Annex A
Technical background to computations in Chapter 2

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This Annex to Chapter 2 provides technical background to the computations supporting the discussion in section 2.2. In addition, further detail is provided on the use of negative emissions (Box A.1).

A.1 Methodology

Section 2.2 “Global emission pathways and the importance of enhanced action” re-analyzes the IPCC AR5 Scenario Database[1] to extract the characteristics of pathways that limit warming to below 1.5°C or 2°C.

In Figure 2.1 of the underlying report, both baselines and 2°C-consistent pathways are shown, as well as the outcomes in terms of global mean temperature increase. These emission pathways are selected from the IPCC AR5 by applying the steps described in Table A.1.

Note that values reported in the UNEP 2014 Emissions Gap Report for both baselines and 2°C scenarios were based on a preliminary version of the IPCC AR5 Scenario Database. For the 2015 update, all data have been updated to the final release of the IPCC AR5 Scenario Database, available on: https://tntcat.iiasa.ac.at/AR5DB/.

[1] Hosted at the International Institute for Applied Systems Analysis (IIASA) and available online on: https://secure.iiasa.ac.at/web-apps/ene/AR5DB/

Table A.1: Overview selection criteria for scenario subsets discussed in Chapter 2

Scenario subset	**Selection criteria from IPCC AR5 Scenario Database**
Baselines	Policy variable: 'P0' Global Kyoto-GHG data available until 2050
2°C (>66%)	Policy variable: 'P2' 2°C exceedance probability <0.34 during the entire century Exclude scenarios with 'RefPol-450-EE' and 'RefPol-450-PC' labels (as these are merely burden sharing variations from the same global pathway described in 'RefPol-450')
2°C (>66% in 2100)	Policy variable: 'P2' 2°C exceedance probability <0.34 in 2100 Exclude scenarios with 'RefPol-450-EE' and 'RefPol-450-PC' labels (as these are merely burden sharing variations from the same global pathway described in 'RefPol-450')
2°C (50-66%)	Policy variable: 'P2' 2°C exceedance probability ≥ 0.34 and 2°C exceedance probability < 0.5 during the entire century Exclude scenarios with 'RefPol-450-EE' and 'RefPol-450-PC' labels (as these are merely burden sharing variations from the same global pathway described in 'RefPol-450')
2°C (>66% in 2100)	Policy variable: 'P2' 2°C exceedance probability ≥ 0.34 and 2°C exceedance probability < 0.5 in 2100 Exclude scenarios with 'RefPol-450-EE' and 'RefPol-450-PC' labels (as these are merely burden sharing variations from the same global pathway described in 'RefPol-450')
1.5°C (>50% in 2100)	From study on 1.5°C scenarios: Rogelj *et al.* (2015)
2030 emission ranges consistent with keeping warming to below a given temperature limit with >66% probability until 2100 (Chapter 3)	Based on emissions pathways assessed in earlier UNEP emissions gap reports and described in the literature (Joeri *et al.*, 2011).

A.2 Supplementary tables

Table A.2: Overview of pathway characteristics of 1.5°C and 2°C scenarios based on a re-analysis of the IPCC AR5 Scenario Database and a recent study on 1.5°C scenarios (see Joeri *et al.* (2015)). All scenarios have prescribed 2020 emissions, consistent with the GHG pledges made by Parties in Cancun in 2010, and hence do not represent least-cost emission levels until then. Variations in 2020 emissions levels between scenario sets are due to sampling of available model runs. All available scenarios with limited action until 2020 rely on net negative CO_2 emissions from energy and industry during the 21st century

Limiting warming in 2100 (allowing for overshoot)					
1.5°C (>50% in 2100)	**Pathways limiting warming to below 1.5°C by 2100 with >50% chance Limited action until 2020 and least-cost mitigation afterwards**				
Number of available scenarios: **6;** Number of contributing modelling frameworks: **2** Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **(2060-2080);** total CO_2 (including LULUCF): **(2045-2050);** CO_2 from energy and industry: **(2045-2055)**					
	Annual emissions of global total greenhouse gases [$GtCO_2e/yr$]				
Year	2020	2025	2030	2050	2100
median*	**56**	**47**	**39**	**8**	**-5**
range and spread**	53(-/-)56	46(-/-)48	37(-/-)40	4(-/-)14	-5(-/-)-3
2°C (>66%)	**Pathways limiting warming to below 2°C during the 21st century with >66% chance Limited action until 2020 and least-cost mitigation afterwards**				
Number of available scenarios: **6;** Number of contributing modelling frameworks: **3** Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **(2080-2090);** total CO_2 (including LULUCF): **(2055-2075);** CO_2 from energy and industry: **(2055-2080)**					
	Annual emissions of global total greenhouse gases [$GtCO_2e/yr$]				
Year	2020	2025	2030	2050	2100
median*	**52**	**48**	**37**	**23**	**-5**
range and spread**	49(-/-)55	44(-/-)51	29(-/-)44	17(-/-)29	-11(-/-)0
2°C (>66% in 2100)	**Pathways limiting warming to below 2°C by 2100 with >66% chance Limited action until 2020 and least-cost mitigation afterwards**				
Number of available scenarios: **10;** Number of contributing modelling frameworks: **4** Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **2085 (2080-2090);** total CO_2 (including LULUCF): **2070 (2060-2075);** CO_2 from energy and industry: **2070 (2060-2075)**					
	Annual emissions of global total greenhouse gases [$GtCO_2e/yr$]				
Year	2020	2025	2030	2050	2100
median*	**52**	**48**	**42**	**23**	**-3**
range and spread**	49(49/53)55	44(46/50)53	29(31/44)44	17(18/27)29	-11(-9/-1)0
2°C (50-66%)	**Pathways limiting warming to below 2°C during the 21st century with 50-66% chance Limited action until 2020 and least-cost mitigation afterwards**				
Number of available scenarios: **6;** Number of contributing modelling frameworks: **4** Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **(2085-2095);** total CO_2 (including LULUCF): **(2060-2075);** CO_2 from energy and industry: **(2065-2080)**					
	Annual emissions of global total greenhouse gases [$GtCO_2e/yr$]				
Year	2020	2025	2030	2050	2100
median*	**53**	**49**	**43**	**26**	**-2**
range and spread**	49(-/-)55	46(-/-)53	33(-/-)47	19(-/-)29	-8(-/-)0
2°C (50-66% in 2100)	**Pathways limiting warming to below 2°C by 2100 with 50-66% chance Limited action until 2020 and least-cost mitigation afterwards**				
Number of available scenarios: **4;** Number of contributing modelling frameworks: **2** Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **(2095-2095);** total CO_2 (including LULUCF): **(2065-2070);** CO_2 from energy and industry: **(2070-2080)**					
	Annual emissions of global total greenhouse gases [$GtCO_2e/yr$]				
Year	2020	2025	2030	2050	2100
median*	**53**	**50**	**47**	**28**	**-1**
range and spread**	50(-/-)55	49(-/-)51	46(-/-)48	27(-/-)29	-2(-/-)-1
† Rounded to nearest 5 years. Explanation of format: 'median (20th percentile – 80th percentile)' – for example, '2085 (2080-2090)'; no median is provided if fewer than 10 scenarios are available '(minimum-maximum)' – for example, '(2060-2080)' * Rounded to the nearest 1 $GtCO_2e/yr$ ** Rounded to the nearest 1 $GtCO_2e/yr$. Explanation of format: 'minimum value (20th percentile/80th percentile) maximum value' – for example, '44(46/50)53'. No percentiles are provided if fewer than 10 scenarios are available – for example, '46(-/-)48'.					

Table A.3: Overview model-scenario combinations per category described in Table A.1 that were drawn from the IPCC AR5 Scenario Database: *Baselines*

Baselines	
Model name	**Scenario name**
AIM-Enduse 12.1	EMF27-Base-Conv
AIM-Enduse 12.1	EMF27-Base-EERE
AIM-Enduse 12.1	EMF27-Base-FullTech
AIM-Enduse 12.1	EMF27-Base-LimBio
AIM-Enduse 12.1	EMF27-Base-LimSW
AIM-Enduse 12.1	EMF27-Base-LimTech
AIM-Enduse 12.1	EMF27-Base-LowEI
AIM-Enduse 12.1	EMF27-Base-NucOff
AIM-Enduse[Backcast] 1.0	LIMITS-Base
DNE21 V.11	AME Reference
DNE21 V.12	AMPERE2-Base-FullTech-OPT
DNE21 V.12	AMPERE2-Base-LowEI-OPT
DNE21 V.12	AMPERE2-Base-NucOff-OPT
DNE21 V.12	AMPERE3-Base
EC-IAM 2012	EMF27-Base-Conv
EC-IAM 2012	EMF27-Base-EERE
EC-IAM 2012	EMF27-Base-FullTech
EC-IAM 2012	EMF27-Base-LimBio
EC-IAM 2012	EMF27-Base-LimSW
EC-IAM 2012	EMF27-Base-LimTech
EC-IAM 2012	EMF27-Base-LowEI
EC-IAM 2012	EMF27-Base-NucOff
ENV-Linkages (WEO2012 calibration)	EMF27-Base-Conv
ENV-Linkages (WEO2012 calibration)	EMF27-Base-FullTech
ENV-Linkages (WEO2012 calibration)	EMF27-Base-LimBio
ENV-Linkages (WEO2012 calibration)	EMF27-Base-LimSW
ENV-Linkages (WEO2012 calibration)	EMF27-Base-NucOff
GCAM 2.0	AME Reference
GCAM 3.0	AMPERE2-Base-Conv-OPT
GCAM 3.0	AMPERE2-Base-EERE-OPT
GCAM 3.0	AMPERE2-Base-FullTech-OPT
GCAM 3.0	AMPERE2-Base-LimBio-OPT
GCAM 3.0	AMPERE2-Base-LimSW-OPT
GCAM 3.0	AMPERE2-Base-LowEI-OPT
GCAM 3.0	AMPERE2-Base-NucOff-OPT
GCAM 3.0	AMPERE3-Base
GCAM 3.0	AMPERE3-Base-EUback
GCAM 3.0	EMF27-Base-Conv
GCAM 3.0	EMF27-Base-EERE
GCAM 3.0	EMF27-Base-FullTech
GCAM 3.0	EMF27-Base-LimBio
GCAM 3.0	EMF27-Base-LimSW
GCAM 3.0	EMF27-Base-LimTech
GCAM 3.0	EMF27-Base-LowEI
GCAM 3.0	EMF27-Base-NucOff
GCAM 3.0	ROSE BAU DEF
GCAM 3.0	ROSE BAU FS Gr
GCAM 3.0	ROSE BAU HI Coal
GCAM 3.0	ROSE BAU HI Fos
GCAM 3.0	ROSE BAU HI Gas
GCAM 3.0	ROSE BAU HI Pop
GCAM 3.0	ROSE BAU LO Fos
GCAM 3.0	ROSE BAU LO Oil
GCAM 3.0	ROSE BAU SL Gr
GCAM 3.1	LIMITS-Base

Baselines	
Model name	**Scenario name**
GEM-E3-ICCS	AMPERE3-Base
GEM-E3-ICCS	AMPERE3-Base-EUback
GRAPE ver2011	EMF27-Base-Conv
GRAPE ver2011	EMF27-Base-EERE
GRAPE ver2011	EMF27-Base-FullTech
GRAPE ver2011	EMF27-Base-LimBio
GRAPE ver2011	EMF27-Base-LowEI
GRAPE_ver1998	AME Reference
GTEMREF32	AME Reference
IMAGE 2.4	AME Reference
IMAGE 2.4	AMPERE2-Base-Conv-OPT
IMAGE 2.4	AMPERE2-Base-EERE-OPT
IMAGE 2.4	AMPERE2-Base-FullTech-OPT
IMAGE 2.4	AMPERE2-Base-LimBio-OPT
IMAGE 2.4	AMPERE2-Base-LimSW-OPT
IMAGE 2.4	AMPERE2-Base-LowEI-OPT
IMAGE 2.4	AMPERE2-Base-NucOff-OPT
IMAGE 2.4	AMPERE3-Base
IMAGE 2.4	EMF27-Base-Conv
IMAGE 2.4	EMF27-Base-EERE
IMAGE 2.4	EMF27-Base-FullTech
IMAGE 2.4	EMF27-Base-LimBio
IMAGE 2.4	EMF27-Base-LimSW
IMAGE 2.4	EMF27-Base-LimTech
IMAGE 2.4	EMF27-Base-LowEI
IMAGE 2.4	EMF27-Base-NucOff
IMAGE 2.4	LIMITS-Base
IMAGE 2.4 EMF22	EMF22 Reference
MERGE-ETL_2011	AMPERE2-Base-Conv-OPT
MERGE-ETL_2011	AMPERE2-Base-EERE-OPT
MERGE-ETL_2011	AMPERE2-Base-FullTech-OPT
MERGE-ETL_2011	AMPERE2-Base-LimBio-OPT
MERGE-ETL_2011	AMPERE2-Base-LimSW-OPT
MERGE-ETL_2011	AMPERE2-Base-LowEI-OPT
MERGE-ETL_2011	AMPERE2-Base-NucOff-OPT
MERGE-ETL_2011	AMPERE3-Base
MERGE-ETL_2011	AMPERE3-Base-EU
MERGE-ETL_2011	AMPERE3-Base-EUback
MERGE_AME	AME Reference
MERGE_EMF22	EMF22 Reference
MERGE_EMF22	EMF22 Reference Pessimistic Growth
MERGE_EMF27	EMF27-Base-Conv
MERGE_EMF27	EMF27-Base-EERE
MERGE_EMF27	EMF27-Base-FullTech
MERGE_EMF27	EMF27-Base-LimBio
MERGE_EMF27	EMF27-Base-LimSW
MERGE_EMF27	EMF27-Base-LimTech
MERGE_EMF27	EMF27-Base-LowEI
MERGE_EMF27	EMF27-Base-NucOff
MESSAGE V.1	EMF22 Reference
MESSAGE V.2	RCP 8.5
MESSAGE V.3	AME Reference
MESSAGE V.3	GEA Counterfactual
MESSAGE V.4	AMPERE2-Base-Conv-OPT
MESSAGE V.4	AMPERE2-Base-EERE-OPT
MESSAGE V.4	AMPERE2-Base-FullTech-OPT
MESSAGE V.4	AMPERE2-Base-LimBio-OPT
MESSAGE V.4	AMPERE2-Base-LimSW-OPT

Baselines	
Model name	**Scenario name**
MESSAGE V.4	AMPERE2-Base-LowEI-OPT
MESSAGE V.4	AMPERE2-Base-NucOff-OPT
MESSAGE V.4	AMPERE3-Base
MESSAGE V.4	EMF27-Base-Conv
MESSAGE V.4	EMF27-Base-EERE
MESSAGE V.4	EMF27-Base-FullTech
MESSAGE V.4	EMF27-Base-LimBio
MESSAGE V.4	EMF27-Base-LimSW
MESSAGE V.4	EMF27-Base-LimTech
MESSAGE V.4	EMF27-Base-LowEI
MESSAGE V.4	EMF27-Base-NucOff
MESSAGE V.4	LIMITS-Base
MiniCAM_EMF22	EMF22 Reference
REMIND 1.5	AMPERE2-Base-Conv-OPT
REMIND 1.5	AMPERE2-Base-EERE-OPT
REMIND 1.5	AMPERE2-Base-FullTech-OPT
REMIND 1.5	AMPERE2-Base-LimBio-OPT
REMIND 1.5	AMPERE2-Base-LimSW-OPT
REMIND 1.5	AMPERE2-Base-LowEI-OPT
REMIND 1.5	AMPERE2-Base-NucOff-OPT
REMIND 1.5	AMPERE3-Base
REMIND 1.5	AMPERE3-Base-EU
REMIND 1.5	AMPERE3-Base-EUback
REMIND 1.5	EMF27-Base-Conv
REMIND 1.5	EMF27-Base-EERE
REMIND 1.5	EMF27-Base-FullTech
REMIND 1.5	EMF27-Base-LimBio
REMIND 1.5	EMF27-Base-LimSW
REMIND 1.5	EMF27-Base-LimTech
REMIND 1.5	EMF27-Base-LowEI
REMIND 1.5	EMF27-Base-NucOff
REMIND 1.5	LIMITS-Base
SGM_EMF22	EMF22 Reference
TIAM-ECN	LIMITS-Base
TIAM-World_2007_version	EMF22 Reference
TIAM-World_Mar2012	AME Reference
TIMES-VTT-2011	AME Reference
WITCH_AME	AME Reference
WITCH_AMPERE	AMPERE2-Base-FullTech-OPT
WITCH_AMPERE	AMPERE2-Base-LowEI-OPT
WITCH_AMPERE	AMPERE2-Base-NucOff-OPT
WITCH_AMPERE	AMPERE3-Base
WITCH_AMPERE	AMPERE3-Base-EU
WITCH_AMPERE	AMPERE3-Base-EUback
WITCH_EMF22	EMF22 Reference
WITCH_EMF27	EMF27-Base-Conv
WITCH_EMF27	EMF27-Base-EERE
WITCH_EMF27	EMF27-Base-FullTech
WITCH_EMF27	EMF27-Base-LimBio
WITCH_EMF27	EMF27-Base-LimSW
WITCH_EMF27	EMF27-Base-LimTech
WITCH_EMF27	EMF27-Base-LowEI
WITCH_EMF27	EMF27-Base-NucOff
WITCH_LIMITS	LIMITS-Base
WITCH_ROSE	ROSE BAU DEF
WITCH_ROSE	ROSE BAU FS Gr
WITCH_ROSE	ROSE BAU FS Gr SL Con
WITCH_ROSE	ROSE BAU HI Coal

Baselines	
Model name	**Scenario name**
WITCH_ROSE	ROSE BAU HI Fos
WITCH_ROSE	ROSE BAU HI Gas
WITCH_ROSE	ROSE BAU HI Pop
WITCH_ROSE	ROSE BAU LO Fos
WITCH_ROSE	ROSE BAU LO Oil
WITCH_ROSE	ROSE BAU LO Oil HI Gas
WITCH_ROSE	ROSE BAU SL Gr
WITCH_ROSE	ROSE BAU SL Gr SL Con

Table A.4: Overview model-scenario combinations per category described in Table A.1 that were drawn from the IPCC AR5 Scenario Database: *Scenarios limiting warming to below 2°C during the entire 21st century with >66% chance*

2°C (>66%)	
Model name	**Scenario name**
GCAM 3.1	LIMITS-RefPol-450
GCAM 3.1	LIMITS-StrPol-450
GCAM 3.1	LIMITS-StrPol-500
IMAGE 2.4	LIMITS-RefPol-450
REMIND 1.5	LIMITS-RefPol-450
REMIND 1.5	LIMITS-StrPol-450

Table A.5: Overview model-scenario combinations per category described in Table A.1 that were drawn from the IPCC AR5 Scenario Database: *Scenarios limiting warming to below 2°C with >66% chance in 2100*

2°C (>66% in 2100)	
Model name	**Scenario name**
GCAM 3.1	LIMITS-RefPol-450
GCAM 3.1	LIMITS-RefPol-500
GCAM 3.1	LIMITS-StrPol-450
GCAM 3.1	LIMITS-StrPol-500
IMAGE 2.4	LIMITS-RefPol-450
IMAGE 2.4	LIMITS-StrPol-450
MESSAGE V.4	LIMITS-RefPol-450
MESSAGE V.4	LIMITS-StrPol-450
REMIND 1.5	LIMITS-RefPol-450
REMIND 1.5	LIMITS-StrPol-450

Table A.6: Overview model-scenario combinations per category described in Table A.1 that were drawn from the IPCC AR5 Scenario Database: *Scenarios limiting warming to below 2°C during the entire 21st century with 50-66% chance*

2°C (50-66%)	
Model name	**Scenario name**
GCAM 3.1	LIMITS-RefPol-500
IMAGE 2.4	LIMITS-StrPol-450
MESSAGE V.4	LIMITS-RefPol-450
MESSAGE V.4	LIMITS-StrPol-450
REMIND 1.5	LIMITS-RefPol-500
REMIND 1.5	LIMITS-StrPol-500

Table A.7: Overview model-scenario combinations per category described in Table A.1 that were drawn from the IPCC AR5 Scenario Database: *Scenarios limiting warming to below 2°C with 50-66% chance in 2100*

2°C (50-66% in 2100)	
Model name	**Scenario name**
MESSAGE V.4	LIMITS-RefPol-500
MESSAGE V.4	LIMITS-StrPol-500
REMIND 1.5	LIMITS-RefPol-500
REMIND 1.5	LIMITS-StrPol-500

Box A.1: Negative emissions

Negative emissions can be achieved by several means, including afforestation or reforestation, carbon storage from active air capture, and the combination of energy from biomass with carbon capture and geological storage (Scott *et al.*, 2015). The latter option is also referred to as BECCS – an option that gained prominence after being introduced about 15 years ago in the scientific literature (Obersteiner *et al.*, 2001) and that has been studied since (see, for example, Azar *et al.*, 2010, Tavoni and Socolow, 2013). Unlike many other proposed negative emissions technologies, BECCS also produces energy. Many integrated scenarios that model a possible transition towards a low-carbon society over the 21st century use important amounts of negative emissions, but its large-scale deployment comes with several issues that require attention.

First, BECCS requires sufficient amounts of sustainable biomass energy. Bioenergy is already used today as a fuel in the global energy system, and in the future it is projected to continue as a key element in the global energy mix (IPCC, 2014a). If not accompanied by appropriate policies and incentives, however, bioenergy use can lead to important adverse side effects such as deforestation or pressure on food prices – the latter becoming more intense if food crops are used for bioenergy production. However, so-called second generation bioenergy can be extracted from a variety of cellulosic feedstock, including dedicated biomass crop as well as forest residues and agricultural waste products. A recent review found that up to 300 EJ of bioenergy per year can be produced sustainably (with 'medium agreement', see Creutzig *et al.*, 2014). While the technical potential for sustainable bioenergy is thus available, its large-scale use will have implications for fertilizer and water use. Only a limited number of studies are currently available on this topic (for example, Lenton, 2010, Smith and Torn, 2013, Vuuren *et al.*, 2013). Further research is thus needed, and policies that mitigate potential adverse side effects are essential.

A second issue is the large-scale integration of BECCS into the energy system. BECCS offers the prospect of energy supply with large-scale net negative emissions, thus playing an important role in many low-stabilization scenarios (IPCC, 2014a). While bioenergy and CCS are technologies which are known today, their large-scale application requires significant investment, both in infrastructure to transport captured CO_2 to long-term storage sites and in research to understand the long-term consequences of storing vast amounts of CO_2.

Finally, there is the issue of geological storage. While storage capacity during this century is not generally considered a limiting factor for BECCS (IPCC, 2005), a recent study shows that it might be a greater constraint than initially assumed (Scott *et al.*, 2015). Questions of public acceptance of large-scale biomass production as well as the deployment of CCS near inhabited areas need to be dealt with and overcome. These public concerns might reduce effective storage availability. Ultimately, BECCS also competes with available storage capacity for CCS from fossil fuels. But importantly only BECCS provides the benefit of both energy generation and CO_2 removal from the atmosphere through negative emissions.

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