EMF Round:

Carbon Pricing after Paris (CarPri)

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I. Background and objectives

Anthropogenic climate change is one of the most important global challenges. The Paris agreement of 2015 is the central international agreement to deal with this challenge. Against this background, the overall objective of the CarPri project is to provide a thorough economic impacts assessment (i) for the implementation of the national greenhouse gas emission reduction targets that have been submitted in the context of the Paris agreement and (ii) of alternative climate policy futures to comply with more ambitious global reduction requirements in line with a 2°C or even a 1.5°C temperature target as proclaimed in the Paris agreement.

The analysis will be based on a systematic cross-comparison of internationally established energy-economy models to derive viable guidelines for future climate policy design that will be disseminated to decision makers. Since extended carbon pricing – as it is e.g. recommended by the High Level Commission on Carbon Pricing (Stiglitz et al. 2017) – is commonly regarded as a central policy instrument to the Paris targets at relatively low costs, it will be at the core of the analyzed scenarios.

CarPri involves organizing and coordinating a multi-model study in the well-established context of the Energy Modelling Forum (EMF). The EMF (see https://emf.stanford.edu/about) was established at Stanford University in 1976 to bring together leading experts and decision makers from governments, industry, universities and other research organizations for the systematic analysis of important energy and environmental issues. The main objective of the EMF studies is to derive robust insights on policy responses to energy and environmental challenges and thereby put decision making on an informed basis. In this vein, EMF studies built on the collective capabilities of experts who apply and compare analytical models to the policy issues in a systematic manner. For each study, a working group is set-up to develop the study design, analyze and compare each model's results and discuss key conclusions.

CarPri sets up and supervises such an EMF-working group to address the fundamental question on how the Paris targets can be reached through a mix of instruments but in particular via extended carbon pricing. Carbon pricing is viewed by many politicians and economists as cost-effective policy instrument which levels the playing field among competitors in international trade while internalizing the costs of climate damage into prices of goods and services. The starting point are the national pledges submitted to the Paris agreement by individual countries (the so-called Nationally Determined Contributions – NDCs)[1] as well as the existing climate policy instruments including market-based instruments such as carbon pricing via emission trading or emission taxes but also command-and-control

[1] NDCs have been initially termed INDCs where "I" stands for "intended" because countries were communicating proposed climate actions ahead of the Paris Agreement being finalized. However, as countries formally join the Paris Agreement and look forward to implementation of these climate actions – the "intended" is dropped and an INDC is converted into a Nationally Determined Contribution (NDC).

instruments such as efficiency standards and renewable portfolio standards. The modeling exercise will investigate alternative policy regimes to meet the Paris targets and thereby quantify the respective economic impacts across the different parties to the Paris agreement. This sheds light on both the magnitude as well as the distribution of economic adjustment costs of decarbonization across countries, industries, and consumers. The cross-comparison thus will deliver important information on the pattern of burden sharing across various stakeholders and the potential trade-offs between cost-effectiveness at the global level and equity plus competitiveness concerns across countries and industries. The economic impacts of stringent emission regulation as mandated under the Paris agreement must be measured against a hypothetical business-as-usual (BaU) which describes a policy reference path for the case that the Paris agreement would not be put into place. The BaU would constitute one inevitable reference point in the scenario space ‑ another relevant benchmark for the assessment of climate policy outcomes is a uniform global carbon pricing scheme where all emitters face an identical price reflecting perfect "where-flexibility" in emission reduction such that emission reduction takes place where it is cheapest worldwide. One major task of the modeling exercise will be to specify policy transitions starting from currently fragmented and uncoordinated national climate policy plans towards more coordinated and harmonized emission pricing.

As usual for EMF studies, a synthesis report as well as specific findings by individual modeling groups will be published in a special issue of a peer-reviewed internationally renowned journal (such as e.g. Energy Economics). The format of an EMF project also includes established outreach formats and channels to political decision makers especially in Europe and the US.

Analyzing climate policy scenarios on the targets of the Paris agreement and the role of extended carbon pricing within the CarPri project has both scientific as well as practical (policy making) objectives.

The scientific objective is in the first place to contribute to the knowledge about the economic implications of such scenarios. Since it is well known that – for a given scenario – different model an data assumptions affect results, the objective is also to generate a "map" of outcomes for some core scenarios and to understand the driving forces behind differences in model results. The sound development of core scenarios within the working group is also to be seen as a scientific contribution to informing the public debate on viable futures of the international climate policy sphere, more specifically the future evolution of the Paris agreement. Besides the development and processing (simulation) of a limited number of the core (joint) scenarios, each participating modelling team will undertake complementary in-depth analysis on a topic of their choice focusing reflecting e.g. policy priorities or constraints in specific region (China, India USA, EU, etc.) or industries (e.g. energy-intensive and trade-exposed sectors). In this

way, the working group as a whole can provide a relatively complete picture of pre-selected policy topics.

In a nutshell, the project aims to deliver robust analysis of a set of climate policy scenarios relevant for the implementation of the Paris agreement. As part of the rigorous scientific quality management, all major findings will be published in a special issue of a peer-reviewed international renowned field journal and also posted on the EMF website to be accessible to the scientific community.

The scientific progress in economic impact assessment of future climate policy designs also goes along with the objectives (as in each EMF study)

- to harness the collective capabilities of multiple modeling groups for a better understanding of important energy and environmental challenges,
- to explain the strengths and limitations of competing modeling approaches to the scientific analysis of the problem at stake,
- to provide guidance for future research needs and efforts.

CarPri also intends to advance the state of economy-climate modelling, not so much through pushing new modeling paradigms or collecting new data but rather through identifying best practices in applied economic analysis with climate-policy models. While the primary objective is not to develop new models, the assessment of specific scenarios analyzed by the modelling teams will require model adjustments/advancements as well as thorough data preparation to address the policy issues at stake.

The main practical policy-oriented objective of CarPri is to contribute to the process of implementing the Paris agreement by providing decision makers from policy, business and society with robust information on the economic consequences of alternative policy designs. The established channels and contacts of the EMF network and the applicants of CarPri will assure that results are disseminated to decision makers in a timely and effective manner.

II. Research agenda

The Paris agreement includes in its Article 6 the provisions to support and leverage market-based emission-reduction systems implemented by regional, national, and sub-national jurisdictions. The high-level experts of a recent workshop on Market mechanisms and the Paris Agreements Stavins & Stowe (2017) agreed on the potential of these approaches, but also stress that “a great deals needs to be done to elaborate the Paris Agreement before this potential might be realized”. The discussed issues at this workshop – including legal political but also economic ones – show that there is still the need to learn more about the role that carbon pricing can play to reach the Paris Agreement. In terms of carbon pricing, the most recent report on the

"State and Trends of Carbon Pricing" by the World Bank et al. (2017) stresses five key priorities, of which three relate to different ways of extended carbon pricing (expanding coverage through new initiatives and the broadening of existing initiatives; raising carbon prices; aligning carbon pricing with complementary and enabling policies at the domestic level to ensure coherence with the broader policy framework) that will be analyzed in this project. Also, linking domestic pricing schemes which is a focus within this project is highlighted as an important issue.

Scenario-based simulation analyses with numerical computer-based climate-policy models is a well-established scientific approach to assess the impacts of alternative climate policy designs while accounting for complex interrelationships between the economy on the one hand and the energy system as well as the climate system on the other hand. There is a long history of model-based studies on international climate regime scenarios as well as on more specific sectoral and regional proposals to which the applicants have contributed significantly in the past.

In the late 1990ies studies focused on the national and international effects of the Kyoto Protocol and the potential cost savings though emission trading - also within a related EMF working group (EMF 16, Weyant 1999). Springer (2003) gives an overview of modelling studies with about 25 different models related to the Kyoto Protocol and their results.

At the beginning of the millennium model studies focused on proposals for a Post-Kyoto design analyzing predominantly the economic and environmental implications of the so-called Kyoto mechanisms to promote international "where-flexibility" in emission abatement via international emissions trading systems (ETS), joint implementation or the clean development mechanism (for a summary of such Post-Kyoto studies see e.g. *van Ruijven et al. 2012*)[2].

Reflecting the need for practical policy designs from a national perspective, past modelling studies also addressed country-specific issues such as support schemes for renewables (e.g. analyzed in the EU context within EMF 22) or the role of revenue recycling for reducing the costs and steering the incidence of stringent emission regulation (EMF 32).

Increased "where-flexibility" at a sub-global level through regional and sectoral expansion of emissions trading is analyzed as well as through linking different ETS. This central mechanism to extend uniform carbon pricing remained high on the agenda. Flachsland et al. (2009) discuss economic, political and regulatory implications of linking. Alexeeva & Anger (2016) and Dellink et al. (2014) stress potential benefits based on theoretical and model-based analysis respectively while potential detrimental trade-effects are outlined e.g. in Marschinski et al. (2012), Flachsland et al. (2009) or Copeland And Taylor (2005). Several studies analyze linking between specific emission trading systems. Hawkins & Jegou (2014) consider a potential linkage between the EU and South Korean ETS. Vöhringer (2012) uses a national CGE model to investigate

[2] Literature in italic is found in the CVs in Appendix II; the other references are listed in Appendix I.

economic effects of linking the EU and Swiss ETS. Anderson et al. (2009) investigate the requirements and chances of a link between EU-ETS and a hypothetical US-ETS. Zetterberg (2012) analyzes the design features of the EU and Californian ETS. Hübler et al. (2014) link a hypothetical Chinese to the EU ETS using the CGE model PACE. Alexeeva & Anger (2016) analyze linking between the EU and a number of other real and/or hypothetical ETS. Finally, Nong & Sriwardana (2016) investigate the options for Australia to bilaterally link its formerly planned ETS to several potential partners using a CGE model.

With respect to the Paris agreement as the latest outcome of international climate policy negotiations, a simple back-on-the-envelope calculation reveals that the so-far submitted NDCs are not sufficient to meet the 2°C target (Rogelji et al. 2016) and that the emission level will still be higher in 2030 than in 2010 (den Elzen et al. 2016). More detailed modelling studies on the NDCs have been initiated meanwhile. Hof et al. (2017) assess the costs of achieving the NDCs and additional costs of meeting the 2°C or even a 1.5°C target. They find that costs are very sensitive to assumptions concerning economic and population growth. To reach the 2°C (1.5 °C) target implies much higher costs than just sticking to the less ambitious NDCs, though there could be a significant cost reduction in global emission abatement when switching to comprehensive emissions trading. The importance of coordinated (uniform) carbon pricing for the global and regional cost incidence is confirmed in a more recent study by Fujimori et al. (2016) on the economic impacts of the Paris agreement. They estimate that the global welfare loss of achieving the NDCs in 2030 can be decreased by 75% due to emissions trading as compared to the implementation of NDCs through strictly national action. Campagnolo & Davide (2017) evaluate the effects of the achieving NDCs along multiple dimensions of sustainable development such as income inequality and poverty for alternative revenue recycling schemes. They find that the fulfilment of the NDCs might actually increase poverty. Several region-specific modelling studies meanwhile have investigated on how single countries can reach their NDC targets – often through some form of emission pricing (e.g. Young & Hafstead 2016 for the US, Li et al. 2017 for China, Wakiyama & Kuramochi 2017 for Japan).

Among the so far 34 EMF modelling exercises (see https://emf.stanford.edu/projects) there are a few that are more closely related to the policy issues at stake in the proposed next EMF round. Besides the already mentioned EMF 16 on “The Costs of the Kyoto Protocol”, there is EMF 22 on “Climate Change Control Scenarios” with the focus on long-run climate stabilization policies as well as intermediate-term transition scenarios; for the latter, specific attention was paid to implementation of the EU 20/20/2020 targets (*Böhringer et al. 2009*). EMF 29 on “The Role of Border Carbon Adjustment in Unilateral Climate Policy“ investigated the economic impacts of border carbon adjustment in unilateral climate policy as a means of implementing more comprehensive destination-based carbon pricing (*Böhringer et al. 2012a*). Finally, EMF 32 on “US GHG and Revenue Recycling Scenarios” used energy-economic models to assess emissions, energy and economic outcomes from a plausible range of US policies to reduce greenhouse

gases); a particularly important aspect of the analysis has been how fiscal decisions on revenue distribution from carbon pricing might affect the outcomes on emissions, energy and macroeconomic performance.

Altogether, modelling studies on a Post-Paris regime and the NDCs are still quite limited so there is scope for an extended analysis within the proposed project. In particular, the challenge of more comprehensive and stringent carbon pricing (see World Bank 2017 for the latest summary on pre-existing carbon prices across countries) together with the associated opportunities for revenue recycling calls for a rigorous analysis in the EMF spirit. Furthermore, there is a need to inform the climate policy debate on possible policy regimes that go beyond the announced national contributions (NDCs) to fill the significant gap in emission reductions which are necessary to meet the 2°C target.

All cooperators of the proposed EMF working group are proficient CGE modelers with their respective models used for policy-relevant climate policy analysis over many years. Given the global nature of the greenhouse gas externality, all these climate-economy models share a global coverage of economic transactions and energy use. Pending on the primary research interests, the models differ in sectoral and regional coverage, technology resolution, time treatment, and the representation of initial market distortions such as pre-existing taxes or imperfectly competitive market structures. Table 1 provides a brief summary of the modeling groups that already expressed interest in the proposed exercise, their models, specific non-standard features, and illustrative examples of previous applications which are closely linked to the theme of the proposed EMF round to international climate policy issues.

Table 1: Overview about models and contributions of cooperators

Cooperator	Model Acronym	Model Specifics	Examples of Analyzed Topics
B. Bednar-Friedl & K. Steininger, Univ. Graz, Austria	WEG-C-CGE	Detailed treatment of GHG process and transport sector	Carbon leakage, border carbon adjustment, consumption based emissions
J. Carbone, Colorado School of Mines, USA E. Balistreri, Iowa State Univ., USA, C. Böhringer, Univ. of Oldenburg, Germany, T. Rutherford, University of Wisconsin, USA	BC-CGE	Trade representation based on monopolistic competition with firm heterogeneity	Unilateral climate policy, carbon tariffs / taxes, strategic environmental policy design
C. Carraro, CMCC, Italy	WITCH	Endogenous technological change	Technological development & climate policy, EU climate policy
R. Dellink, OECD, France	ENV-Linkages	Incorporation of detailed baseline projections	Competitiveness, carbon leakage, linking of carbon markets, carbon taxes

T. Faehn, Statistics Norway	SNoW,	Imperfectly competitive fossil fuel markets	Welfare and competitiveness effects of anti-leakage policies
C. Fischer Resources for the Future (RFF), USA	RFF-ITC-CGE	Detailed data on initial trade restrictions (tariff /non-tariff barriers)	Competitiveness and leakage effects of sub-global climate policies
M. Gonzales-Equino, Basque Center for Climate Change	BC3-E3	Household heterogeneity	Distributional effects of climate policy, efficiency standards
B. Kriström, Univ. Umea, Sweden	CERE-CGE	Bottom-up representation of the electricity sector	Green energy, renewable energy promotion
A. Löschel, Univ. Münster, Germany	CGE model	Complementary use of the WIOD data base	EU climate policy design, efficiency gains from multi-gas mitigation, revenue recycling
N. Macaluso, Economic Analysis Directorate Canada	EC-MS-MR	Technological resolution of the electricity sector	Canadian climate policy contributions in the context of international mitigation efforts
S. Paltsev, MIT, USA	EPPA	Inclusion of conventional air-pollution, land-use change and food demand	Country-specific climate policy analysis (Brazil, China, Mexico, and USA), regulatory measures for transport emission
S. Rausch, ETH Zürich, Switzerland	CEPE-CGE	Household disaggregation, power system representation	Renewable energy policies, green tax reforms
B. Saveyn, M.Weitzel, EU Joint Research Center (JRC), Spain	GEM-E3	Inclusion of conventional air pollution, damages from pollutant	EU climate policy impacts for industrial competitiveness Low carbon path for China, India and Japan, unilateral climate policy, carbon tariffs
L. Wu, Fudan Univ. Shanghai, China	Fudan-CGE	Disaggregation of China into regional provinces	Chinese climate policy, carbon tariffs
S. Voigt, Center for European Economic Research (ZEW), Mannheim, Germany	PACE	Household heterogeneity, bottom-up representation of electricity generation	Incidence of emission regulation / renewable energy promotions across households, competitive-ness effects of climate policies
S. Fujimori, National Institute for Environmental Studies, (NIES), Tsukuba, Japan	AIM/CGE	Disaggregated agricultural sector, climate component through soft-link	Renewable energy, land-based mitigation measures
S. Peterson, Kiel Institute for the World Economy, Germany	DART	Technology-rich representation of the energy sector (electricity, biofuels, etc.)	Economic and environmental impact assessment of biofuel mandates
C. Böhringer, University of Oldenburg, Germany		Household heterogeneity and bottom-up representation of the electricity sector	Incidence of alternative promotion strategies for RES-E

III. Work program

In our work-program we will follow the typical steps for an EMF working group. In parallel, both applicants will undertake their own specific research refinements and modelling analysis in line with the overall EMF study.

Preparation phase (ca. 6 month)

The preparation phase includes two broad tasks. The first is to start the EMF process and to shape the focus of the EMF working group, to disseminate an open call to the modelling community and to organize and prepare a kick-off meeting for all interested modelling groups. A significant number of groups have already expressed their strong interest to participate (see Appendix), most of them even indicating the willingness to host workshops. To enhance the global coverage of involved experts, we will in addition actively seek for participation of modelling teams from India, Latin America and Australia during the preparation phase. Altogether, we are very optimistic that there will be at least around 15 participating modelling groups from all over the world. Preparing for the kick-off includes

- to collect and exchange information about the models of the participants (regional and sectoral coverage, model horizon, further specifics, and key calibration data (such as baseline GDP and emission development),
- to develop a "strawman proposal" as the basis for the common business-as-usual (BaU) scenario and a small set of joint scenarios on future climate policies that all modelling teams are required to analyze.

The Post-Paris climate futures include scenarios along two key dimensions. One dimension sets the emission reduction obligations that are either given by the NDCs or may emerge from additional efforts to meet the 2°C (1.5°C) temperature targets; the other dimension refers to the policy strategies and instruments for meeting the emission reduction requirements.

Another key task within the preparation phase is the streamlining of data. On the one hand, exchange of pre-existing data between the modeling groups should ensure positive synergies; on the other hand, additional data requirements should be allocated across participants and later on shared in order to avoid double-work.

The second task is to update the climate-policy models of the applicants towards the requirements of the EMF study.

Also, a literature survey on model-based analysis of NDCs and options for more comprehensive carbon pricing after Paris will be undertaken as a pre-requisite for the definition of EMF scenarios.

Summarized, the milestones of the preparation phase are

- Overview document on participating models
- Strawman proposal for the joint EMF scenarios
- Model versions of the DART and the UOL model tailored to the project
- Survey on Post-Paris modelling studies

Modelling and dissemination phase (ca. 18 month)

The core modelling and dissemination phase of an EMF projects typically extends for about 1.5 years from the first kick-off meeting to the finalized papers by all modelling groups.

At the kick-off meeting all participants present their models and ideas for the working group. The main objective of the kick-off meeting is to tie down the "strawman-proposal" of the preparation phase to commonly agreed detailed EMF core scenarios and to settle the reporting details for the model cross comparison. Also, the proposals for complementary individual analysis will be collected, discussed and selected with the overarching objective to enrich the core cross-comparison study by individual contributions which strengthen both the scientific as well as the policy-information appeal of the project.

After the kick-off meeting, modelling groups then have to up-date their models, implement the scenarios and report first model results which are presented and discussed at the next joint meeting after around six month. The intermediate model-comparison meeting will allow for constructive adjustments to the scenarios and additional runs based on the insights gained so far.

In the next six months the core scenario runs which are executed jointly across all modelling groups will be finalized while teams work in parallel on their individual analyses. First results of these analyses are discussed at the second modelling meeting.

The last six months of the modelling and dissemination phase are needed to summarize the results in an overview paper and to finalize the individual studies as well as papers towards submission for a special issue in an internationally renowned peer-reviewed journal. These will be discussed at the last and forth modelling meeting.

The role of the coordinators is – besides organizing the workshops – to generate reporting sets, synthesize information for the baseline and policy scenarios, collect and compare results for all models, summarize the general findings in an overview paper and last but not least to stay in permanent exchange with and support of the participating teams in order to ensure that results are submitted in time.

Scenarios are ultimately to be developed together with all participating teams (taking advantage of the bulk of international expertise on climate policy analysis) but will go in the following direction:

First there will be a best case scenario where NDCs (USA: -28% rel. to 2005 by 2025; EU28 + Norway, Iceland, Switzerland / Russia: - 40% / - 30% rel. to 1990 by 2030; China: emission peak by 2030; Australia / New Zealand / Brazil / Canada: -28% / -30% / -43%/ -30% rel. to 2005 by 2030; Indonesia / Korea / Mexico / Turkey: -30% / -37% / -40% / -21% rel. to BaU by 2030; Japan: -25% rel. to 2010 by 2030; South Africa: return to 2000 levels by 2030) are reached efficiently

with a global carbon price. For this, the targets are translated into effective abatement relative to baseline, e.g. for 2020, 2025 and 2030, assuming a linear abatement path over that period. This best-case CarPri scenario with uniform comprehensive emission pricing can be compared to the current ineffective policy mix where abatement action across parties to the Paris agreement are hardly coordinated and individual regions may even apply a myriad of policy instruments within national borders.

There will then be a scenario cluster 1 (lead by IfW) where different levels of "where-flexibility" by means of sectoral and regional expansion of emissions trading affect the global and regional impacts of Paris compliance. As can e.g. be seen in the latest report "State and Trends of Carbon Pricing" by the World Bank (2017), since 2016 eight new carbon pricing initiatives have been launched (especially in the Americas) and further initiatives especially in the US, South America, Turkey and in China are under consideration. Furthermore, some jurisdictions such as California, Mexico, Ontario and Québec or Japan, Korea and China already explore opportunities for linking their emissions trading systems (World Bank 2017). Within the EMF round different regional analysis will be fostered to analyze the effects of new initiatives. The IfW itself plans to focus on linking as one mechanism to increase "where-flexibility". It intends to analyze scenarios where the European Emissions Trading Scheme (EU-ETS) is linked to other existing and emerging emissions trading schemes, to analyze efficiency gains, competitiveness effects and practical design issues. A special focus will be given to linking the EU-ETS to the planned Chinese ETS.

Scenario cluster 2 (lead by UOL) investigates how instrument choice affects the magnitude and distribution of economic costs. Instruments include market-based instruments such as emission taxes or emission permits as well as command-and-control instruments such as efficiency (emission) standards or renewable portfolio standards. These instruments can be used in isolation or – reflecting common policy practice – can be in combination. Policy mixes can apply across different sectors of the economy (e.g. emission taxes to industry and efficiency standards to households) or within a certain segment of the economy (e.g. the EU electricity sector is subject to the EU-ETS as well as a mix of national renewable promotion policies and energy efficiency prescriptions). Likewise a specific policy instrument can be used in different stringency across segments of the economy – e.g. emission taxes that are differentiated across industries including the option of full tax exemptions. From a more narrow cost-effectiveness perspective, the mix of policy instruments to achieve a single target such as emission reduction runs the risk of counterproductive overlapping regulation. However, in policy practice, the use of multiple instruments is often motivated by political economy considerations on the specific incidence of policy regulation across stakeholders. There is typically a trade-off between efficiency and equity considerations which has to be taken into account for policy advice. Furthermore – in the context of the global greenhouse gas externality and differential emission pricing across countries – there might be an efficiency rationale for multiple instruments (such as emission taxes complemented with carbon tariffs and export rebates) to reduce carbon leakage and

foster global cost-effectiveness. Finally, instrument choices are also linked to the important issue of revenue recycling of regulatory rents which could be used to increase overall efficiency (e.g. in the context of a green tax reform by tax swaps of environmental taxes for labor or capital taxes) or to counteract undesired incidence). Against this background the objective of scenario cluster 2 is to assess alternative regulatory instruments for compliance to the Paris Agreement across key signatory regions (China, India, US, EU) and to identify potential trade-offs across central evaluation criteria such as cost-effectiveness and incidence.

The kick-off meeting is planned to take place at the IfW in Kiel and the last modelling meeting after two years at the UOL. To increase networking and be present outside Germany as well, the two additional modelling meetings will be located at institutes of the project partners abroad. As can be seen in the letters of intent basically all cooperators are potentially willing to host a meeting. The final decision will be made together with the group and also depends on how economically a meeting can be organized at a certain location. The plan is to organize the second meeting in southern Europe (e.g. Italy or Spain) and the third meeting, which can potentially be combined with some kind of policy outreach event, in Asia or North America.