Early Action on Paris Agreement Allows for More Time to Change Energy Systems

Climatic Change – Supplementary Information

Heleen L. van Soest[a,b]*, Harmen Sytze de Boer[a,b], Mark Roelfsema[a], Michel G.J. den Elzen[a], Annemiek Admiraal[a], Detlef P. van Vuuren[a,b], Andries F. Hof[a,b], Maarten van den Berg[a,b], Mathijs J.H.M. Harmsen[a,b], David E.H.J. Gernaat[a,b], Nicklas Forsell[c]

[a] PBL Netherlands Environmental Assessment Agency, P.O. Box 30314, 2500 GH The Hague, The Netherlands

[b] Copernicus Institute of Sustainable Development, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht, The Netherlands

[c] International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria

* Corresponding author:

Heleen van Soest

E-mail: Heleen.vanSoest@pbl.nl

Supplementary text to section 2.1

LULUCF emissions

To construct the final emission projections including emissions from LULUCF, IIASA provided the MAC curves for land use CO_2 emissions, using G4M (Böttcher et al., 2011; Kindermann et al., 2008), differentiating between activities (deforestation, afforestation, and forest management), as well as sources (biomass, soil, and dead organic matter). Only the activities deforestation and afforestation were considered in the final estimates of land use CO_2 emissions, and only emissions and removals related to biomass were incorporated. For most countries, IIASA's business-as-usual projections for this combination of activities and sources were used in the current policies scenario, after harmonisation to FAO (FAOSTAT, 2015). For some countries, updated projections to include current policies from den Elzen et al. (2015) and historical emissions from national communications were used instead. For the 2.8 W/m^2 scenarios, carbon prices resulting from FAIR projections were used to derive the additional reductions of land use CO_2 emissions in G4M. These additional LULUCF CO_2 emission reductions were subtracted from the harmonised BAU projections. In countries where further emission reductions would still be possible according to the *enhanced policy (bottom-up)* scenario as reported by den Elzen et al. (2015), these projections for LULUCF emissions were used instead (Turkey, Mexico, and India). The optimisation in FAIR was done with IMAGE land LULUCF emission pathways reflecting the expected effect of current policies and (I)NDCs on LULUCF emissions. Optimisation focused on energy and industry emissions, given uncertainties in land use emissions, but in the optimisation, an IMAGE land use emissions pathway consistent with 2°C and abatement costs including land use effects (more biomass use) was used. The IMAGE land LULUCF emission pathways started from higher 2010 emission levels (based on IPCC AR5) than the IIASA projections, but showed similar trends between 2010 and 2050. Differences in 2010 emission levels are largely explainable by different definitions of emissions and removals (Grassi and Dentener, 2015). The IMAGE land LULUCF CO_2 emissions were replaced by G4M emission levels after the optimisation. Increased biomass utilisation did not have a feedback on the LULUCF emissions and removals. Overall biomass utilisation in the 2.8 W/m^2 scenarios (Fig. 3) was in line with G4M biomass potentials.

Data sources

The main data sources behind the IMAGE model, relevant for this study, are:

- SSP economic projections from OECD (Dellink et al., in press)
- IEA Statistics and Data (IEA, 2015)
- Enerdata Global Energy & CO_2 Data (Enerdata, 2016)
- Survey of Energy Resources (World Energy Council, 2010)
- The future of nuclear power - an interdisciplinary MIT study (MIT, 2003)
- The potential role of hydrogen in energy systems with and without climate policy (van Ruijven et al., 2007)
- Power and heat productions: plant developments and grid losses (Hendriks et al., 2004)
- Assessment of the global fossil fuel reserves and resources for TIMER (Mulders et al., 2006)
- Future bio-energy potential under various natural constraints (van Vuuren et al., 2009)
- On the global and regional potential of renewable energy sources (Hoogwijk, 2004)

Table S.1 Overview of current policies and the reduction targets under 2020 pledges and 2025/2030 NDCs implemented in the scenarios. Assumptions on the achievement of 2020 pledges and inclusion of countries' pledges and NDCs within a model region are italicised

IMAGE region	Current policies	2020 pledge	2025 NDC	2030 NDC
Brazil	Forest code for the Amazon; renewable energy targets	36% - 39% below national BAU	37% below 2005	43% below 2005 (indicative target)
Canada	Fuel standard for light-duty vehicles and heavy-duty trucks; power plant standard	17% below 2005 *(12% from domestic action: current policies)**		30% below 2005, excl. LULUCF
China	15% share of non-fossil fuels; renewable capacity targets for 2020 and 2030; CAFE standard (5 l/100 km by 2020); 10% ethanol blending mandate in selected provinces; subsidies for electric vehicles; forest area and stock volume increase	CO_2 /GDP -40–45% vs. 2005; 15% share of non-fossil fuel in primary energy consumption; increased forest coverage / stock volume		Peak CO_2 emissions around 2030; CO_2/GDP -60%-65% vs. 2005; 20% share of non-fossil fuels; increase forest stock volume
Eastern Africa	N.A.	N.A.		Ethiopia: 64% below BAU (conditional) Kenya: 30% below BAU (conditional) *SSP2 BAU minus effect of Ethiopia and Kenya NDCs*
India	Renewable energy targets (incl. 40% renewables in total power capacity by 2030); PAT scheme (reduce industrial energy consumption); Green India Mission (GIM).	GHG/GDP (except agriculture) -20–25% vs. 2005; 15% share of RES in electricity supply; wind and solar capacity targets		GHG/GDP -35%; 40% renewable energy in total power capacity; additional carbon sink of 2.5 to 3 Mt CO_2e (forest cover)
Indonesia	Renewable energy target; 15% biofuels in transportation by 2025; Forestry/agriculture/peatland policies	26% below national BAU		29% (unconditional) – 41% (conditional) below BAU
Japan	13.5% renewable electricity by 2020, 20% by 2030; Transport: 16.8 km/l by 2015, 20.3 km/l by 2020	3.8% below 2005; 38 GW wind, 20 GW solar, 14 GW solar thermal capacity		25.4% below 2005 (excl. LULUCF); 20-22% nuclear, 22-24% renewables
Kazakhstan region	*2020 pledge + continuation of 2010-2020 trend toward 2030*	15% below 1992		15% below 1990
Korea (South Korea (SK) and North Korea)	SK: Renewable energy target; ETS (30% reduction below baseline by 2020)	SK: 30% below national BAU *(Korea region: policies leading to 3% above 2010 by 2020)* *		SK: 37% below BAU
Mekong region (incl. Singapore (SP))	N.A.	SP: 16% below BAU		SP: emission intensity 36% below 2005 *SSP2 BAU minus effect of Singapore pledge and NDC*
Mexico	Renewable electricity targets (Special Renewable Energy Programme); zero net emissions from land use change by 2020;	30% below national BAU *(current policies, leading to 9.5% above 2010 (excl. LULUCF) by 2020)* *		GHG incl. LULUCF -22% (unconditional) below national BAU (-36% conditional)
Middle East (including Israel, Jordan)	N.A.	Israel: 20% below BAU		Israel: 26% below 2005 Jordan: 1.5% below BAU (conditional: 14%) *SSP2 BAU minus effect of Israel pledge and Jordan NDC*

Northern Africa	N.A.	N.A.		Morocco: 13% below BAU (conditional: 32%) *SSP2 BAU minus effect of Morocco NDC*
Oceania (Australia (AUS), New Zealand (NZ))	AUS: RES target (20% share in electricity supply); close 2000 MW brown-coal-fired power plants (replaced by gas); NZ: Not analysed	AUS: 5%-25% below 2000 *(policies leading to 5% below 2000 by 2020)* NZ: 10-20% below 1990		AUS: 26-28% below 2005 NZ: 30% below 2005.
Rest Central America	N.A.	Costa Rica: -16 Mt relative to BAU *SSP2 BAU minus effect of Costa Rica pledge*		
Rest South America	N.A.	Chile: -30 Mt relative to BAU		Colombia: 20% below BAU (conditional: 30%) Peru: 20% below BAU (conditional: 30%) *SSP2 BAU minus effect of Chile pledge and Colombia and Peru NDCs*
Rest Southern Africa	N.A.	N.A.		BAU
Russian Federation	2.5% to 4.5% renewable energy in the power sector by 2020	15-25% below 1990; 5% RES in electricity supply		25-30% below 1990
South Africa	RES capacity target (25 GW 2030);	34% - 42% below national BAU *(policies leading to 19% above 2010 by 2020)**; RES capacity target	Peak, Plateau and Decline scenario: 398 – 614 $MtCO_2eq$	Peak, Plateau and Decline scenario: 398 – 614 $MtCO_2eq$
Southern Asia	N.A.	N.A.		BAU
Turkey	*Current policies scenario + continuation of 2010-2020 trend toward 2030*	N.A.		21% below BAU
Ukraine region	N.A.	20% below 1990		40% below 1990
United States	Light-duty vehicles and heavy-duty trucks efficiency standards; biofuels in transport; 16% REN in electricity supply by 2020; carbon tax to realise 30% emission reduction in power sector between 2005 and 2030	17% below 2005; standards in transport, 14% share of RES in electricity supply	26-28% below 2005 (average 27%). Incl. LULUCF.	36-38% (linear interpolation to long-term target of -83% by 2050)
Western Africa	N.A.	N.A.	Congo: 48% below BAU (conditional)	Congo: 55% below BAU by 2035 *SSP2 BAU minus effect of Congo NDC*
Western + Central Europe	Fuel standard for new vehicles (95 g CO_2/km)	20% below 1990, 30% conditional *(current policies, leading to 25% below 1990 by 2020)*		40% below 1990 (excl. LULUCF)

* *For the NDC scenarios, we assumed partial implementation of the 2020 pledge.*

Table S.2 Share of renewable energy sources and nuclear in primary energy use and in electricity production in 2030 and 2050, under the current policies scenario and the 2.8 W/m^2 scenarios (*2.8 W/m^2-NDC, 2.8 W/m^2-NDC bridge,* and *2.8 W/m^2- 2020 action*)

Share of renewables (including biomass) and nuclear in *primary energy use*	**Current policies**	**2.8 W/m^2-NDC**	**2.8 W/m^2-NDC bridge**	**2.8 W/m^2-2020 action**
2030	18.5%	23.3%	26.4%	26.5%
2050	19.5%	46.7%	50.0%	50.7%
Share of renewables (including biomass) and nuclear in *electricity production*	**Current policies**	**2.8 W/m^2-NDC**	**2.8 W/m^2-NDC bridge**	**2.8 W/m^2-2020 action**
2030	39.7%	50.7%	57.8%	57.1%
2050	37.4%	81.7%	82.0%	83.1%

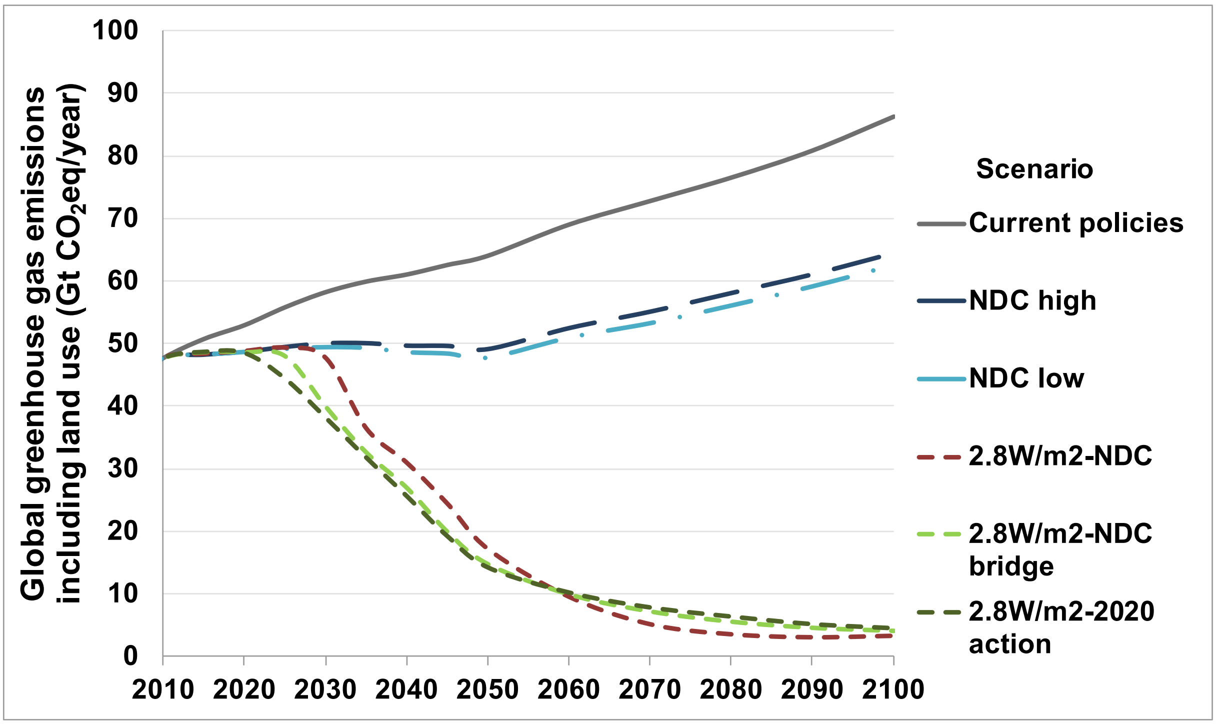

Fig. S.1 Global GHG emissions (Gt CO_2eq/year) between 2010 and 2100, including CO_2 emissions from land use, under the current policies scenario (solid line), *NDC high* and *NDC low* (long dashed lines), and the 2.8 W/m^2 scenarios (*2.8 W/m^2-NDC*, *2.8 W/m^2-NDC bridge* and *2.8 W/m^2-2020 action*; short dashed lines)

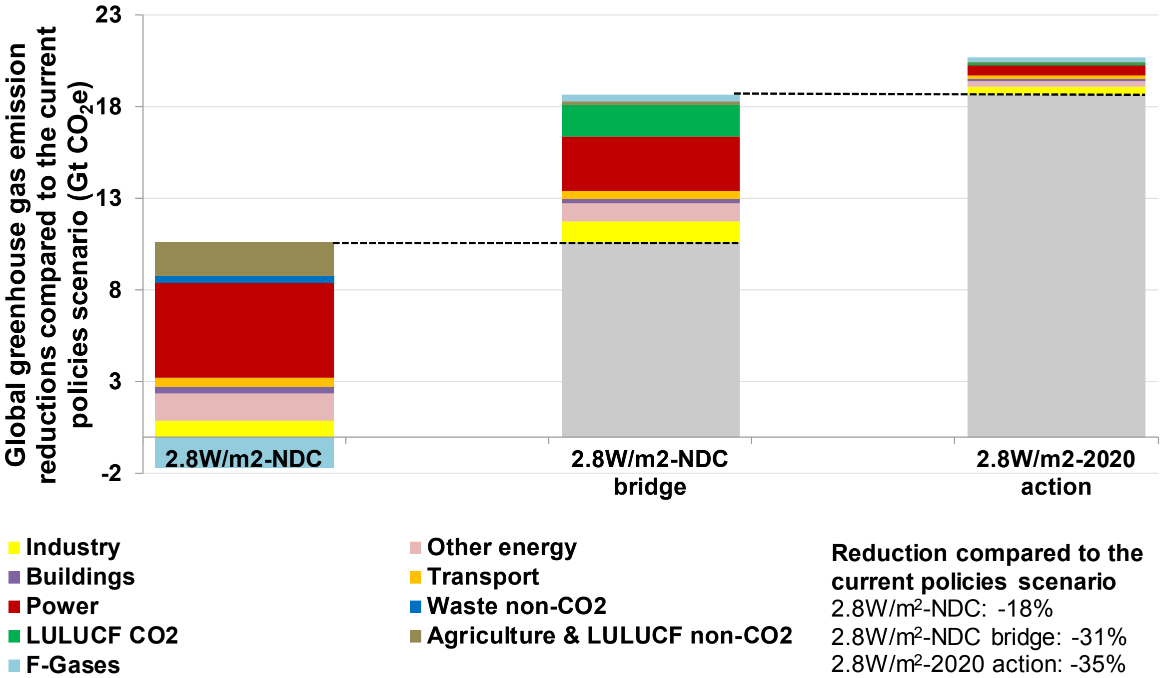

Fig. S.2 Differences in sectoral contributions to global emissions between the current policies scenario and 2.8 W/m^2 scenarios (*2.8 W/m^2-NDC*, *2.8 W/m^2-NDC bridge*, and *2.8W/m^2-2020 action*), 2030. Positive numbers indicate emission reductions in 2030, relative to the current policies scenario

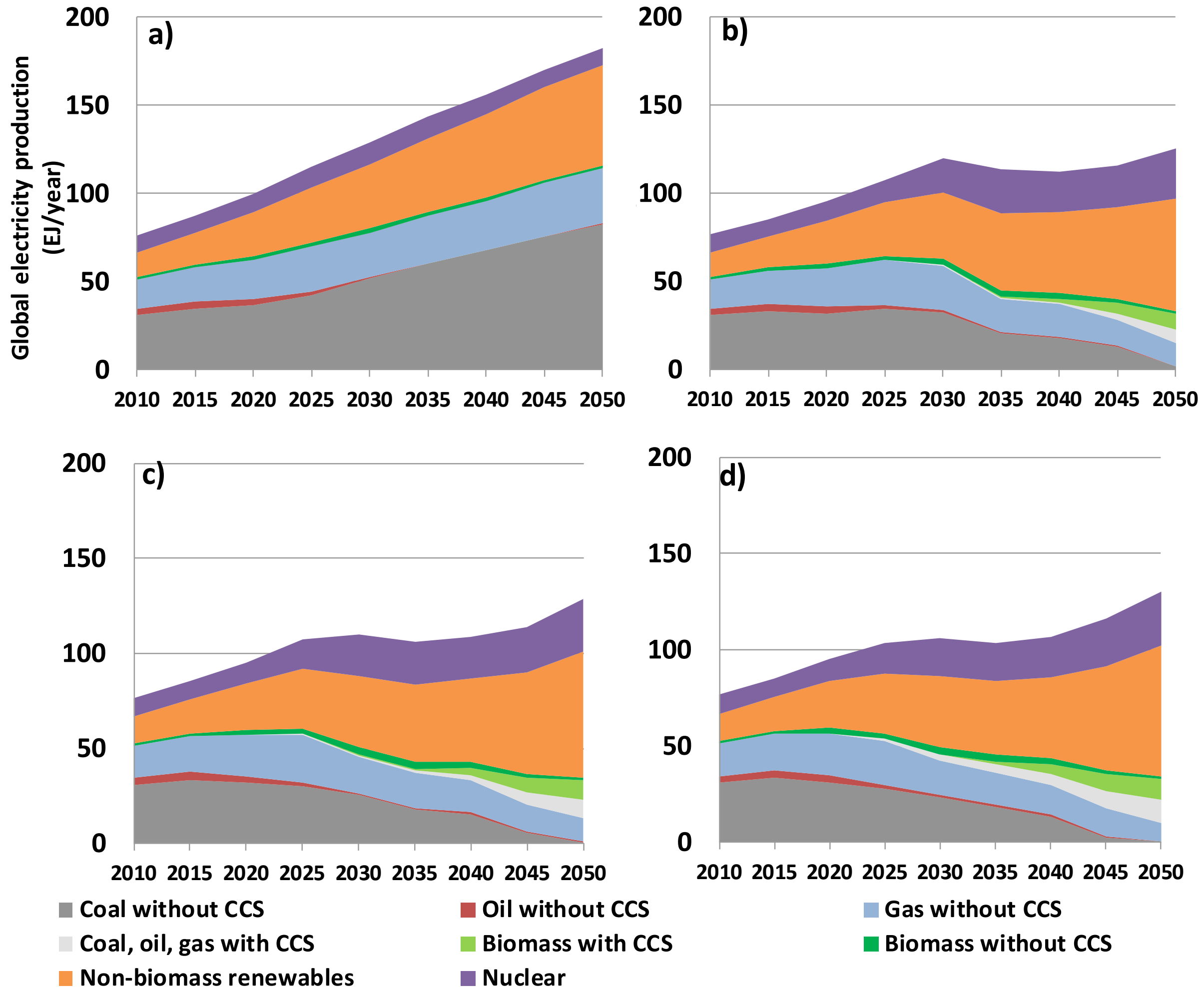

Fig. S.3 Global electricity production (EJ/year) between 2010 and 2050, per source, in the current policies scenario (a), *2.8 W/m²-NDC* scenario (b), *2.8 W/m²-NDC bridge* scenario (c), and *2.8 W/m²-2020 action* scenario (d)

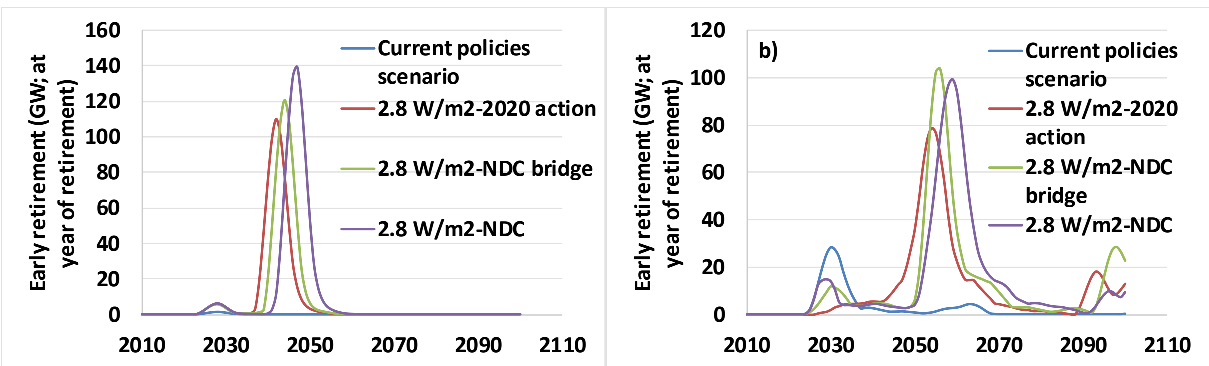

Fig. S.4 Early retirement (GW) at year of retirement for a) unabated coal-fired power plants and b) natural gas fired power plants, for the current policies scenario and 2.8 W/m² scenarios (*2.8 W/m²-NDC*, *2.8 W/m²-NDC bridge*, and *2.8W/m²-2020 action*)

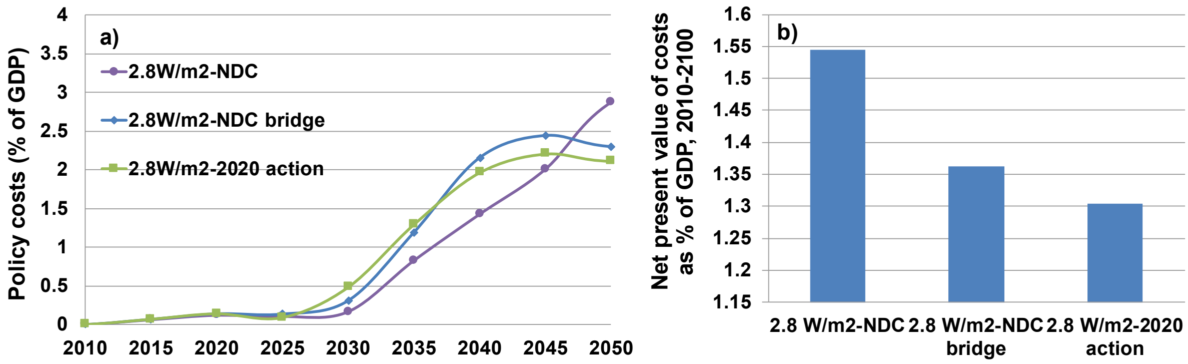

Fig. S.5 Global abatement costs (determined as area under MAC curve) of 2.8 W/m^2 scenarios relative to GDP, between 2010 and 2050 (a), and net present value of costs as % of GDP in the 2010–2100 period, with a 5% discount rate (b)

References

Böttcher H, Gusti M, Mosnier A, Havlik P (2011) Global Forestry Emissions Projections and Abatement Costs. Final Report submitted to The Secretary of State of Energy and Climate Change. IIASA. Available at http://www.iiasa.ac.at/publication/more_XO-11-051.php, Laxenburg, Austria.

Dellink R, Chateau J, Lanzi E, Magné B Long-term economic growth projections in the Shared Socioeconomic Pathways (in press). Global Environmental Change

den Elzen MGJ, Fekete H, Admiraal A, Forsell N, Höhne N, Korosuo A, Roelfsema M, van Soest H, Wouters K, Day T, Hagemann M, Hof A, Mosnier A (2015) Enhanced Policy Scenarios for Major Emitting Countries. Analysis of Current and Planned Climate Policies, and Selected Enhanced Mitigation Measures. PBL Netherlands Environmental Assessment Agency, The Hague.

Enerdata (2016) Global Energy & CO_2 Data. http://www.enerdata.net/enerdatauk/knowledge/subscriptions/database/energy-market-data-and-co2-emissions-data.php

FAOSTAT (2015) Emissions - Land Use. http://faostat3.fao.org/download/G2/GF/E, FAOSTAT.

Grassi G, Dentener F (2015) Quantifying the contribution of the Land Use sector to the Paris Climate Agreement. EUR 27561. EC Joint Research Centre. DOI: 10.2788/096422.

Hendriks C, Harmelink M, Burges K, Ransel K (2004) Power and heat productions: plant developments and grid losses. Ecofys, Utrecht.

Hoogwijk M (2004) On the global and regional potential of renewable energy sources, Utrecht University, Utrecht, The Netherlands.

IEA (2015) IEA Statistics and Data. http://www.iea.org/statistics/

Kindermann G, Obersteiner M, Sohngen B, Sathaye J, Andrasko K, Rametsteiner E, Schlamadinger B, Wunder S, Beach R (2008) Global cost estimates of reducing carbon emissions through avoided deforestation. Proceedings of the National Academy of Sciences of the United States of America 105:10302-10307.

MIT (2003) The future of nuclear power - an interdisciplinary MIT study. Massachusetts Institute of Technology, Cambridge, USA.

Mulders FMM, Hettelar JMM, van Bergen F (2006) Assessment of the global fossil fuel reserves and resources for TIMER. TNO Built Environment and Geosciences, Utrecht, The Netherlands.

van Ruijven B, van Vuuren DP, de Vries B (2007) The potential role of hydrogen in energy systems with and without climate policy. International Journal of Hydrogen Energy 32:1655-1672.

van Vuuren DP, van Vliet J, Stehfest E (2009) Future bio-energy potential under various natural constraints. Energy Policy 37:4220-4230.

World Energy Council (2010) 2010 Survey of Energy Resources. World Energy Council, London & https://www.worldenergy.org/data/resources/.