Climate Analytics Working Paper 2012-1
8 May 2012

Evaluation of IEA ETP 2012 emission scenarios

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Acknowledgements

The authors like to thank Markus Wrake at IEA for providing the 2009-2050 energy/industry emission data from ETP 2012, as well as valuable comments to an earlier draft of this paper.

Summary

IEA recently developed three updated scenarios for the 2012 edition of *Energy Technology Perspectives*. The scenarios, labeled 6DS, 4DS and 2DS, reflect three different ambition levels of global emission reductions: based on carbon-cycle/climate-model runs and necessary assumptions on longer-term emissions, the scenarios are projected to lead to roughly 6°C global warming above pre-industrial in the long term (4°C by 2100), to 4°C in the long term (3°C by 2100) and to 2°C in the long term (below 2°C by 2100) respectively. In relation to the long-term climate goals mentioned in the 2010 Cancun Agreements, the 6DS, 4DS and 2DS scenarios lead to a probability to hold warming below 2°C of 0%, 5% and 80% over the 21st century respectively.

Contents

I.

Introduction

IEA recently developed three updated scenarios for the 2012 edition of *Energy Technology Perspectives (ETP 2012).* The scenarios are labeled here 6DS, 4DS and 2DS and reflect three different ambition levels of global emission reductions, formulated in terms of energy-related CO_2 emissions (figure 1).

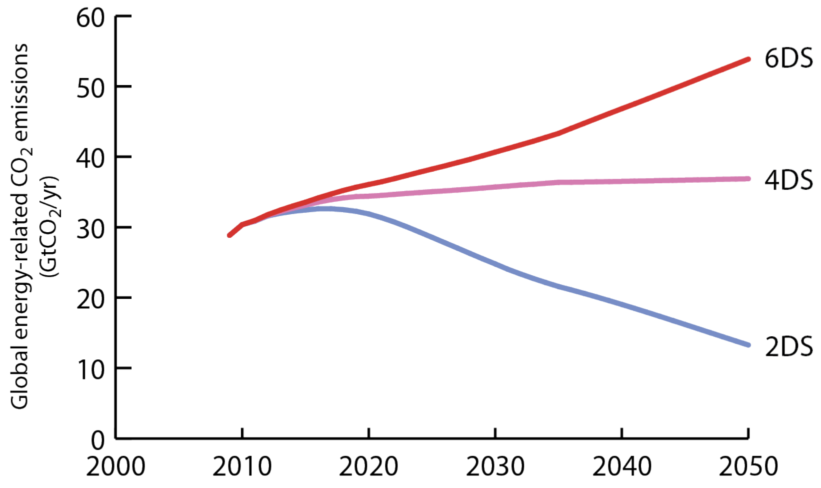

Figure 1: CO_2 emissions from energy and industry as defined in ETP 2012.

The IEA developed emission scenarios defined by CO_2 emissions from energy and industrial sources. In order to estimate the full climate consequences of these scenarios, it is necessary to look at all greenhouse gases and all sources (going beyond CO_2 emissions from energy and industrial sources) and to look at a long-term horizon. In sections 2 and 3, we estimate the climate impacts using two different approaches: climate modeling and emission budget calculations.

II. Climate modeling (requiring extension with non-CO_2 GHGs and beyond 2050)

To allow for an assessment using climate models, the IEA scenarios needed to be extended beyond 2050. Moreover, emissions from other sources and those from non-CO_2 greenhouse gases and aerosol precursors needed to be added. We have used RCP scenarios (Van Vuuren et al., 2011, Moss et al., 2010), developed to be assessed by all Working Groups for the 5th assessment report of IPCC, to extend the IEA scenarios using the following protocol:

- Since energy/industry-related CO_2 emissions were defined until 2050, post-2050 emissions were added to the IEA pathways by applying growth rates from 2051 onwards, based on interpolated growth rates between RCP3PD and RCP8.5, using as interpolation key the cumulative energy/industry-CO_2 emissions over 2000-2050.

- Non-CO_2 and aerosol precursors were inserted by applying grow rates from 2005 onwards, interpolating growth rates between RCP3PD and RCP8.5, using as interpolation key the energy/industry-CO_2 emissions in the year for which emissions were to be inserted.
- Land-use CO_2 emissions were inserted by taking the mean of the RCP scenarios for the year in question, with the motivation that land-use CO_2 does not correlate well with energy-CO_2.

The resulting CO_2 and total GHG emissions are shown in Figure 2. The 2DS scenario is very close to RCP3PD, the 4DS scenario somewhat higher than RCP4.5 and the 6DS scenario higher than RCP6, but lower than the highest RCP8.5 scenario. Note that this approach leads to specific developments of each scenario (2DS, 4DS and 6DS) beyond 2050 that are defined by the assumptions above (and thus not automatically a result of the IEA emission scenarios that are defined up to the year 2050). For instance, the "extended" 2DS scenario includes global net-negative energy/industry-CO_2 emissions from around 2070 consistent with RCP3PD.

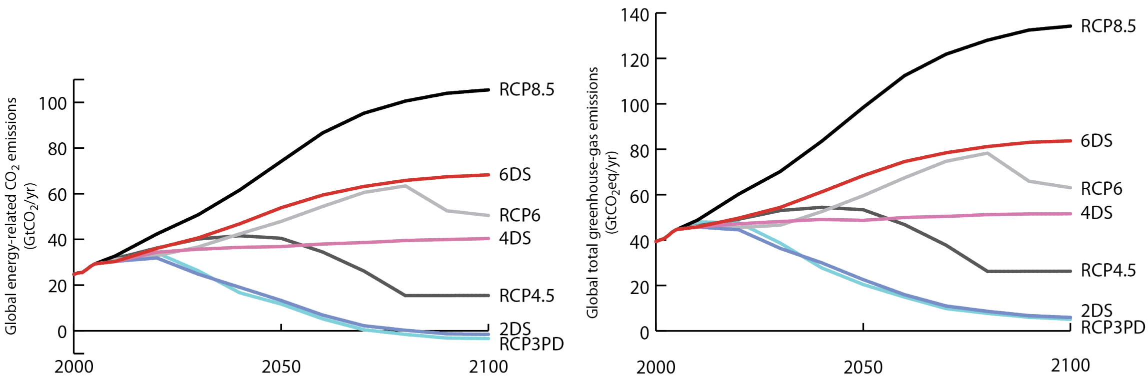

Figure 2. Energy-related CO_2 emissions (left) and total greenhouse gas emissions (right) derived from ETP 2012 scenarios and compared to RCPs.

The climate implications of the scenarios were assessed using the reduced-complexity coupled carbon-cycle/climate model MAGICC6 (Meinshausen et al 2011). The setup of this model was updated during the RCP exercise in terms of historical emissions and forcings, but still relies on the Monte-Carlo setup with Bayesian updating developed by Meinshausen et al (2009) that allows drawing sets of model parameters that provide an optimal reproduction of a selection of climate variables over the historical observation period. For each emission scenario, MAGICC6 was run 600 times with different parameter sets, providing a probability distribution of projected GHG concentrations, forcings and global-mean temperature increase. Median projections are provided here. A typical carbon-cycle/climate-modeling uncertainty estimate of warming by 2100 for a medium emission scenario is ±0.5°C and of CO_2-equivalent concentrations by 2100 ±50 ppmv (±1SD).

Figure 3 shows global-mean warming above pre-industrial for the IEA and RCP scenarios. By 2100, 2DS is projected to reach a peak warming very close to RCP3PD and possibly leading to stabilization of warming, or a slow decline, after 2100. By contrast, both 4DS and 6DS show no transition to a stabilization of warming within the 21st century and instead lead to a still-increasing warming by 2100 of 3°C, respectively 4°C above pre-industrial. For each scenario Table 1 shows CO_2 and CO_2eq concentrations by 2100, and the probability to hold warming below 2°C during the 21st century. Note that the probability to stay below 2°C if much higher for the 2DS scenario than for the other ETP scenarios, which is linked to the width of the temperature projection probability distribution. Since a typical standard deviation of warming projections around 2100 is 0.5°C, a median warming of 2.5°C is associated with only a 16% chance to hold warming below 2°C and a 3°C median with only a 2% chance.

Table 1 further provides the median projection of warming by 2100, a rough estimate of long-term warming by 2500 and an estimate of very long-term warming after the climate system reaches an hypothetical equilibrium for a long-term stabilization of concentration levels of the scenarios. For the latter two cases, we applied the post-2100 extensions for RCP scenarios from Meinshausen et al (2011) and for the 4DS and 6DS scenarios a post-2100 extension similar to the RCP6 extension, given that these two ETP scenarios flank RCP6 over the course of the 21st century. The extension implies a linear decline in emissions to provide a smooth transition between 2100 and 2150 towards stabilization of concentrations from 2150 onwards. The post-2100 extension of the 2DS scenario follows the RCP3PD extension of Meinhausen et al (2011) until 2150 (fixed emissions at 2100 levels), followed by stabilized concentrations from 2150 onwards like the other scenarios.

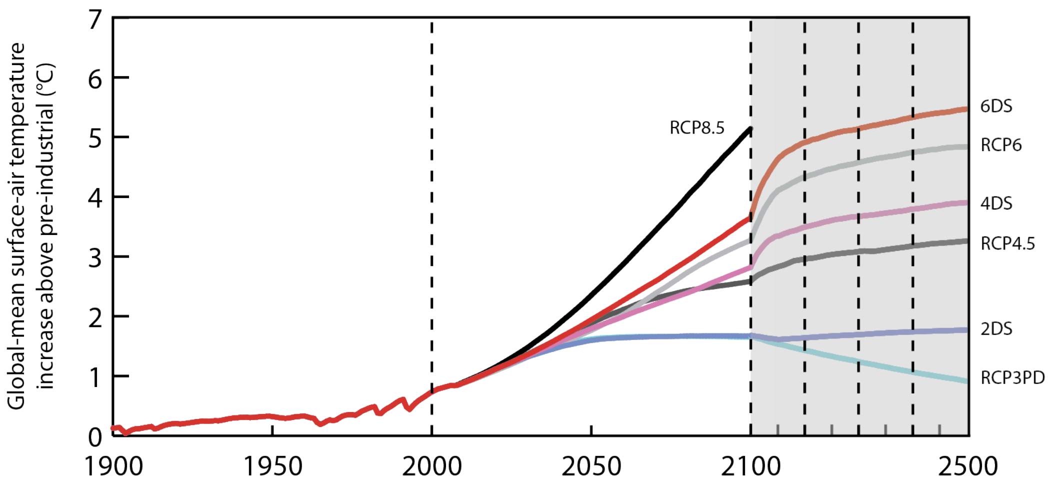

Figure 3. Global-mean near-surface-air temperature increase (above pre-industrial) for IEA and RCP scenarios. Note the grey area on the right-hand side has a strongly compressed time axis. Given the extreme high stabilization level of RCP8.5 and lack of literature on long-term global-warming estimates at such high emission levels no attempt is made to estimate warming for RCP8.5 after 2100.

As Figure 3 shows, even if concentrations were to be held constant after 2100, the climate system would still not have achieved full equilibrium by 2500, although the rate of warming in, for example, 4DS would decrease to 0.01°C per decade by 2500, compared to 0.2°C per decade around 2100. The temperature increase at equilibrium can be approximated on the basis of estimates of the so-called climate sensitivity (i.e. the warming associated with a doubling of the greenhouse gas concentration). Figure 4 shows, on the basis of such estimates, the probability at equilibrium to hold warming below a range of temperature levels (relative to pre-industrial) for a selection of fixed CO_2-equivalent concentration levels, indicating by dashed lines the 2100 levels implied by the ETP 2012 scenarios (for calculation method see Schaeffer et al 2008). Median equilibrium warming is roughly 6°C, 4°C and 2°C for the high, medium and low ETP 2012 scenarios (on the basis of the stabilized concentrations by 2150), which was used ex-post for labeling these scenarios 6DS, 4DS and 2DS, respectively. Aspects of climate-system characteristics and emission reductions related to long-term stabilization are further explained in Box 1.

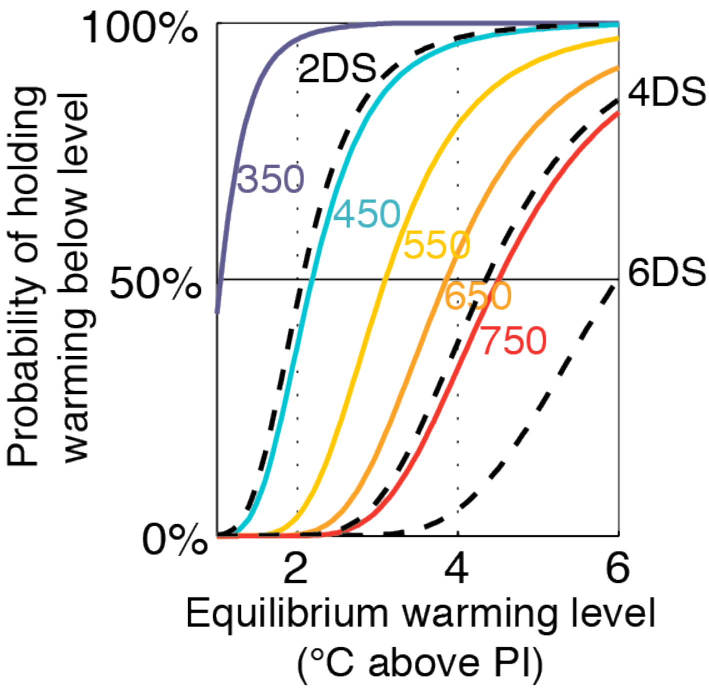

Figure 4. Probability to hold warming below temperature targets after the climate system reached equilibrium with a range of long-term fixed CO_2-equivalent concentration levels (ppm CO_2eq). The long-term concentration levels derived from the three ETP 2012 scenarios (See Table 1) are indicated by black dashed lines.

Table 1. Climate modeling indicators for emissions scenarios. Given the extreme high stabilization level of RCP8.5 and lack of literature on long-term global-warming estimates at such high emission levels no attempt is made to estimate concentration or warming by 2500, or in equilibrium. In addition, since concentrations in RCP3PD do not stabilize, the equilibrium warming and concentration were not estimated.

Scenario	CO_2 concentration by 2100 (ppmv)	CO_2-equivalent concentration by 2100 (ppmv) Between brackets: stabilization level by 2150	Probability to hold warming below 2°C over 21st century (%)	Global-mean temperature increase above pre-industrial by 2100 (°C)	Estimated global-mean temperature increase above pre-industrial by 2500, based on post-2100 extensions (°C)	Estimated global-mean temperature increase above pre-industrial at equilibrium, based on stabilization of concentrations by 2150 (°C)
IEA 6DS	770	890 (1040)	0%	3.7	5.5	6.0
IEA 4DS	630	690 (730)	5%	2.8	3.9	4.3
IEA 2DS	440	460 (440)	80%	1.7	1.8	2.1
RCP8.5	980	1330 (-)	0%	5.1	-	-
RCP6	700	790 (900)	1%	3.3	4.8	5.3
RCP4.5	560	620 (630)	10%	2.6	3.3	3.7
RCP3PD	440	450 (-)	80%	1.7	0.9	-

III. Comparison with literature on emission budgets

Papers by Meinshausen et al (2009) and Allen et al (2009) showed that the probability of exceeding ambitious temperature targets is correlated (to first order) with total cumulative emissions in the coming decades: the so-called emission "budget". Meinshausen et al. estimated that a 2000-2049 budget of total CO_2 emissions of 1437 $GtCO_2$ corresponds to an "illustrative" probability of 50% to exceed 2°C in the 21st century. Assuming land CO_2 emissions (e.g. from deforestation) from RCP scenarios, table 1 shows cumulative total CO_2 emissions over 2000-2049 for the IEA scenarios vis-à-vis other scenarios as published in various recent model comparison studies. It should be noted that in the original work of Meinshausen et al (2009) and Allen et al (2009) a library was used of emission scenarios dating from several years ago, which included different relations between CO_2 emissions and aerosols than more recent scenarios, and did mostly not include technologies that might lead to net-negative CO_2 emissions late this century (e.g. biomass energy combined with carbon capture and storage – BECCS). In Table 3 we used a more updated set of scenarios that also include results from more recent research.

For meeting the 2°C target with a probability between 50 and 66% (in the 21st century), the updated scenario literature indicates a fossil-fuel CO_2 emission budget in the 2000-2049 period in the order of 1250-1450 $GtCO_2$. For a higher probability of 66% to hold warming below 2°C, the budget should be in the order of 1150-1350 $GtCO_2$. In other words, the 2D scenario (2000-2049 cumulative fossil CO_2 of 1260 $GtCO_2$) can indeed be interpreted as a scenario that leads to a maximum warming of 2°C with medium to high probability.

Box 1: Long-term stabilization

For long-term climate projections of scenarios, it is important to know how emissions develop beyond 2100. For the long-term climate projections here, it is assumed that each of these scenarios stabilize greenhouse gas concentrations after 2100. The lowest scenario (IEA 2DS) illustrates that this requires total emissions to be very close to zero at that time (the IEA 2DS scenario itself reaches a level of zero emissions for energy-related CO_2 emissions around 2070; total greenhouse gas emissions in contrast remain slightly positive given the limits to reduction potential of other greenhouse gases assumed in the RCP3PD). For the other scenarios, however, it also requires that over time (centuries) emissions need to come down to zero. This can be simply be understood by the dynamics of the carbon cycle. In a natural (stable) situation, the natural processes removing CO_2 from the atmosphere (to the oceans and biosphere) are in equilibrium with those processes that add CO_2 to atmosphere, averaged over long time scales. The historical and current anthropogenic emissions, combined with observed increases of CO_2 concentrations in the atmosphere, imply that currently such equilibrium does not exist: the additional CO_2 emissions from combustion of fossil fuels, industrial processes and land-use change together add more CO_2 to the atmosphere than is removed by the natural flows. As a consequence, the CO_2 concentration in the atmosphere is increasing rapidly. This situation also temporarily enhances the natural CO_2 removal rates from the atmosphere to the biosphere and ocean. It should be noted that in the future the enhanced removal is uncertain: the global warming and ocean acidification impacts associated with increased CO_2 concentration may also destabilize the ability of natural processes to remove CO_2 from the atmosphere. For example, a warming ocean surface leads to outgassing of CO_2 back into the atmosphere, thereby offsetting the initially increased ocean uptake as a result of rising atmospheric concentrations. In order to stabilize CO_2 concentrations, the anthropogenic and natural emissions combined need to return to a level equal to the current (enhanced) natural removal rate. By the end of the 21st century this could still be in the order of a few $GtCO_2$ per year. In the long-run, however, the storage of CO_2 in oceans and biosphere will return to equilibrium with the atmosphere reducing the net natural removal over the natural emissions back to zero. Due to the slow removal from the atmosphere of a large fraction of CO_2 emissions, any level of concentration stabilization requires a reduction to (near) zero CO_2 emissions (see also Weaver and Zickfeld 2007). To first order, a later reduction to zero that results in higher cumulative emissions leads to concentrations stabilizing at a higher level. Overshoot scenarios that aim to profit somewhat from increased short-term emission levels should have emissions below the net natural removal rate. These scenarios critically depend on low (often negative) emissions in the second half of the 21st century in order to return to low concentration levels fast enough.

Table 2. 2°C target probability estimates using cumulative emissions tool (Meinshausen et al. 2009) based on total CO_2 emissions (including from land use). Numbers in brackets are fossil-fuel CO_2 emissions from energy and industry only.

Scenario	Total CO_2 emissions budget 2000-2049 ($GtCO_2$)	"Illustrative" probability to hold warming below 2°C in the 21st century
IEA 6DS	2060 (~1900)	11%
IEA 4DS	1810 (~1670)	22%
IEA 2DS	1400 (~1260)	53%
RCP8.5	2500	2%
RCP6	1810	22%
RCP4.5	1910	16%
RCP3PD	1430	50%

Table 3. Budget of Fossil-fuel CO_2 emissions from energy and industry for meeting the 2°C target (median values with 20-80 percentile range between brackets).

target	**P(<2°C) >50% <66% (35 scenarios)**	**P(<2°C) >66% (60 scenarios)**
Fossil-fuel CO_2 budget 2000-2049 ($GtCO_2$)	1350 (1250 - 1450)	1250 (1150 - 1350)
Fossil-fuel CO_2 budget 2000-2100 ($GtCO_2$)	1750 (1500 - 2200)	1350 (1300 - 1700)

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