t CO_2-eq / cap in 2050. By comparing the projections of future GHG emissions based on already undertaken or planned measures with Austria's target paths we conclude that without fundamental changes in economy and its citizens' way of life Austria will not be able to comply with a global warming target of less than 4 °C.

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Acronyms

ACRP	Austrian Climate Research Programme
BMLFUW	Austria's Federal Ministry Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft)
BMWFJ	Austria's Federal Ministry of Economy, Family and Youth (Bundesministerium für Wirtschaft, Familie und Jugend)
C&C	contraction and convergence
CO_2-eq	CO_2 equivalent
ETU	emissions-temperature-uncertainty
GEE	global emissions equity
GHG	greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LUC	land use/land-use change
UBA	Environment Agency Austria (Umweltbundesamt)
UNFCCC	United Nations Framework Convention on Climate Change

Appendix A: Reduction targets of international agreements

This appendix summarizes emissions reductions targets of parties to the Kyoto protocol (i.e., Annex B countries) and Burden Sharing agreements between member states of the EU that aimed to ensure the compliance of the EU as a whole with the Kyoto target of 8% reductions (cf. Table A1 and Table A2, respectively). Post-Kyoto mitigation targets until 2020 for the EU as a whole and each EU member country are outlined in Tables A3 and A4.

Table A1: Emissions reductions targets of parties to the Kyoto Protocol.[17]

Country Group	Annex B Country	Base Year(s) for CO_2, CH_4, N_2O	Base Year for HFCs, PFCs, SF_6	Commitment Period	Commitment KP %
1a	see **1** below	1990	1995	2008–12	92
1b	see **2** below	1990	1990	2008–12	92
1c	RO	1989	1989	2008–12	92
1d	BG	1988	1995	2008–12	92
1e	SI	1986	1995	2008–12	92
2	US (see **3** below)	1990	1990	2008–12	93
3a	JP	1990	1995	2008–12	94
3b	CA	1990	1990	2008–12	94
3c	PL	1988	1995	2008–12	94
3d	HU	1985–87	1995	2008–12	94
4	HR	1990	1995	2008–12	95
5a	RU	1990	1995	2008–12	100
5b	NZ, UA	1990	1990	2008–12	100
6	NO	1990	1990	2008–12	101
7	AU	1990	1990	2008–12	108
8	IS	1990	1990	2008–12	110

1: BE, CZ, DE, DK, EC (= EU-15; the EU-27 does not have a common Kyoto target), EE, ES, FI, GR, IE, LT, LU, LV, MC, NL, PT, SE, UK. Member States of the EU-27 but without individual Kyoto targets: CY, MT. Listed in the Convention's Annex I but not included in the Protocol's Annex B: BY and TR (BY and TR were not Parties to the Convention when the Protocol was adopted.) BY requested becoming an Annex B country by amendment to the Kyoto Protocol at CMP 2 in 2006. BY's base years and KP commitment are 1990 (1995) and 92%, respectively.

2: AT, CH, FR, IT, LI, SK.

3: The US has indicated its intention not to ratify the Kyoto Protocol.
The US reports all its emissions with reference to 1990. However, information on 1990 in its national inventory submissions does not reflect or prejudge any decision that may be taken in relation to the use of 1995 as base year for HFCs, PFCs and SF_6 in accordance with Article 3.8 of the Kyoto Protocol.

[17] Source: Lesiv *et al.* 2011

Table A2: Emissions reductions targets of individual EU member countries under the Burden Sharing agreement.[18]

EU Member State	ISO Country Code	EU Burden Sharing 1990 - (2008-2012) [%]
Austria	AT	13.0
Belgium	BE	7.5
Bulgaria	BG	8.0
Cyprus	CY	
Czech republic	CZ	8.0
Denmark	DK	21.0
Estonia	EE	8.0
Finland	FI	0.0
France	FR	0.0
Germany	DE	21.0
Greece	GR	-25.0
Hungary	HU	6.0
Ireland	IE	-13.0
Italy	IT	6.5
Latvia	LV	8.0
Lithuania	LT	8.0
Luxembourg	LU	28.0
Malta	MT	
Netherlands	NL	6.0
Poland	PL	6.0
Portugal	PT	-27.0
Romania	RO	8.0
Slovak Republic	SK	8.0
Slovenia	SI	8.0
Spain	ES	-15.0
Sweden	SE	-4.0
United Kingdom	UK	12.5
EU-15	**EC**	**8.0**

Table A3: Joint pledges of reductions of the EU member countries for the post-Kyoto period submitted to the UN Framework Convention on Climate Change in the aftermath of Copenhagen Agreement.[19]

EU – 27 pledge for reductions in period 1990 - 2020	Reductions [%]
Pessimistic	20
Optimistic	30

[18]Source: supplementary materials to Lesiv *et al.* 2011
[19] Source: Center for Climate and Energy Solutions http://www.c2es.org/international/history-international-negotiations/2020-targets#ref2

Table A4: EU member states' targets under the Effort Sharing agreement implementing the Climate and Energy Package (20 – 20 – 20 targets).[20] The base year is 2005.

EU Member State	ISO Country Code	EU Climate and Energy Package Effort Sharing targets 2013-2020 [%]
Austria	AT	16.0
Belgium	BE	15.0
Bulgaria	BG	20.0
Cyprus	CY	5.0
Czech republic	CZ	9.0
Denmark	DK	20.0
Estonia	EE	11.0
Finland	FI	16.0
France	FR	14.0
Germany	DE	14.0
Greece	GR	4.0
Hungary	HU	10.0
Ireland	IE	20.0
Italy	IT	13.0
Latvia	LV	17.0
Lithuania	LT	15.0
Luxembourg	LU	20.0
Malta	MT	5.0
Netherlands	NL	16.0
Poland	PL	14.0
Portugal	PT	1.0
Romania	RO	19.0
Slovak Republic	SK	4.0
Slovenia	SI	13.0
Spain	ES	10.0
Sweden	SE	17.0
United Kingdom	UK	16.0
EU-27		**20**

[20] Source: Center for Climate and Energy Solutions http://www.c2es.org/international/history-international-negotiations/2020-targets#ref2

Appendix B: Emissions scenarios of models external to the ETU framework

As representative examples for long-term energy-climate scenarios - the three models that we use are GTEM, POLES and IMAGE - we rely on three scenarios from the EMF22 (Clarke *et al.* 2009; Gurney *et al.* 2009) and ADAM (Edenhofer *et al.* 2010; Kitous *et al.* 2010) modeling comparison exercises as well as from an individual scenario publication (van Vuuren *et al.* 2007). These have been assessed in the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (Fischedick *et al.* 2011; Krey and Clarke 2011).

The models follow different methodological approaches. GTEM (scenario taken from Gurney *et al.* 2009) is an intertemporal computable general equilibrium model that emphasizes the link between mitigation action and the economy and its different sectors; while POLES (Kitous *et al.* 2010) is a simulation model with high technology resolution in the energy system; and IMAGE (van Vuuren *et al.* 2007) is an integrated assessment model with an elaborate land-use module. Regardless of these differences, decision making in all three models is based on economic criteria under first best assumptions, i.e., allowing full when-and-where flexibility for achieving global mitigation targets.

Brief model synopses are available at: Global Trade and Environment Model (GTEM); Prospective Outlook on Ling-term Energy Systems (POLES); and Integrated Model to Assess the Greenhouse Effect (IMAGE).

Appendix C: IEA's ETP scenarios

The Energy Technology Perspectives 2015 report (IEA, 2015) provides the following synopsis for the scenarios used in our study:

The ETP scenario analysis is based on four interlinked, technology-rich models for the energy supply, buildings, industry, and transport sectors. Depending on the sector, this modeling framework covers 28 to 39 world regions or countries, over the time horizon from 2012 to 2050. Based on the ETP modeling framework, the scenarios are constructed using a combination of forecasting to reflect known trends in the near term and back-casting to develop plausible pathways for a desired long-term outcome.

The ETP scenarios should not be considered as predictions of what is going to happen, rather they explore the impacts and trade-offs of different technology and policy choices, thereby providing a quantitative approach to support decision making in the energy sector. While different, the ETP scenarios are complementary to those explored in the IEA World Energy Outlook (WEO).

The ***6DS (6°C Scenario)*** *is largely an extension of current trends. By 2050, primary energy use grows by almost two-thirds (compared with 2012) and total GHG emissions rise even more. In the absence of efforts to stabilize atmospheric concentration of GHGs,* *average global temperature rise above pre-industrial levels is projected to reach almost 5.5°C in the long term (by 2050) and almost 4°C by the end of this century. A 4°C increase within this century is already likely to cause severe impacts, such as substantial sea level rise, reduced crop yields, stressed water resources, and disease outbreaks in new areas (World Bank Group, 2014). The 6DS is broadly consistent with the WEO Current Policy Scenario through 2040.*

The ***4DS (4°C Scenario)*** *takes into account recent pledges made by countries to limit emissions and step up efforts to improve energy efficiency, which helps limit long-term temperature rise to 4°C (by 2050). The 4DS is, in many respects, already an ambitious scenario that requires significant changes in policy and technologies compared with the 6DS. This long-term target also requires significant additional cuts in emissions in the period after 2050, yet with average temperature likely to rise by almost 3°C by 2100, it still carries the significant hazard of bringing forth drastic climate impacts. The 4DS is broadly consistent with the WEO New Policies Scenario.*

The ***2DS (2°C Scenario)*** *is the main focus of the ETP 2015. It lays out the pathway towards an energy system and emissions trajectory consistent with what recent climate science research indicates would give at least a 50% chance of limiting average global temperature increase to 2°C. The 2DS sets the target of cutting energy- and process-related CO_2 emissions by almost 60% by 2050 (compared with 2012) and ensuring they continue to decline thereafter. It identifies changes that help ensure a secure and affordable energy system in the long run, while also emphasizing that transforming the energy sector is vital but not solely capable of meeting the ultimate goal. Substantial effort must also be made to reduce CO_2 and GHG emissions in non-energy sectors. The 2DS is broadly consistent with the WEO 450 Scenario (referring to concentration levels of 450 parts per million in the atmosphere).*

Additional information on the model used in the ETP report are available at: http://www.iea.org/etp/etpmodel/

Appendix D: Austria's WEM and WAM scenarios

Report (UBA, 2015) provides projections of Austria's GHG emissions until 2035 obtained for two scenarios: "with existing measures" (WEM), and "with additional measures" (WAM).

WEM scenario considers the policies and measures (PAMs) implemented before the 1st of May 2014. The effects of these policies and measures were assessed jointly, with their interactions taken into account. Investigated PAMs were selected on the basis of their relevance for reductions of emissions from at least one of emissions sectors as defined in the UN Framework Convention on Climate Change guidelines.

The WAM scenario also takes into account planned polices and measures which have a chance to be adopted and implemented in time to influence the emissions in the period between 2015 and 2035.

The detailed list of considered policies and measures and exact definitions of WEM and WAM scenarios are given in Chapters 4 and 5 of the report (UBA, 2015).