LIMITS Work Package 1 - 2°C scenario study protocol

1. Objective and overview of the study

The LIMITS WP1 2°C Scenario study aims to explore the following key research questions for the LIMITS project:

- How are the feasibility and costs of reaching the 2°C target affected by the stringency of associated radiative forcing targets?
- What is the impact of different levels of stringency of fragmented climate policy action prior to the establishment of a global carbon market (until 2020 or 2030) on the feasibility and costs of reaching the 2 °C target?
- How do different burden sharing regimes influence the regional distribution of climate mitigation costs?

The LIMITS global scenarios architecture was designed to answer these research questions. The individual scenarios are specified by a combination of radiative forcing targets (determining the probability of achieving 2°C target), fragmented climate policy regimes until 2020 / 2030, and burden sharing regimes for international cooperation after 2020 / 2030.

2. Scenario dimensions

In the following, we define the individual dimensions of the LIMITS 2°C scenarios.

2.1 Climate policy target formulation

Two different target levels of total radiative forcing in the year 2100 are considered:

- 2.8 W/m^2 giving a likely to very likely (>70%) chance of reaching the 2 °C target, and
- 3.2 W/m^2 making it as likely as not (~50%) to reach the 2 °C target.

Both targets are overshoot targets, i.e. the 2100 target levels can be exceeded prior to 2100. They refer to the aggregate radiative forcing from the following substances that were investigated by source in the RCP work: Kyoto gases (CO2, CH4, N2O, HFCs, PFCs, SF6), Non-Kyoto gases (substances controlled under the Montreal protocol, i.e. chlorides, halons, bromine; tropospheric and stratospheric ozone; stratospheric water vapor), and aerosols (sulfate, black and organic carbon from fossil fuel and biomass burning, indirect aerosol forcing). Direct forcing from nitrate aerosols, mineral dust and land surface albedo changes are *not* included in the list. Thus the target refers to the anthropogenic forcing not including direct forcing from land use albedo changes, mineral dust aerosols, and nitrate aerosols (Abbreviation: A3NA).

2.2 No policy baseline and fragmented policy reference cases

A serious investigation of the feasibility and costs of reaching the 2 °C target needs to take into account the fact that a global mitigation regime will only emerge after a period of fragmented climate policy action. This requires establishing fragmented policy reference cases on which global cooperative action at a later stage can be imposed. The LIMITS comparison study includes two such reference cases besides the no new climate policy case: **A weak and a stringent climate policy reference case.** These policy reference cases take up existing commitments and pledges – mostly specified until 2020 – and extrapolate the level of stringency reflected in the commitments until the end of the century. They describe situations in which regions enact domestic climate policy without emissions trading or other international climate policy mechanisms. The weak and stringent climate policy reference cases differentiate GHG emissions reductions targets, renewable energy shares in power generation or final energy, and renewable and nuclear capacity installation targets for 26 world regions. They have been developed in the AMPERE project based on a collection of national targets and Copenhagen pledges for 2020 and beyond. The detailed definition of moderate and stringent policy packages and instructions on how to aggregate the information to model regions are given in the Supplementary Material (Section 3) of *Kriegler et al., 2013, What does the 2°C target imply for a global climate agreement in 2020? The LIMITS study on Durban Platform scenarios, Climate Change Economics 4(4), 1340008*.

2.3 Transition from fragmented action to global cooperation

The LIMITS 2 °C scenarios follow either the weak or the stringent climate policy reference case until the start year of global cooperative action (either 2020 or 2030 depending on the scenario). No anticipation of a more binding future long-term radiative forcing target is assumed, i.e. models should fix their emissions and energy trajectories to the weak / stringent climate policy reference case until the start year. At the start year of global actions, all regions adopt the long-term radiative forcing target as binding commitment for joint mitigation action. Implementation of the target is via a global carbon market (where the allocation of emission allowances is described below). In the case of no burden sharing, a globally harmonized carbon tax leading to the attainment of the radiative forcing target could also be imposed. The post-2020 GHG taxes in the weak / stringent climate policy reference cases (that models might have implemented to achieve the prescribed GHG intensity improvements after 2020) are superseded by the implementation of the forcing target. Any post-2020 energy efficiency, renewable energy or capacity targets that are included in the weak / stringent climate policy package should be retained. In burden sharing scenarios designated as “full cooperation thereafter”, unconstrained emissions trading between world regions is allowed after 2020. We reiterate that no emissions trading is allowed in the case of no burden sharing.

2.4 Burden sharing regimes

The LIMITS 2 °C scenarios assume three different burden sharing regimes that would be imposed at the start year of global cooperative action (i.e. either 2020 or 2030).

No burden sharing: This benchmark case describes the situation of a global carbon tax adopted by all regions. The global tax regime implies an equalization of marginal abatement costs across regions without transfers of emission permits between regions. In the absence of uncertainty, this is equivalent to an emission trading scheme, in which the allocations correspond to the optimal regional abatement levels, such that the net emissions trading balances are zero for all regions.

Resource sharing: Different allocation schemes can be categorized as "resource-sharing" and "effort sharing" regimes. The "resource-sharing" regimes allocate emissions rights based on different equality principles. Per Capita (PC) scheme is chosen as a "resource-sharing" regime to be employed in the LIMITS 2 °C scenarios. This comprises a linear transition to equal per capita emissions rights from 2020 – 2050 with grandfathering of emissions allowances in 2020.

Effort sharing: In addition to the "resource-sharing" regimes, which are based on the distribution of emission rights, allocation of future commitments can also be made according to the distribution of the global mitigation effort. Here, we propose a new "effort-sharing" regime by considering the mitigation costs as an indicative factor for measuring the effort. The objective of the proposed burden sharing is to have a fair distribution of climate mitigation costs (in percentage GDP) among world regions. The LIMITS 2°C scenarios will employ the simplest case of equal relative mitigation costs for all regions after emissions trade.

3. Scenario architecture

The LIMITS WP1 2 °C scenario architecture includes 12 mandatory and 4 optional scenarios. Modeling teams are free to conduct the scenarios based on their default model assumptions. However, the choice of assumptions must not be changed between different scenarios of the study. We will make an effort to elicit key model assumptions underlying the LIMITS scenarios as much as possible to establish transparency of results. A spread in GDP and population assumptions of participating models would be desirable to explore the effect of uncertainty about those assumptions. Models may be harmonized from previous model comparison exercises, but no de-harmonization is foreseen at this stage. All scenario specifications refer to the time period after 2012. The model should only be allowed to respond to future climate policy (in any model variable) in the first model year following 2012. Models should reproduce historic emissions until 2010/11. Modeling teams are free to use their default method for reproducing historic emissions, including emissions constraints or carbon taxes (e.g. reflecting the first commitment period of the Kyoto protocol or domestic climate policies) if applicable.

Scenario Base (No policy baseline): This is the standard no climate policy baseline run. Carbon prices should be zero (after 2012) throughout the time horizon of the model, and all constraints leading to

non-zero (shadow) prices of greenhouse gas emissions should be removed. Fossil fuel taxes and subsidies that are not related to climate change policy are not affected by these requirements.

Scenario RefPol (Lenient climate policy reference case): The weak climate policy reference case as defined in Appendix A.1 [*Not reproduced here. See Section S3*] should be implemented until the end of the time horizon of the model. Average emissions intensity reduction rates after 2020 can be implemented either by imposing a CO_2 (equivalent) tax or an emissions constraint that leads to the achievement of these rates. If the emissions reduction targets and intensity improvement rates foreseen in the weak climate policy case are above (targets) / below (rates) baseline, they should be set to their baseline value for the years and regions concerned. No trade of emissions allowances between regions should be allowed.

Scenario StrPol (Strengthened climate policy reference case): The stringent climate policy reference case as defined in Appendix A.1 [*Not reproduced here. See Section S3*] should be implemented until the end of the time horizon of the model. Average emissions intensity reduction rates after 2020 can be implemented by imposing a CO_2 (equivalent) tax or an emissions constraint that leads to the achievement of these rates. If the emissions reduction targets and intensity improvement rates foreseen in the weak climate policy case are above (for targets) / below (for rates) baseline, they should be set to their baseline value for the years and regions concerned. No trade of emissions allowances between regions should be allowed.

Scenario 450 (2.8 W/m^2 benchmark case): This is the standard benchmark climate policy scenario to reach a radiative forcing target of 2.8 W/m^2 in 2100. Full when (to the extent allowed by the model) and where flexibility, as reflected in a globally harmonized carbon price, should be assumed from the first model year after 2012. If the carbon price is established via a global emissions trading system, the allocation of emissions allowances should be chosen such that no emissions trading between regions occurs (e.g. as it would be the case for a globally harmonised carbon tax without transfers between regions or across time).

Scenario 500 (3.2 W/m^2 benchmark case): This is the standard benchmark climate policy scenario to reach a radiative forcing target of 3.2 W/m^2 in 2100. Full when (to the extent allowed by the model) and where flexibility, as reflected in a globally harmonized carbon price, should be assumed from the first model year after 2012. If the carbon price is established via a global emissions trading system, the allocation of emissions allowances should be chosen such that no emissions trading between regions occurs (e.g. as it would be the case for a globally harmonised carbon tax without transfers between regions or across time).

Further Scenarios: The additional 7 LIMITS 2°C scenarios are defined in the following scenario matrix.

Radiative forcing level	**Near-term fragmented policy action**	*No burden sharing:* Global carbon tax	*Resource Sharing:* Per Capita Convergence until 2050 (Grandfathering in 2020)	*Effort sharing:* Equal Mitigation costs
2.8 W/m2 in 2100, overshoot allowed	Lenient climate policy case until 2020, full cooperative action after 2020	**RefPol-450**	**RefPol-450-PC**	**RefPol-450-EE**
2.8 W/m2 in 2100, overshoot allowed	Strengthened climate policy case until 2020, full cooperative action after 2020	**StrPol-450**		
3.2 W/m2 in 2100, overshoot allowed	Lenient climate policy case until 2020, full cooperative action after 2020	**RefPol-500**		
3.2 W/m2 in 2100, overshoot allowed	Strengthened climate policy case until 2020, full cooperative action after 2020	**StrPol-500**		
3.2 W/m2 in 2100, overshoot allowed	Lenient climate policy case until 2030, full cooperative action after 2030	**RefPol-2030-500**		