AMPERE WP5 study protocol – European decarbonisation pathways

1. Objective and Overview

This model comparison study for the participating models in AMPERE Work Package 5 analyses the role of path dependency in energy systems for mitigation pathways for the EU27 and member states.

Research questions (to be answered from the core set of scenarios):

- What are the implications of the global mitigation pathways for EU27?
- What are the implications of limited technology availability for the EU-27 mitigation costs?
- Does myopia about EU emissions reductions targets lead to lock-ins in the EU energy sector? What are the additional mitigation costs for the EU-27 energy sector in the case of myopic anticipations in the period 2020-2030?
- What are the implications for emission reduction measures of EU27 and individual EU member states?

The core experimental design comprises a sequence of 8 scenarios:

1. The ***Reference Scenario*** for the EU-27 member states
2. The standard ***Decarbonisation scenario*** for the EU-27 with perfect foresight and all technological mitigation options available
3. A series of *Decarbonisation scenarios* for the EU-27 **under technology limitations**
4. A series of *Decarbonisation scenarios* for the EU-27 **under myopic anticipations until 2030 (delayed climate action until 2030 and catch up after 2030 and before 2050)**

2. General information and guidelines:

Input harmonization: All scenarios for Work Package 5 should be run with harmonized population and GDP trajectories up to 2050. Population harmonisation based on the medium fertility variant of the 2010 version of the UN World Population Prospects. GDP harmonisation is based on European Commission projections from 2009 (EU Energy Trends to 2030: Update 2009).

Long-term climate target specification*:* All decarbonisation scenarios are constrained to deliver a cumulative carbon budget in the EU-27 region in the period 2011 to 2050. See Appendix A on the carbon budget and the emission trajectory.

Treatment of climate policy revenues*:* Results of macro-economic models (GEM-E3, NEMESIS, WORLDSCAN) depend on the details of who will receive the revenues from imposing a price on GHG emissions ("GHG tax") and how these revenues will be recycled in the economy. We do not propose to fully harmonize the specifications between the models, and allow each model to select the optimal revenue recycling scheme (in terms of GDP impact), but also follow the guidelines below:

- Revenue recycling schemes should not change between the different WP5 scenario runs for a single model. The comparability of mitigation strategies and associated costs is the priority of these runs.
- When deciding on the revenue recycling scheme, the EU27 mitigation scenarios should reflect the least cost mitigation strategy. This implies that the most efficient revenue recycling schemes should be adopted.

3. Scenario definition

All specifications refer to the time period after 2012. The models should only be allowed to respond to future climate policy (in any model variable) in the first model year (or period) following 2012 and they should reproduce historic emissions until 2010/11. The models will implement energy efficiency and RES supporting policies in the more appropriate way depending on modelling methodology. The macro models should consider simple ways for reflecting assumptions such as transport electrification (e.g. changing technical coefficients), RES, CCS and nuclear phase-out, in case these options are not yet included in detail. The models that are not intertemporal should assume emission restrictions by year which would be consistent with the cumulative carbon budget (the annual emission restrictions must be different for the delayed action scenarios which are assumed to deliver the same carbon budget but in a shorter period of time).

Scenario Label	Scenario Name	Definition
AMPERE5-EU-Ref	EU27 Reference scenario	The EU has established an internal target to reduce overall GHG emissions by 20% from their 1990 levels and to increase RES share in final energy demand to 20% by 2020. The Reference scenario should reflect these policies up to 2020. Beyond 2020, the reference scenario assumes a linear annual reduction of the ETS cap, no additional policies for efficiency and RES (but it may be that measures implemented until 2020 will continue to deliver efficiency and RES facilitation after 2020 without specifying further targets beyond 2020), no electrification of transport and non-ETS emissions remaining not above the cap specified for 2020. See Appendix for ETS and non ETS caps for the Reference scenario. ETS emission targets should be implemented by imposing a CO_2 (equivalent) tax that leads to the achievement of those targets. ***Non-CO_2 gases and other radiative forcing agents:*** Models which consider also non-CO_2 GHGs (N_2O, CH_4, SF_6, CF_4, and long-lived halocarbons) should use the resulting CO_2-price from the cumulative CO_2 budget constraint to price non-CO_2 gases (using 100 year GWPs as provided in IPCC AR4). Emissions of all radiative forcing agents accounted for in the model should be reported. Non EU countries are assumed to implement the low end of Cancun-Copenhagen pledges and no intensification of emission reduction effort after 2020.

AMPERE5-Decarb-AllOptions	EU27 mitigation scenario	The climate change mitigation target should be implemented by imposing the cumulative CO_2 (GHG) emissions budget (see Appendix A). The budget refers to total CO_2 emissions from all sectors, excluding the sector LULUCF. The overall GHG emissions budget should be imposed on top of the climate policies and measures that were implemented in the reference case (scenario *AMPERE5-EU-Ref*) until 2020. A carbon price, ensuring full flexibility of emissions reductions, should be established in both ETS and non-ETS sectors **after 2025**. Foresight models should be free to adopt the intertemporally optimal GHG emissions reduction trajectory. This means that emissions reductions in 2020 might deviate from the 2020 emissions reductions in the reference case. All mitigation options (including transport electrification) are available and optimistic technical progress should be considered regarding the carbon free technologies, especially for RES in power generation. The models should decide on the optimal mix of different mitigation options and technologies, including energy efficiency improvement in all sectors. ***Non-CO_2 gases and other radiative forcing agents:*** Models which consider also non-CO_2 GHGs (N_2O, CH_4, SF_6, CF_4, and long-lived halocarbons), should use the resulting CO_2-price from the cumulative CO_2 budget constraint to price non-CO_2 gases (using 100 year GWPs as provided in IPCC AR4). Non EU countries undertake strong emission reduction effort for achieving 450ppm. Carbon budget for the world as defined in WP3 protocol, i.e. total CO_2 emissions from all sectors including land use should not exceed 1400 Gtn of CO_2 in the period 2000-2050 (for the models that do not include CO_2 emissions from land use the carbon budget for the period 2000-2050 is 1300 Gtn of CO_2). Non-CO_2 GHGs should be priced with the same carbon price as CO_2 emissions.
AMPERE5-HiEFF-HiRES	EU27 mitigation scenario with high energy efficiency gains and high RES penetration	All mitigation options are available (like in the *AMPERE5-Decarb-AllOptions* scenario), but the emphasis should be given to **energy efficiency gains and RES** (wind, solar, hydro, biomass, geothermal, tidal etc) **penetration** in the energy mix. Both they should contribute close to maximum possibilities, but the actual mix is left to be determined by the model. These two options should be facilitated by bottom-up policies (standards, financing, obligations etc.) and technology push. Electrification of the transport sector through the gradual penetration of plug-in and electric vehicles in car stocks should be included as a mitigation option (like in the standard mitigation scenario *AMPERE5-Decarb-AllOptions*). As a result, the deployment of other mitigation options, specifically nuclear power and CCS technologies, should be significantly lower than in the *AMPERE5-Decarb-AllOptions* scenario.

		All other specifications (including the overall carbon budget) are identical to the *AMPERE5-Decarb-AllOptions* scenario. Non EU countries undertake strong emission reduction effort for achieving 450ppm. Carbon budget for the world as defined in WP3 protocol, i.e. total CO_2 emissions from all sectors including land use should not exceed 1400 Gtn of CO_2 in the period 2000-2050 (for the models that do not include CO_2 emissions from land use the carbon budget for the period 2000-2050 is 1300 Gtn of CO_2). Non-CO_2 GHGs should be priced with the same carbon price as CO_2 emissions.
AMPERE5-HiEFF-NoCCS-NoNUKE	EU27 mitigation scenario with high energy efficiency gains, no CCS and nuclear phase out	**No CCS** allowed in all energy sectors (including industrial applications), in all EU member states, and for all combinations with fossil fuels (coal and natural gas) or bioenergy. **Nuclear phase out** is defined as no construction of new nuclear power plants beyond those already under construction or planned. In addition, no lifetime extensions beyond the retirement rate assumed in the models should be implemented. The nuclear phase out concept is driven by public scepticism about nuclear technology. In this scenario **energy efficiency improvements** are considered as the most important option in order to achieve the mitigation target for the EU-27 member states and a series of bottom-up policies and obligations are assumed to be implemented so as to give first priority to energy efficiency. **RES deployment** should be kept moderate (higher but comparable to the *AMPERE5-Decarb-AllOptions* scenario). Electrification of the transport sector through the gradual penetration of plug-in and electric vehicles in car stocks should be included as a mitigation option (like in the *AMPERE5-Decarb-AllOptions* scenario). All other specifications (including the overall carbon budget) are identical to the *AMPERE5-Decarb-AllOptions* scenario. Non EU countries undertake strong emission reduction effort for achieving 450ppm. Carbon budget for the world as defined in WP3 protocol, i.e. total CO_2 emissions from all sectors including land use should not exceed 1400 Gtn of CO_2 in the period 2000-2050 (for the models that do not include CO_2 emissions from land use the carbon budget for the period 2000-2050 is 1300 Gtn of CO_2). Non-CO_2 GHGs should be priced with the same carbon price as CO_2 emissions.
AMPERE5-HiRES-NoCCS-NoNUKE	EU27 mitigation scenario with high RES penetration, no CCS and nuclear phase out	**No CCS** allowed in all energy sectors (including industrial applications), in all EU member states, and for all combinations with fossil fuels (coal and natural gas) or bioenergy. **Nuclear phase out** is defined as no construction of new nuclear power plants beyond those already under construction or planned. In addition, no lifetime extensions beyond the retirement rate assumed in the models should be implemented. The nuclear phase out concept is triggered by

		public scepticism about nuclear technology. Energy efficiency gains higher but comparable to the *AMPERE5-Decarb-AllOptions* scenario. In this scenario, **RES deployment** is considered as the most important option in order to achieve the overall mitigation target and so RES facilitation policies and higher learning by doing are assumed. All RES technologies (including wind, solar, hydro, biomass etc.) should penetrate the energy mix and gain higher shares than in the standard decarbonisation scenario (*AMPERE5-Decarb-AllOptions*). Electrification of the transport sector through the gradual penetration of plug-in and electric vehicles in car stocks should be included as a mitigation option (like in the *AMPERE5-Decarb-AllOptions* scenario). All other specifications (including the overall carbon budget) are identical to the *AMPERE5-Decarb-AllOptions* scenario. Non EU countries undertake strong emission reduction effort for achieving 450ppm. Carbon budget for the world as defined in WP3 protocol, i.e. total CO_2 emissions from all sectors including land use should not exceed 1400 Gtn of CO_2 in the period 2000-2050 (for the models that do not include CO_2 emissions from land use the carbon budget for the period 2000-2050 is 1300 Gtn of CO_2). Non-CO_2 GHGs should be priced with the same carbon price as CO_2 emissions.
AMPERE5-NoTransElec	EU27 mitigation scenario without transport electrification	**Electrification of the transport sector** should **NOT** be included as a mitigation option in the EU27 decarbonisation effort. Plug-in and electric vehicles should not be introduced in the European car stock and the only option to decarbonise the transport sector will be the extensive use of biofuels however constrained by feedstock potential limitations. All other mitigation options (energy efficiency, CCS development, large scale RES penetration in the energy mix, nuclear power) should be available, like in the standard decarbonisation scenario *AMPERE5-Decarb-AllOptions*. All other specifications (including the overall carbon budget) are identical to the *AMPERE5-Decarb-AllOptions* scenario. Non EU countries undertake strong emission reduction effort for achieving 450ppm. Carbon budget for the world as defined in WP3 protocol, i.e. total CO_2 emissions from all sectors including land use should not exceed 1400 Gtn of CO_2 in the period 2000-2050 (for the models that do not include CO_2 emissions from land use the carbon budget for the period 2000-2050 is 1300 Gtn of CO_2). Non-CO_2 GHGs should be priced with the same carbon price as CO_2 emissions.

AMPERE5-Delay	EU27 mitigation scenario with delayed action until 2030 (variant of *AMPERE5-Decarb-AllOptions*)	The delayed climate action scenario assumes the achievement of the EU energy and climate package for 2020 (20%reduction in GHG emissions compared to 1990,20% RES share in final energy mix), but assumes that in the decade 2020-2030 no further climate action is implemented apart the ETS regulations. As a result, CO_2 emissions in the *AMPERE5-Delay* scenario are similar to the reference scenario until 2030. After 2030, the mitigation effort is intensified in line with the specifications of *AMPERE5-Decarb-AllOptions* decarbonisation scenario so as to deliver the overall carbon budget (2011-2050) as specified for the decarbonisation scenarios. All mitigation options are available after 2030 and should be optimally deployed, but obviously at a much higher degree than in the *AMPERE5-Decarb-AllOptions* as emission reduction will have to take place in a shorter period of time. The models may also assume lower learning rates as an indication of the difficulties to improve technologies in a shorter period of time. The overall carbon budget should be the same as in the standard decarbonisation scenario (*AMPERE5-Decarb-AllOptions* scenario). The emissions of the period 2010-2030 should be subtracted from the total carbon budget of the period 2010-2050 and the remaining emissions should be imposed as a constraint in the period 2030 to 2050. ***Non-CO_2 gases and other radiative forcing agents:*** Models which consider also non-CO_2 GHGs (N_2O, CH_4, SF_6, CF_4, and long-lived halocarbons),should use the resulting CO_2-price from the cumulative CO_2 budget constraint to price non-CO_2 gases (using 100 year GWPs as provided in IPCC AR4). Non EU countries undertake strong emission reduction effort for achieving 450ppm with delayed action (after 2030). Carbon budget for the world as defined in WP3 protocol, i.e. total CO_2 emissions from all sectors including land use should not exceed 1400 Gtn of CO_2 in the period 2000-2050 (for the models that do not include CO_2 emissions from land use the carbon budget for the period 2000-2050 is 1300 Gtn of CO_2). Non-CO_2 GHGs should be priced with the same carbon price as CO_2 emissions.
AMPERE5-Delay-NoCCS-NoNUKE	EU27 mitigation scenario with delayed action until 2030 without CCS and without nuclear (variant of *AMPERE5-HiEFF-HiRES*)	**No CCS** allowed in all energy sectors (including industrial applications), in all EU member states, and for all combinations with fossil fuels (coal and natural gas) or bioenergy. **Nuclear phase out after 2030** is defined as no construction of new nuclear power plants beyond those already under construction or planned. In addition, no lifetime extensions beyond the retirement rate assumed in the models should be implemented. The nuclear phase out concept is triggered by public scepticism about nuclear technology. All other specifications (including the overall carbon budget) are identical to the *AMPERE5-Delay* scenario. Non EU countries undertake strong emission reduction effort for achieving 450ppm with delayed action (after 2030). Carbon budget for the

		world as defined in WP3 protocol, i.e. total CO_2 emissions from all sectors including land use should not exceed 1400 Gtn of CO_2 in the period 2000-2050 (for the models that do not include CO_2 emissions from land use the carbon budget for the period 2000-2050 is 1300 Gtn of CO_2). Non-CO_2 GHGs should be priced with the same carbon price as CO_2 emissions.

Summary of technology options in decarbonisation scenarios:

	Energy efficiency	**RES**	**Nuclear**	**CCS**	**Electrification in Transport**
AMPERE5-Decarb-AllOptions	Optimal	Optimal	Optimal	Optimal	Full
AMPERE5-HiEFF-HiRES	Highest possible	Highest possible	Low	Low	Full
AMPERE5-HiEFF-NoCCS-NoNUKE	Highest possible	Optimal	Phase out	No	Full
AMPERE5-HiRES-NoCCS-NoNUKE	Optimal	Highest possible	Phase out	No	Full
AMPERE5-NoTransElec	Optimal	Optimal	Optimal	Optimal	No
AMPERE5-Delay	As *AMPERE5-Decarb-AllOptions* but delayed climate policy which starts from 2030 onwards				
AMPERE5-Delay-NoCCS-NoNUKE	As *AMPERE5-HiEFF-HiRES* but delayed climate policy which starts from 2030 onwards				

APPENDIX A:

AMPERE5-EU-Ref (Reference)

ETS cap for scenario *AMPERE5-EU-Ref* (Reference). Yellow highlights indicate Phase II – before auctioning – allowances. Banking is allowed but no borrowing from the future. ETS includes aviation and includes the effects of CDM carbon credits. So you may ignore CDM in the modeling and consider the ETS cap as applying on domestic EU emissions.

EU27	ETS cap (Mt CO2-eq.)
2008	2,257
2009	2,257
2010	2,257
2011	2,257
2012	2,257
2013	2,337
2014	2,299
2015	2,261
2016	2,223
2017	2,184
2018	2,146
2019	2,108
2020	2,070
2021	1,909
2022	1,871
2023	1,832
2024	1,794
2025	1,756
2026	1,718
2027	1,680
2028	1,641
2029	1,603
2030	1,565
2031	1,548
2032	1,530
2033	1,513
2034	1,496
2035	1,479
2036	1,461
2037	1,444
2038	1,427
2039	1,409

2040	1,392
2041	1,375
2042	1,357
2043	1,340
2044	1,323
2045	1,306
2046	1,288
2047	1,271
2048	1,254
2049	1,236
2050	1,219
Cumul.	**73,948**

Non-ETS emissions cap for EU27 (assuming flexibility regarding the specific targets by Member-State):

> *Non-ETS emissions (in terms of all GHGs) in 2020 and beyond 2020 should not exceed 2400 MtCO2-eq which is 10% below levels of 2005.*

Decarbonisation scenarios

GHG emissions trajectory and the equivalent Carbon budget for the EU-27 in the decarbonisation scenarios (all scenarios except the reference scenario AMPERE5-EU-Ref)

	GHGs emissions in Mtn CO2-eq					**Cumulative emissions in Gtn CO2-eq**	
	1990	**2005**	**2020**	**2030**	**2050**	**2010-2050**	**2020-2050**
Total	***5532.3***	***5129.6***	***4114.0***	***3277.4***	***1112.5***	***123.6***	***78.9***
Energy related CO2 emissions	**4030.6**	**3946.6**	**3187.9**	**2431.2**	**587.4**	**90.6**	**55.5**
Non-energy related CO2 emissions	**329.5**	**304.5**	**305.7**	**304.9**	**33.6**	**9.8**	**6.8**
From Industrial Processes	296.0	274.9	280.0	288.1	29.0	9.1	6.4
Other CO2 emissions	33.5	29.5	25.7	16.8	4.6	0.7	0.4
Non-CO2 GHGs emissions	**1172.1**	**878.5**	**620.4**	**541.3**	**491.6**	**23.2**	**16.6**

APPENDIX B:

World fossil fuel prices for Reference and for Decarbonisation scenarios (boundary conditions from WP3). This uses POLES results for the world fossil fuel prices in the reference and in the decarbonisation cases as it offers the most detailed representation of the world energy sector and the interactions of fossil fuel prices with both energy supply and demand.

			2005	2010	2020	2030	2040	2050
Oil	**Reference**	**US$2005/GJ**	9.55	12.05	14.53	18.46	23.16	29.38
	Decabonisation	**US$2005/GJ**	9.55	12.05	12.62	15.22	9.96	9.22
Natural Gas	**Reference**	**US$2005/GJ**	6.63	5.67	5.61	6.95	8.78	10.95
	Decabonisation	**US$2005/GJ**	6.63	5.67	5.08	5.70	4.39	4.42
Coal	**Reference**	**US$2005/GJ**	2.32	3.86	4.12	4.33	4.49	4.65
	Decabonisation	**US$2005/GJ**	2.32	3.86	3.99	4.08	4.09	4.29