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LIMITS

Low climate IMpact scenarios and the Implications of required Tight emission control Strategies

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1. LIMITS Special Issue on Durban Platform scenarios

(the LIMITS special issue has been published on Climate Change Economics, November 2013, Vol. 04/Issue 04 and February 2014, Vol. 05/Issue 01; Posted online on June 11, 2014)

1.1 E. Kriegler, M. Tavoni, K. Riahi, D. van Vuuren (2013): **Introducing the LIMITS Special Issue**

Climate Change Economics, World Scientific, vol. 04/Issue 04, 1302002, DOI: 10.1142/S2010007813020028, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813020028

Abstract: This paper provides an introduction to the Special issue of Climate Change Economics containing twelve papers describing findings of the LIMITS project. These papers assess post 2020 climate policies aimed at achieving the 2°C target. The assessment is based on an ensemble of scenarios consistently implemented by a suite of leading integrated assessment models. The scenarios, conceptualized as possible outcomes of the Durban Platform negotiation process, allow for a comprehensive assessment of the implementation of policies consistent with 2°C in the major economies, under different assumptions about medium-term action and its distribution across regions.

1.2 E. Kriegler, M. Tavoni, T. Aboumahboub, G. Luderer, K. Calvin, G. De Maere, V. Krey, K. Riahi, H. Rosler, M. Schaeffer, D. van Vuuren (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, World Scientific, vol. 04/Issue 04, 1340008, DOI: 10.1142/S2010 007813400083, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813400083

Abstract: This paper provides a novel and comprehensive model-based assessment of possible outcomes of the Durban Platform negotiations with a focus on emissions reduction requirements, the consistency with the 2°C target and global economic impacts. The Durban Platform scenarios investigated in the LIMITS study — all assuming the implementation of comprehensive global emission reductions after 2020, but assuming different 2020 emission reduction levels as well as different long-term concentration targets — exhibit a probability of exceeding the 2°C limit of 22–41% when reaching 450 (450–480) ppm CO2e, and 35–59% when reaching 500 (480–520) ppm CO2e in 2100. Forcing and temperature show a peak and decline pattern for both targets. Consistency of the resulting temperature trajectory with the 2°C target is a societal choice, and may be based on the maximum exceedance probability at the time of the peak and the long run exceedance probability, e.g., in the year 2100. The challenges of implementing a long-term target after a period of fragmented near-term

climate policy can be significant as reflected in steep reductions of emissions intensity and transitional and long-term economic impacts. In particular, the challenges of adopting the target are significantly higher in 2030 than in 2020, both in terms of required emissions intensity decline rates and economic impacts. We conclude that an agreement on comprehensive emissions reductions to be implemented from 2020 onwards has particular significance for meeting long-term climate policy objectives.

Keywords: Climate change; climate policy; 2°C target; Durban Platform; integrated assessment

1.3 M. Tavoni, E. Kriegler, T. Aboumahboub, K. Calvin, G. De Maere, J. Jewell,T. Kober, P. Lucas, G. Luderer, D. McCollum, G. Marangoni, K. Riahi, D. van Vuuren (2013): **The distribution of the major economies' effort in the Durban platform scenarios**

Climate Change Economics, World Scientific, vol. 04/Issue 04, 1340009, DOI: 10.1142/S2010 007813400095, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813400095

Abstract: The feasibility of achieving climate stabilization consistent with the objective of 2°C is heavily influenced by how the effort in terms of mitigation and economic resources will be distributed among the major economies. This paper provides a multi-model quantification of the mitigation commitment in 10 major regions of the world for a diversity of allocation schemes. Our results indicate that a policy with uniform carbon pricing and no transfer payments would yield an uneven distribution of policy costs, which would be lower than the global average for OECD countries, higher for developing economies and the highest, for energy exporters. We show that a resource sharing scheme based on long-term convergence of per capita emissions would not resolve the issue of cost distribution. An effort sharing scheme which equalizes regional policy costs would yield an allocation of allowances comparable with the ones proposed by the Major Economies. Under such a scheme, emissions would peak between 2030 and 2045 for China and remain rather flat for India. In all cases, a very large international carbon market would be required.

Keywords: Climate change economics; equity; burden sharing; regional mitigation costs; integrated assessment models; bioenergy; integrated assessment; climate change

1.4 D. McCollum, Y. Nagai, K. Riahi, G. Marangoni, K. Calvin, R. Pietzcker, J. van Vliet, B. van der Zwaan (2013): **Energy investments under climate policy: a comparison of global models**

Climate Change Economics, World Scientific, vol. 04/Issue 04, 1340010, DOI: 10.1142/S2010 007813400101, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813400083

Abstract: The levels of investment needed to mobilize an energy system transformation and mitigate climate change are not known with certainty. This paper aims to inform the ongoing dialogue and in so doing to guide public policy and strategic corporate decision making. Within the framework of the LIMITS integrated assessment model comparison exercise, we analyze a multi-IAM ensemble of long-term energy and greenhouse gas emissions scenarios. Our study provides insight into several critical but uncertain areas related to the future investment environment, for example in terms of where capital expenditures may need to flow regionally, into which sectors they might be concentrated, and what policies could be helpful in spurring these financial resources. We find that stringent climate policies consistent with a 2°C climate change target would require a considerable upscaling of investments into low-carbon energy and energy efficiency, reaching approximately $45 trillion (range: $30–$75 trillion) cumulative between 2010 and 2050, or about $1.1 trillion annually. This represents an increase of some $30 trillion ($10–$55 trillion), or $0.8 trillion per year, beyond what investments might otherwise be in a reference scenario that assumes the continuation of present and planned emissions-reducing policies throughout the world. In other words, a substantial "clean-energy investment gap" of some $800 billion/yr exists — notably on the same order of magnitude as present-day subsidies for fossil energy and electricity worldwide ($523 billion). Unless the gap is filled rather quickly, the 2°C target could potentially become out of reach.

Keywords: Integrated assessment; energy scenarios; climate change; policy analysis; carbon financing

1.5 J. Jewell, A. Cherp, V. Vinichenko, N. Bauer, T. Kober, D. McCollum, D. van Vuuren, B. van der Zwaan (2013): **Energy security of China, India, the E.U. and the U.S. under long-term scenarios: Results from six IAMs**

Climate Change Economics, World Scientific, vol. 04/Issue 04, 1340011, DOI: 10.1142/S2010 007813400113, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813400113

Abstract: This paper assesses energy security in three long-term energy scenarios (business as usual development, a projection of Copenhagen commitments, and a 450 ppm stabilization scenario) as modeled in six integrated assessment models: GCAM, IMAGE, MESSAGE, ReMIND, TIAM-ECN and WITCH. We systematically evaluate long-term vulnerabilities of vital energy systems of four major economies: China, the European Union (E.U.), India and the U.S., as expressed by several characteristics of energy trade, resource extraction, and diversity of energy options. Our results show that climate policies are likely to lead to significantly lower global energy trade and reduce energy imports of major economies, decrease the rate of resource depletion, and increase the diversity of energy options. China, India and the E.U. would derive particularly strong benefits from climate policies, whereas the U.S. may forego some opportunities to export fossil fuels in the second half of the century.

Keywords: Energy security; climate change; major economies; energy scenarios

1.6 M. van Sluisveld, D. Gernaat, S. Ashina, K. Calvin, A. Garg, M. Isaac, P. Lucas, I. Mouratiadou, S. Otto, S. Rao, P. Shukla, J. van Vliet, D. van Vuuren (2013): **A multi-model analysis of post-2020 mitigation efforts of five major economies**

Climate Change Economics, World Scientific, vol. 04/Issue 04, 1340012, DOI: 10.1142/S2010 007813400125, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813400125

Abstract: This paper looks into the regional mitigation strategies of five major economies (China, EU, India, Japan, and USA) in the context of the 2°C target, using a multi-model comparison. In order to stay in line with the 2°C target, a tripling or quadrupling of mitigation ambitions is required in all regions by 2050, employing vigorous decarbonization of the energy supply system and achieving negative emissions during the second half of the century. In all regions looked at, decarbonization of energy supply (and in particular power generation) is more important than reducing energy demand. Some differences in abatement strategies across the regions are projected: In India and the USA the emphasis is on prolonging fossil fuel use by coupling conventional technologies with carbon storage, whereas the other main strategy depicts a shift to carbon-neutral technologies with mostly renewables (China, EU) or nuclear power (Japan). Regions with access to large amounts of biomass, such as the USA, China, and the EU, can make a trade-off between energy related emissions and land related emissions, as the use of bioenergy can lead to a net increase in land use emissions. After supply-side changes, the most important abatement strategy focuses on end-use efficiency improvements, leading to considerable emission reductions in both the industry and transport sectors across all regions. Abatement strategies for non-CO2 emissions and land use emissions are found to have a smaller potential. Inherent model, as well as collective, biases have been observed affecting the regional response strategy or the available reduction potential in specific (end-use) sectors.

Keywords: Regional; mitigation efforts; abatement; technological implication; climate policy

1.7 B. van der Zwaan, H. Rösler, T. Kober, T. Aboumahboub, K. Calvin, D. Gernaat, G. Marangoni and D. McCollum (2013): **A Cross-Model Comparison of Global Long-Term Technology Diffusion under a 2°C Climate Change Control Target**

Climate Change Economics, World Scientific, vol. 04/Issue 04, 1340013, DOI: 10.1142/S2010 007813400137, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813400137

Abstract: We investigate the long-term global energy technology diffusion patterns required to reach a stringent climate change target with a maximum average atmospheric temperature increase of 2°C. If the anthropogenic temperature increase is to be limited to 2°C, total CO2 emissions have to be reduced massively, so as to reach substantial negative values during the second half of the century. Particularly power sector CO2 emissions should become negative from around 2050 onwards according to most models used for this analysis in order to compensate for GHG emissions in other sectors where abatement is more costly. The annual additional capacity deployment intensity (expressed in GW/yr) for solar and wind energy until 2030 needs to be around that recently observed for coal-based power plants, and will have to be several times higher in the period 2030–2050. Relatively high agreement exists across models in terms of the aggregated low-carbon energy system cost requirements on the supply side until 2050, which amount to about 50 trillion US$.

Keywords: Climate policies; low-carbon energy growth; technological innovation; mitigation costs

1.8 K. Calvin, M. Wise, D. Klein, D. McCollum, M. Tavoni, B. van der Zwaan, D. van Vuuren (2013): **A multi-model analysis of the regional and sectoral roles of bioenergy in near- and long-term CO2 emissions reduction**

Climate Change Economics, World Scientific, vol. 04/Issue 04, 1340014, DOI: 10.1142/S2010 007813400149, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007813400149

Abstract: This paper examines the near- and the long-term contribution of regional and sectoral bioenergy use in response to both regionally diverse near-term policies and longer-term global climate change mitigation policies. The use of several models provides a source of heterogeneity in terms of incorporating uncertain assumptions about future socioeconomics and technology, as well as different paradigms for how different regions and major economies of the world may respond to climate policies. The results highlight the heterogeneity and versatility of bioenergy itself, with different types of resources and applications in several energy sectors. In large part due to this versatility, the contribution of bioenergy to climate mitigation is a robust response across all models. Regional differences in bioenergy consumption, however, highlight the importance of assumptions about trade in bioenergy feedstocks and the influence of energy and climate policies. When global trade in bioenergy is possible, regional patterns of bioenergy use follow global patterns. When trade is assumed not to be feasible, regions with high bioenergy supply potential tend to consume more bioenergy than other regions. Energy and climate policies, such as renewable energy targets, can incentivize bioenergy use, but specifics of the policies will dictate the degree to which this is true. For example, renewable final energy targets, which include electric and non-electric renewable sources, increase bioenergy use in all models, while electric-only renewable targets have a mixed effect on bioenergy use across models.

Keywords: Bioenergy; integrated assessment; climate change

1.9 T. Kober, B. van der Zwaan, H. Rösler (2014): **Emission Certificate Trade and Costs under Regional Burden-Sharing Regimes for a 2°C Climate Change Control Target**

Climate Change Economics, World Scientific, vol. 05/Issue 01, 1440001, DOI: 10.1142/S2010 007814400016, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007814400016

Abstract: In this article we explore regional burden-sharing regimes for the allocation of greenhouse gas emission reduction obligations needed to reach a 2°C long-term global climate change control target by performing an integrated energy-economy-climate assessment with the bottom–up TIAM-ECN model. Our main finding is that, under a burden-sharing scheme based on the allowed emissions per capita, the sum of merchandized carbon certificates yields about 2000 billion US$/yr worth of inter-regional trade around 2050, with China and Latin America the major buyers, respectively Africa, India, and other Asia the main sellers. Under a burden-sharing regime that aims at equal cost distribution, the aggregated amount of transacted carbon certificates involves less than 500 billion US$/yr worth of international trade by 2050, with China and other Asia representing the vast majority of selling capacity. Restrictions in the opportunities for international certificate trade can have significant short- to mid-term impact, with an increase in global climate policy costs of up to 20%.

Keywords: Climate policy; energy system; greenhouse gases; emissions abatement; resource versus cost sharing; carbon certificate trade

1.10 T. Aboumahboub, G. Luderer, E. Kriegler, M. Leimbach, N. Bauer, M. Pehl, L. Baumstark (2014): **On the regional distribution of climate mitigation costs: the impact of delayed cooperative action**

Climate Change Economics, World Scientific, vol. 05/Issue 01, 1440002, DOI: 10.1142/S2010 007814400028, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007814400028

Abstract: This paper analyzes the results of the climate-energy-economy model, Regionalized Model of Investment and Technological Development (REMIND), to assess the regional costs of climate-change mitigation for reaching the 2°C target with a medium to high likelihood. We assume that the global climate regime remains fragmented until 2020 after which a global mitigation target is adopted. We decompose the regional mitigation costs into (a) domestic and energy trade effects and (b) permit trade effects. Delaying cooperative action affects domestic costs by increasing the energy system's costs as a consequence of lock-in of carbon-intensive infrastructures. This is particularly true in developing countries with low near-term emissions reduction commitments. In a global cap-and-trade system, the effect of delayed action highly depends on whether or not the

regions are over- or under-allocated with emissions allowances in the long term. Those with allowances exceeding their long-term emissions will likely benefit from the delay, while others suffer the consequences of higher long-term carbon prices.

Keywords: Regional mitigation costs; delayed cooperative action; burden sharing; integrated assessment models

1.11 G. Marangoni, M. Tavoni (2014): **The clean energy R&D strategy for 2°C**

Climate Change Economics, World Scientific, vol. 05/Issue 01, 1440003, DOI: 10.1142/S2010 00781440003X, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S201000781440003X

Abstract: This paper uses an integrated assessment model to quantify the climate R&D investment strategy for a variety of scenarios fully consistent with 2°C. We estimate the total climate R&D investment needs in approximately 1 USD Trillion (all monetary values in this paper are given in 2005 US dollars using market exchange rates) cumulatively in the period 2010–2030, and 1.6 USD Trillions in the period 2030–2050. Most of the R&D would be carried out in industrialized countries initially, but would be evenly split after 2030. We also assess a "climate R&D deal" in which countries cooperate on innovation (while innovation is a broad topic, in this paper, we will be referring to its R&D component) in the short term, and find that an R&D agreement slightly underperforms a climate policy based on the extension of the Copenhagen pledges till 2030. Both policies are inferior to full cooperation on mitigation starting in 2020. A global agreement on clean energy innovation beyond 2030 without sufficiently stringent GHG emissions reduction policies is found to be incompatible with 2°C.

Keywords: Clean energy R&D; endogenous technical change; climate policy; 2 Degrees; Durban Action platform

1.12 I. Staub-Kaminski, A. Zimmer, M. Jakob, R. Marschinski: Climate Policy in Practice (2014): **A Typology of Obstacles and Implications for Integrated Assessment Modeling**

Climate Change Economics, World Scientific, vol. 05/Issue 01, 1440004, DOI: 10.1142/S2010 007814400041, (.pdf), http://www.worldscientific.com/doi/abs/10.1142/S2010007814400041

Abstract: The implementation of mitigation policies will be complicated by several real-world imperfections ("second-best conditions") and constraints typically not included in the more idealized economies assumed in Integrated Assessment Models (IAMs), based on which such policies are derived. But which of these numerous imperfections found in real economies are actually relevant in this context? And how could they — in principle — be taken into account by IAMs? Based on a literature review, we propose a typology of three categories of obstacles inhibiting "first-best"

conditions and outcomes: first, obstacles impeding the setting of least-cost abatement incentives; second, obstacles limiting the supply and exploitation of abatement options; and, third, obstacles creating distortions between the price and marginal costs of abatement. By reviewing the implementation of energy policy in China, we put our typology into practice and identify specific empirical evidence for each category. IAMs in principle can (and in practice often do) incorporate several relevant obstacles by means of additional cost or quantity constraints. However, the nature of some obstacles relating to strategic interactions between economic agents appears to be incompatible with the standard representative agent social-planner framework often employed in IAMs, suggesting a need for complementary analysis with decentralized "Integrated Policy Assessment Models".

Keywords: Climate policy; barriers; second-best; climate change mitigation; Integrated Assessment Models

1.13 A. Bowen, E. Campiglio, M. Tavoni (2014): **A macroeconomic perspective on climate change mitigation: Meeting the financing challenge**

Climate Change Economics, World Scientific, vol. 05/Issue 01, 1440005, DOI: 10.1142/S2010 007814400053, .pdf, http://www.worldscientific.com/doi/abs/10.1142/S2010007814400053

Abstract: Transitioning to a low-carbon economy will require significant investment to transform energy systems, alter the built environment and adapt infrastructure. A strategy to finance this investment is needed if the limit of a 2°C increase in global mean temperatures is to be respected. Also, high-income countries have pledged to pay the "agreed full incremental costs" of climate-change mitigation by developing countries, which are not necessarily the same as incremental investment costs. Building on simulations using Integrated Assessment Models and historical evidence, this paper explores some of the issues posed by this dual financing challenge. We discuss the "fiscal self-reliance" of the energy sector, finding that carbon pricing would generate sufficient fiscal revenues within each region to finance total investment in energy supply. Even when allowing for trade in emission permits, regional carbon fiscal revenues should still suffice to cover both their own investment in energy supply and permit purchases from abroad. We show that incremental energy-supply investment (and saving) needs are well within the range of past variation of aggregate investment, and argue that the challenge is rather to ensure that revenues from carbon pricing and other sources are complemented by investment in the appropriate sectors. But fairness and equity are likely to warrant transfers from advanced industrial countries to developing nations.

Keywords: Macroeconomics; climate change; Integrated Assessment Models; savings; investments; tax revenues

2. Special Issue on The EMF27 Study on Global Technology and Climate Policy Strategies

(the EMF27 special issue has been published on Climate Change Economics, April 2014, Vol. 123/Issue 03-04)

2.1 E. Kriegler, J.P. Weyant, G.j. Blanford et al. (2014): **The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies**

Climatic Change 123:353–367, DOI: 10.1007/s10584-013-0953-7,
http://rd.springer.com/article/10.1007%2Fs10584-013-0953-7

Abstract: This article presents the synthesis of results from the Stanford Energy Modeling Forum Study 27, an inter-comparison of 18 energy-economy and integrated assessment models. The study investigated the importance of individual mitigation options such as energy intensity improvements, carbon capture and storage (CCS), nuclear power, solar and wind power and bioenergy for climate mitigation. Limiting the atmospheric greenhouse gas concentration to 450 or 550 ppm CO2 equivalent by 2100 would require a decarbonization of the global energy system in the 21st century. Robust characteristics of the energy transformation are increased energy intensity improvements and the electrification of energy end use coupled with a fast decarbonization of the electricity sector. Non-electric energy end use is hardest to decarbonize, particularly in the transport sector. Technology is a key element of climate mitigation. Versatile technologies such as CCS and bioenergy are found to be most important, due in part to their combined ability to produce negative emissions. The importance of individual low-carbon electricity technologies is more limited due to the many alternatives in the sector. The scale of the energy transformation is larger for the 450 ppm than for the 550 ppm CO2e target. As a result, the achievability and the costs of the 450 ppm target are more sensitive to variations in technology availability.

2.2 V. Krey, G. Luderer, L. Clarke, E. Kriegler: **Getting from here to there – Energy technology transformation pathways in the EMF27 scenarios**

Climatic Change 123: 369-382, DOI: 10.1007/s10584-013-0947-5,
http://rd.springer.com/article/10.1007/s10584-013-0947-5

Abstract: Based on a large number of energy-economic and integrated assessment models, the Energy Modeling Forum (EMF) 27 study systematically explores the implications of technology cost and availability for feasibility and macroeconomic costs of energy system transformations toward climate stabilization. At the highest level, the technology strategy articulated in all the scenarios in EMF27 includes three elements: decarbonization of energy supply, increasing the use of low-carbon energy carriers in end-use, and reduction of energy use. The way that the scenarios differ is in the degree to which these different elements of strategy are

implemented, the timing of those implementations, and the associated macroeconomic costs. The study also discusses the value of individual technologies for achieving climate stabilization. A robust finding is that the unavailability of carbon capture and storage and limited availability of bioenergy have the largest impact on feasibility and macroeconomic costs for stabilizing atmospheric concentrations at low levels, mostly because of their combined ability to remove carbon from the atmosphere. Constraining options in the electric sector such as nuclear power, wind and solar energy in contrast has a much smaller impact on the cost of mitigation.

2.3 G.J. Blanford, E. Kriegler, M. Tavoni: **Harmonization vs. fragmentation: overview of climate policy scenarios in EMF27**

Climatic Change 123: 383-396, DOI: 10.1007/s10584-013-0951-9, http://rd.springer.com/article/10.1007/s10584-013-0951-9

Abstract: This paper synthesizes results of the multi-model Energy Modeling Forum 27 (EMF27) with a focus on climate policy scenarios. The study included two harmonized long-term climate targets of 450 ppm CO2-e (enforced in 2100) and 550 pm CO2-e (not-to-exceed) as well as two more fragmented policies based on national and regional emissions targets. Stabilizing atmospheric GHG concentrations at 450 and 550 ppm CO2-e requires a dramatic reduction of carbon emissions compared to baseline levels. Mitigation pathways for the 450 CO2-e target are largely overlapping with the 550 CO2-e pathways in the first half of the century, and the lower level is achieved through rapid reductions in atmospheric concentrations in the second half of the century aided by negative anthropogenic carbon flows. A fragmented scenario designed to extrapolate current levels of ambition into the future falls short of the emissions reductions required under the harmonized targets. In a more aggressive scenario intended to capture a break from observed levels of stringency, emissions are still somewhat higher in the second half due to unabated emissions from non-participating countries, emphasizing that a phase-out of global emissions in the long term can only be reached with full global participation. A key finding is that a large range of energy-related CO2 emissions can be compatible with a given long-term target, depending on assumptions about carbon cycle response, non-CO2 and land use CO2 emissions abatement, partly explaining the spread in mitigation costs.

2.4 G. Luderer, V. Krey et al.: **The role of renewable energy in climate stabilization: results from the EMF27 scenarios**

Climatic Change 123: 427-441, DOI: 10.1007/s10584-013-0924-z, http://rd.springer.com/article/10.1007/s10584-013-0924-z

Abstract: This paper uses the EMF27 scenarios to explore the role of renewable energy (RE) in climate change mitigation. Currently RE supplies almost 20 % of global electricity demand. Almost all EMF27 mitigation scenarios show a strong increase in renewable power production, with a

substantial ramp-up of wind and solar power deployment. In many scenarios, renewables are the most important long-term mitigation option for power supply. Wind energy is competitive even without climate policy, whereas the prospects of solar photovoltaics (PV) are highly contingent on the ambitiousness of climate policy. Bioenergy is an important and versatile energy carrier; however—with the exception of low temperature heat—there is less scope for renewables other than biomass for non-electric energy supply. Despite the important role of wind and solar power in climate change mitigation scenarios with full technology availability, limiting their deployment has a relatively small effect on mitigation costs, if nuclear and carbon capture and storage (CCS)—which can serve as substitutes in low-carbon power supply—are available. Limited bioenergy availability in combination with limited wind and solar power by contrast, results in a more substantial increase in mitigation costs. While a number of robust insights emerge, the results on renewable energy deployment levels vary considerably across the models. An in-depth analysis of a subset of EMF27 reveals substantial differences in modeling approaches and parameter assumptions. To a certain degree, differences in model results can be attributed to different assumptions about technology costs, resource potentials and systems integration.

2.5 D.McCollum, N.Bauer et al.: **Fossil resource and energy security dynamics in conventional and carbon-constrained worlds**

Climatic Change 123: 413-426, DOI: 10.1007/s10584-013-0939-5, http://rd.springer.com/article/10.1007/s10584-013-0939-5

Abstract: Fossil resource endowments and the future development of fossil fuel prices are important factors that will critically influence the nature and direction of the global energy system. In this paper we analyze a multi-model ensemble of long-term energy and emissions scenarios that were developed within the framework of the EMF27 integrated assessment model inter-comparison exercise. The diverse nature of these models highlights large uncertainties in the likely development of fossil resource (coal, oil, and natural gas) consumption, trade, and prices over the course of the twenty-first century and under different climate policy frameworks. We explore and explain some of the differences across scenarios and models and compare the scenario results with fossil resource estimates from the literature. A robust finding across the suite of IAMs is that the cumulative fossil fuel consumption foreseen by the models is well within the bounds of estimated recoverable reserves and resources. Hence, fossil resource constraints are, in and of themselves, unlikely to limit future GHG emissions this century. Our analysis also shows that climate mitigation policies could lead to a major reallocation of financial flows between regions, in terms of expenditures on fossil fuels and carbon, and can help to alleviate near-term energy security concerns via the reductions in oil imports and increases in energy system diversity they will help to motivate. Aggressive efforts to promote energy efficiency are, on their own, not likely to lead to markedly

greater energy independence, however, contrary to the stated objectives of certain industrialized countries.

2.6 S.K. Rose, E. Kriegler et al.: **Bioenergy in energy transformation and climate management**

Climatic Change 123: 477-493, DOI: 10.1007/s10584-013-0965-3, http://rd.springer.com/article/10.1007/s10584-013-0965-3

Abstract: This study explores the importance of bioenergy to potential future energy transformation and climate change management. Using a large inter-model comparison of 15 models, we comprehensively characterize and analyze future dependence on, and the value of, bioenergy in achieving potential long-run climate objectives. Model scenarios project, by 2050, bioenergy growth of 1 to 10 % per annum reaching 1 to 35 % of global primary energy, and by 2100, bioenergy becoming 10 to 50 % of global primary energy. Non-OECD regions are projected to be the dominant suppliers of biomass, as well as consumers, with up to 35 % of regional electricity from biopower by 2050, and up to 70 % of regional liquid fuels from biofuels by 2050. Bioenergy is found to be valuable to many models with significant implications for mitigation and macroeconomic costs of climate policies. The availability of bioenergy, in particular biomass with carbon dioxide capture and storage (BECCS), notably affects the cost-effective global emissions trajectory for climate management by accommodating prolonged near-term use of fossil fuels, but with potential implications for climate outcomes. Finally, we find that models cost-effectively trade-off land carbon and nitrous oxide emissions for the long-run climate change management benefits of bioenergy. The results suggest opportunities, but also imply challenges. Overall, further evaluation of the viability of large-scale global bioenergy is merited.

3. Other LIMITS peer reviewed papers

3.1 M. Tavoni, E. Kriegler, K. Riahi, D. P. van Vuuren, T. Aboumahboub, A. Bowen, K. Calvin, E. Campiglio, T. Kober, J. Jewell, G. Luderer, G. Marangoni, D. McCollum, M. van Sluisveld, A. Zimmer, B. van der Zwaan (2014): **Post-2020 climate agreements in the major economies assessed in the light of global models**
Nature Climate Change, Nature Publishing Group,
DOI: 10.1038/nclimate2475
http://dx.doi.org/10.1038/nclimate2475

Abstract: Integrated assessment models can help in quantifying the implications of international climate agreements and regional climate action. This paper reviews scenario results from model intercomparison projects to explore different possible outcomes of post-2020 climate negotiations, recently announced pledges and their relation to the 2 °C target. We provide key information for all the major economies, such as the year of emission peaking, regional carbon budgets and emissions allowances. We highlight the distributional consequences of climate policies, and discuss the role of carbon markets for financing clean energy investments, and achieving efficiency and equity.

3.2 J. Jewell, A. Cherp and K. Riahi (2014): **Energy security under de-carbonization scenarios: an assessment framework and evaluation under different technology and policy choices**
Energy Policy, Elsevier, vol. 65, 743–760,
DOI: 10.1016/j.enp ol.2013.10.051
http://www.sciencedirect.com/science/article/pii/S0301421513010744

Abstract: How would a low-carbon energy transformation affect energy security? This paper proposes a framework to evaluate energy security under long-term energy scenarios generated by integrated assessment models. Energy security is defined as low vulnerability of vital energy systems, delineated along geographic and sectoral boundaries. The proposed framework considers vulnerability as a combination of risks associated with inter-regional energy trade and resilience reflected in energy intensity and diversity of energy sources and technologies. We apply this framework to 43 scenarios generated by the MESSAGE model as part of the Global Energy Assessment, including one baseline scenario and 42 'low-carbon' scenarios where the global mean temperature increase is limited to 2°C over the pre-industrial level. By and large, low-carbon scenarios are associated with lower energy trade and higher diversity of energy options, especially in the transport sector. A few risks do emerge under low-carbon scenarios in the latter half of the century. They include potentially high trade in natural gas and hydrogen and low diversity of

electricity sources. Trade is typically lower in scenarios which emphasize demand-side policies as well as non-tradable energy sources (nuclear and renewables) while diversity is higher in scenarios which limit the penetration of intermittent renewables.

Keywords: Energy security; Climate change; Indicators

3.3 F. Humpenöder, A. Popp, J.P. Dietrich, D. Klein, H. Lotze-Campen, M. Bonsch, B.L. Bodirsky, I. Weindl, M. Stevanovic, C. Müller (2014): **Investigating afforestation and bioenergy**
Environmental Research Letters, IOP Publishing, vol. 9/Issue 6, 064029,
DOI: 10.1088/1748- 9326/9/6/064029,
http://www.sciencedirect.com/science/article/pii/S0301421512001322

Abstract: The land-use sector can contribute to climate change mitigation not only by reducing greenhouse gas (GHG) emissions, but also by increasing carbon uptake from the atmosphere and thereby creating negative CO2 emissions. In this paper, we investigate two land-based climate change mitigation strategies for carbon removal: (1) afforestation and (2) bioenergy in combination with carbon capture and storage technology (bioenergy CCS). In our approach, a global tax on GHG emissions aimed at ambitious climate change mitigation incentivizes land-based mitigation by penalizing positive and rewarding negative CO2 emissions from the land-use system. We analyze afforestation and bioenergy CCS as standalone and combined mitigation strategies. We find that afforestation is a cost-efficient strategy for carbon removal at relatively low carbon prices, while bioenergy CCS becomes competitive only at higher prices. According to our results, cumulative carbon removal due to afforestation and bioenergy CCS is similar at the end of 21st century (600–700 GtCO2), while land-demand for afforestation is much higher compared to bioenergy CCS. In the combined setting, we identify competition for land, but the impact on the mitigation potential (1000 GtCO2) is partially alleviated by productivity increases in the agricultural sector. Moreover, our results indicate that early-century afforestation presumably will not negatively impact carbon removal due to bioenergy CCS in the second half of the 21st century. A sensitivity analysis shows that land-based mitigation is very sensitive to different levels of GHG taxes. Besides that, the mitigation potential of bioenergy CCS highly depends on the development of future bioenergy yields and the availability of geological carbon storage, while for afforestation projects the length of the crediting period is crucial.

3.4 A. F. Hof , A. Kumar, S. Deetman, S. Ghosh , D. P. van Vuuren (2014): **Disentangling the ranges: climate policy scenarios for China and India**
Regional Environmental Change, Open Access Articles, Springer Verlag,
DOI: 10.1007/s10113-014-0721-x
http://rd.springer.com/article/10.1007/s10113-014-0721-x

Abstract: Greenhouse gas emissions in China and India have been increasing rapidly over the last decade. Scenario studies can provide insight into expected future trends and the emission reduction potential in these regions. The scenarios show that growing population, gross domestic product, and energy demand are likely to lead to a further increase in emissions. At the same time, a decreasing emission intensity would still allow to create decarbonization scenarios in line with the requirements for reaching a maximal warming of 2 °C. There is, however, a wide range of assumptions across these studies. Based on the literature review, this paper observes that key assumptions in scenarios developed by national institutes in China and India differ from those presented by international studies or modeling teams. We explore how this—and other factors like data availability—may influence the interpretation of the scenarios and how international and national modeling groups could learn from each other. Our main recommendation is for more extensive collaboration between national and international research groups, so that national and international scenario studies can be compared in more detail in order to support international negotiations.

3.5 A.Cherp, and J.Jewell (2014): **The Concept of Energy Security: Beyond the 4As**
Energy Policy, Elsevier, Vol. 75: 415-421, DOI:10.1016/j.enpol.2014.09.005,
http://www.sciencedirect.com/science/article/pii/S0301421514004960

Abstract: Energy security studies have expanded from their classic beginnings following the 1970s oil crises to encompass various energy sectors and increasingly diverse issues. This viewpoint contributes to the re-examination of the meaning of energy security that has accompanied this expansion. Our starting point is that energy security is an instance of security in general and thus any concept of it should address three questions: "Security for whom?", "Security for which values?" and "Security from what threats?" We examine an influential approach - the '4As of energy security' (availability, accessibility, affordability, and acceptability) and related concepts of energy security - to show that they do not answer or even ask these questions. We subsequently summarize recent studies which propose a distinctly different concept of energy security as 'low vulnerability of vital energy systems'. This approach opens the road for detailed exploration of vulnerabilities as a combination of risks and resilience and of the links between vital energy systems and critical social functions. The examination of energy security framed by this concept involves several scientific disciplines and provides a useful platform for scholarly analysis and informed policy choices.

3.6 G.C.K. Leung, A. Cherp, J. Jewell, Y. Wei (2014): **Securitization of Energy Supply Chains in China**
Applied Energy, Elsevier, Volume 123, June 2014, 316–326,
DOI: 10.1016/j.ape nergy.2013.12.016,
http://www.sciencedirect.com/science/article/pii/S0306261913010155

Abstract: Energy policies in China, the world's largest energy consumer, are an important factor in shaping the global energy system. While scholars agree that energy security is a major driver of China's energy policies, there is insufficient understanding of what exactly constitutes China's energy security from the policy perspective. We apply recent insights from the Global Energy Assessment, particularly the idea of vital energy systems, and the securitization theory to propose a framework for explaining China's energy security policies in their historic evolution. We pay specific attention to explaining how particular energy supply chains are constructed and securitized. We draw data from over 300 Chinese and over 100 English publications and 30 interviews with energy officials and experts in China. We demonstrate that China's focus on vulnerabilities of its oil supply chain at the expense of improving the reliability of domestic electricity supply is not accidental. It has its roots in historic events, properties of energy systems, as well as the presence of powerful institutional agents interested in securitizing the oil supply chain but not other vital energy systems. We suggest that this focus on the oil supply chain is likely to be maintained in the future, possibly accompanied by increasing concerns over natural gas supply chains. Our proposed framework for energy security policy analysis can be used for other countries and jurisdictions.

Keywords: Energy security; Supply chain; China; Institution; Governance; Securitization

3.7 S. Carrara and G. Marangoni (2013): **Non-CO2 greenhouse gas mitigation modeling with marginal abatement cost curv es: technical change, emission scenarios and policy costs**
Economics and Policy of Energy and the Environment, FrancoAngeli, 01/2013, 91-124, DOI: 10.3280/EFE2013-001006
http://www.francoangeli.it/riviste/Scheda_Rivista.aspx?IDArticolo=48877&Tipo=Articolo%20PDF&lingua=it&idRivista=10

Abstract: The abatement of non-CO2 greenhouse gases (OGHG) has proved to be of paramount importance for reaching global mitigation targets. The modeling of their abatement is normally carried out referring to marginal abatement cost (MAC) curves, which by now represent a standard approach for such an analysis. As no evolution scenarios are available to describe future mitigation opportunities for OGHGs, exogenous technical progress factors (TP) are normally imposed, producing progressive MAC dilatation over time.
The main aim of this work is to perform a sensitivity analysis evaluating climate and economic effects of imposing various TPs under different policy scenarios. The analysis shows that TP variation has a considerable impact on the climatic and economic results.

3.8 D. van Vuuren and E. Stehfest (2013): **If climate action becomes urgent: the importance of response times for various climate strategies**
Economics and Policy of Energy and the Environment, FrancoAngeli, Climatic Change, Springer Netherlands, Vol. 121/Issue 3, 473-486, DOI: 0.1007/s10584-013-0769-5
http://rd.springer.com/article/10.1007/s10584-013-0769-5/fulltext.html

Abstract: Most deliberations on climate policy are based on a mitigation response that assumes a gradually increasing reduction over time. However, situations may occur where a more urgent response is needed. A key question for climate policy in general, but even more in the case a rapid response is needed, is: what are the characteristic response times of the response options, such as rapid mitigation or solar radiation management (SRM)? This paper explores this issue, which has not received a lot of attention yet, by looking into the role of both societal and physical response times. For mitigation, technological and economic inertia clearly limit reduction rates with considerable uncertainty corresponding to political inertia and societies' ability to organize rapid mitigation action at what costs. The paper looks into a rapid emission reductions of 4–6 % annually. Reduction rates at the top end of this range (up to 6 %) could effectively reduce climate change, but only with a noticeable delay. Temperatures could be above those in the year of policy introduction for more than 70 years, with unknown consequences of overshoot. A strategy based on SRM is shown to have much shorter response times (up to decades), but introduces an important element of risk, such as ocean acidification and the risk of extreme temperature shifts in case action is halted. Above all, the paper highlights the role of response times in designing effective policy strategies implying that a better understanding of these crucial factors is required.

3.9 K. Jiang, X. Zhuang, R. Miao, C. Heb (2013): **China's role in attaining the global 2°C target**
Climate Policy, Earthscan, sup01/13, 55-69, DOI: 10.1080/14693062.2012.746070,
http://www.tandfonline.com/doi/abs/10.1080/14693062.2012.746070

Abstract: In the recent climate change negotiations it was declared that the increase in global temperature should be kept below 2°C by 2100, relative to pre-industrial levels. China's CO2 emissions from energy and cement processes already account for nearly 24% of global emissions, a trend that is expected to keep increasing. Thus the role of China in global GHG mitigation is crucial. A scenario analysis of China's CO2 emissions is presented here and the feasibility of China reaching a low-carbon scenario is discussed. The results suggest that recent and continued technological progress will make it possible for China to limit its CO2 emissions and for these emissions to peak before 2025 and therefore that the global 2°C target can be achieved.

3.10 I. Alon and A. Cherp (2012): **Is China's outward investment in oil a global security concern?**

Columbia FDI perspectives, Columbia Vale Centre, 81, 1-3
http://academiccommons.columbia.edu/item/ac:154027

Abstract: The dramatic increase in investment by Chinese SOEs in overseas oil assets is primarily driven by energy security concerns. Whether such investment will benefit or harm energy security of other countries is hotly contested. On one hand, this investment can supplement the overall lack of investment in the sector, benefiting all consumers. On the other hand, it may exacerbate environmental and political problems associated with fossil fuels.

3.11 A. Cherp (2012): **Defining energy security takes more than asking around**

Energy Policy, Elsevier BV, vol. 48, 841-842, DOI: 10.1016/j.enpol.2012.02.016,
http://www.sciencedirect.com/science/article/pii/S0301421512001322

Abstract: The recent contribution by Benjamin Sovacool proposes 20 dimensions and 320 indicators of energy security in Asia. However, the method for identifying these dimensions and indicators – 64 semi-structured interviews – has three shortcomings. First, Asian policy makers responsible for energy security are absent from the pool of respondents dominated by academics. Second, no prioritization or contextualization of energy security concerns is attempted, leading to an excessively long generic list. Third, no disagreements between the interviewed experts are accounted for. Future attempts to define energy security based on perceptions should involve relevant social actors, include mechanisms for discriminating between primary and secondary concerns and find ways to constructively report on disagreements.

Keywords: Energy security; Asia; Definition

3.12 K. Jiang, H. Chenmin et al. (2012): **China's Emission Scenario toward global 2degree target**

Energy of China, Energy of China Press - National Development & Reform Commission, 16-19

Abstract: Globally 2 degree target by 2100 was confirmed in the international negotiation process in recent years. The remained question is whether this target is feasible or not by thinking slow progress in last decades even though Kyoto Protocol set up targets by 2010. The IPCC called research teams on modeling to analyze the possible pathway, policies options, and cost benefit analysis for GHG mitigation. China's CO2 emission from energy and cement process already accounts for nearly 24% of global emission, and the trend is expected to keep increasing. The role of

China in the global GHG mitigation is crucial. This paper presents the scenario analysis for China's CO2 emission in the background of global 2 degree target, and discussed the feasibility for the lower CO2 emission scenario in China. The finding says it is possible for China to limit CO2 emission, reach emission peak before 2025, which make the global 2 degree target feasible. And recent progress of key technologies, availability for further investment on low carbon, policy implementation make it much big possibility for China to go to low carbon emission development pathway.

4. LIMITS papers submitted to peer reviewed journals

4.1 D.E.H.J. Gernaat, D. P. van Vuuren, Maarten van den Berg, Katherine Calvin, Paul Lucas, Gunnar Luderer, Sander A.C. Otto, Shilpa Rao, Jessica Strefler (submitted): **Understanding the contribution of non-carbon dioxide gases in deep mitigation scenarios**

Submitted to Global Environmental Change, Elsevier Limited

Abstract: The combined 2010 emissions of methane (CH4), nitrous oxide (N2O) and the fluorinated gasses (F-gas) account for about 20-30% of total emissions and about 30% of radiative forcing. At the moment, most studies looking at reaching ambitious climate targets project the emission of carbon dioxide (CO2) to be reduced to zero (or less) by the end of the century. In order to support effective climate policy strategies we provide a more in-depth look at the role of non-CO2¬ emission sources (CH4, N2O and F-gases) in achieving deep mitigation targets (radiative forcing target of 2.8 W/m2 in 2100). This annex zooms in at the sectorial mitigation potential and the remaining non-CO2 emissions by using a set of different global energy-environment models. We find that by the end of the century in the current deep mitigation scenarios non-CO2 emissions could form the largest part of remaining greenhouse gas emissions. Most of the remaining methane emissions in 2100 in the climate mitigation scenario come from the livestock sector. Strong reductions are seen in the energy supply sector across all models. For N2O, less reduction potential is seen compared to methane and the sectoral differences are larger between the models. It is concluded that remaining non-CO2 emissions are critical for the feasibility of reaching ambitious climate targets and the associated costs.

Keywords: non-CO2 emissions; deep mitigation scenarios; model comparison; climate policy strategies

4.2 S.D. Herreras Martínez, A. Koberle, P. Rochedo, R. Schaeffer, A. Lucena, A. Szklo, S. Ashina, D.P. van Vuuren (submitted): **Possible energy futures for Brazil and the rest of Latin America in conservative and stringent mitigation pathways up to 2050**

Submitted to Technological Forecasting and Social Change, Elsevier Inc.

Abstract: Latin America has a unique position to address climate change impacts due to its many mitigation opportunities and its growing economy. This study applied two global and one regional integrated assessment models to assess the energy and emissions trends in Brazil and the rest of the Latin American region up to 2050 based on a set of scenarios consistent with current trends and with the 2°C global mitigation target. The models show that to achieve this target, deep CO_2 emission reductions are needed. The power sector offers the greatest mitigation opportunities.

The implementation of CCS, in combination with fossil fuels and bioenergy, and hydro, biomass and wind energy are identified in this study as the most promising low-carbon options for the region. The realistic implementation of these options will depend, however, on their capability to overcome the present technical, economic, environmental and social challenges. Besides, an appropriate policy framework to stimulate the transformation of the energy system is also important. Brazil is the first country in Latin America to adopt a national voluntary mitigation goal by law. However, the assessment of the effectiveness of this goal up to now becomes difficult due to the vague targets established.

4.3 P.L. Lucas, J. Nielsen, K. Calvin, D. McCollum, G. Marangoni, J. Strefler, B. van der Zwaan and D.P. van Vuuren (submitted): **Future energy system challenges for Africa: insights from Integrated Assessment Models**

Submitted to Energy for Sustainable Development, Elsevier

Abstract: Although Africa's share in the global energy system is only small today, the ongoing population 20 growth and economic development imply that this can change significantly. In this paper, we discuss 21 long-term energy developments in Africa using the results of the LIMITS model inter-comparison 22 study. The analysis focusses on the position of Africa in the wider global energy system and climate 23 mitigation. The results show a considerable spread in model outcomes. Without specific climate 24 policy, Africa's share in global CO2 emissions is projected to increase from around 1-4% today to 3-25 23% by 2100. In all models, emissions only start to become really significant on a global scale after 26 2050. Furthermore, by 2030 still around 50% of total household energy use is supplied through 27 traditional bio-energy, in contrast to existing ambitions from international organisations to provide 28 access to modern energy for all. After 2050, the energy mix is projected to converge towards a global 29 average energy mix with high shares of fossil fuels and electricity use. Finally, although the continent 30 is now a large net exporter of oil and gas, towards 2050 it most likely needs most of its resources to 31 meet its rapidly growing domestic demand. With respect to climate policy, the rapid expansion of the 32 industrial and the power sector also create large mitigation potential and thereby the possibility to 33 align the investment peak in the energy system with climate policy and potential revenues from 34 international carbon trading.

Keywords: Africa; Integrated Assessment Modelling; energy; climate policy; energy access; energy trade

5. LIMITS papers to be submitted to peer reviewed journals

5.1 S. Rao, Z. Klimont, J. Leitao, K. Riahi, R. van Dingenen, L. Aleluia Reis, K. Calvin, F. Dentener, L. Drouet, S. Fujimori, J.H.M. Harmsen, G. Luderer, C. Heyes, D. McCollum, J. Strefler, M. Tavoni, D. van Vuren (2015): **Co-Benefits of Climate Policies for Improved Air Quality / A multi-model evaluation**

To be submitted to Environmental Research Letters, Institute of Physics Publishing

Abstract: Air pollution and climate change are increasingly a joint research area with a focus on the short-term health and ecosystem impacts associated with air pollution and the longer-term concerns on the radiative forcing from both short-lived aerosols and GHGs. There is a need for long-term scenarios of air pollution from integrated assessment models that include both clear and documented assumptions in terms of projecting such emissions and a broad representation of pollution control policies in order to evaluate the effectiveness of such policies and the possible co-benefits accruing from climate change policies. This paper addresses for the first time an analysis of the development of global air pollutants over the century across a number of different integrated assessment models, using harmonized assumptions on air pollution legislation until 2030. Key research questions analyzed include the implications of different assumptions on pollution legislations and energy system development for the evolution of short-term and long-term emissions, resulting particulate matter concentrations and human health impacts and secondly how these interactions could influence the co-benefits of climate change policies. The results indicate that continued air pollution policies will be critical in achieving near-term improvements of air pollution. Significant co-benefits are found to accrue from climate change policies in terms of improvements in air quality over the medium and long-term as a result of the associated transitions in the energy-system. The extent of such co-benefits varies significantly both regionally and across pollutants, depending upon the stringency of the short-term pollution policies in place; the types of long-term energy transitions that climate policies entail; and additional assumptions on issues related to energy access policies and technological change. The co-benefits of implementing such climate change policies are found to accrue the most to developing countries in terms of reduced concentrations of PM2.5 and related health impacts.

5.2 J. Jewell, A. Cherp, V. Vinichenko, D. McCollum, K. Riahi, T. Aboumahboub, N. Bauer, M. Harmsen, T. Kober, G. Marangoni, M. Tavoni, B. van der Zwaan, D. van Vuuren (2015): **Energy security has little impact on emissions but climate change mitigation reduces energy imports**

To be submitted to Proceedings of the National Academy of Sciences of the United States, National Academy of Sciences

Abstract: With the rise of energy demand in Asia, the worldwide rush for unconventional gas and oil, and most recently the Ukraine crisis, energy security is at the top of the political agenda. At the same time, policy-makers are concerned about climate change caused by rising greenhouse gas emissions. It is important to understand how policies to tackle climate change and energy security would interact. While there is a growing literature on energy security implications of climate change mitigation, so far there has not been a systematic analysis of the climate implications of energy security policies. Using 5 state-of the-art energy-economy models we examine 6 long-term global scenarios under a combination of energy and oil independence and climate policies. The scenario featuring the most stringent energy independence policies leads to greenhouse gas emission reductions that are insufficient to limit global average temperature increase to 2°C (only 5%-15% cumulatively over the 21st century), despite a decrease in coal-use in China, India and Africa. Policy costs of achieving energy independence are 10 times lower than of ensuring climate stabilization. In both the highest proportion of the costs is borne by the former Soviet Union and Middle Eastern countries due to lost energy export revenues. In the oil independence scenario there is a switch to other fossil fuels in the transport sector and no noticeable reduction of greenhouse gas emissions. In contrast, policies to stabilize greenhouse gas emissions would result in a significant reduction of global energy trade and energy imports of individual regions. Thus, the relationship between energy security and climate policies is asymmetric.

5.3 E. De Cian, A. F. Hof, G. Marangoni, D.P. van Vuuren, M. Tavoni (2015): **Sharing the burden of mitigation, adaptation, and damages**

To be submitted to Environmental Research Letters

Abstract: This paper uses two alternative modelling frameworks combined with two sets of updated regional damage functions to analyze the implications of a scheme that aims at sharing the burden of mitigation costs associated with the 2°C, the residual impacts from climate change, and the associated adaptation costs. We assess the residual climate change damages of the 2°C and the resulting adaptation costs, and explore how emission rights would be allocated if the sum of mitigation costs, residual damage, and adaptation costs as share of GDP would be equalized across regions, compared to mitigation-based equity principles. Sharing the burden of the total costs of climate change requires a different emission allocation compared to what needed to share the burden of mitigation costs only. More

resources, in the order of 100-200 USD bn already in 2030, would flow to the high impact countries in South and East Asia, India, and Africa altogether. OECD countries would be the major contributor to finance those transfers, but lower-than-average-impact-cost countries, such as China, would also need to share the compensation for the new items added to the climate change burden.

Keywords: Adaptation; Mitigation; Burden sharing; Climate Policy; Integrated Assessments

5.4 M. van Sluisveld, M. Harmsen, D. McCollum, K. Riahi, H. Rösler, M. Tavoni, D. van Vuuren, C. Wilson, B. van der Zwaan (2015): **The feasibility and implications of future technology trajectories in 2°C scenarios**

To be submitted to Global Environmental Change, Elsevier Limited

Abstract: This paper assesses the feasibility of required rates of change as depicted under the 2°C objective by comparing future patterns of energy system changes with what has been observed in historical records. Several change indicators have been analysed varying in terms of aggregation (technology-specific or energy system wide), time scale (short or long-term), representation (relative or absolute) and speed (per year or over a lifetime) and extent (single year or over a period of time). We find that modeled rates of change for capacity expansion are within the range of those observed historically for the following decade but increase to unprecedented levels after 2030. In terms of technology diffusion we find that modeled technology diffusion is generally more conservative under the 2°C objective, compared to what has been observed historically. Coal with CCS and biomass with CCS show the shortest diffusion lifecycle, whereas renewable energy technologies require nearly a century to fully materialize (ranging between 60-80 years for solar PV and 75-90 years for wind). On the more aggregate energy system level it is confirmed that transformations in the energy system under 2°C constraints are increasingly diverging from historical norms.

Keywords: climate mitgation, transitions, integrated assessment, modelling, validation.

5.5 M.A.E. van Sluisveld, S. Herreras Martínez, V. Daioglou and D.P. van Vuuren (2015): **The implications of lifestyle change in 2°C scenarios**

To be submitted to Technological Forecasting and Social Change, Elsevier Inc.

Abstract: Most model studies involve an abundance of technical solutions in order to meet the 2°C climate target, such as renewable, carbon caputer and energy efficiency technologies. However, studies have that the 2°C target to becomes increasingly difficult to attain with technical solutions alone. This indicates the need to look more into non-economic and non-technological drivers of energy system transformations that have generally

not been included in long-term emission scenario studies. This study implements a set of lifestyle change measures for residential energy use, mobility and waste management in an integrative assessment context to analyze the implications of lifestyle changes under baseline and 2°C climate mitigation scenarios. We find that lifestyle change measures mostly affect the end-use sectors in the absence of more stringent climate target, and alone are insufficient to meet the 2°C climate objective. However, by preemptively reducing the energy demand and transitioning to a greater electrified system, opportunities are unlocked for greening the more resilient sectors (such as the transport sector with substantial additional emission reductions) or for more cost-efficient mitigation under 2°C ambitions without introducing additional major changes to the energy infrastructure. Integrated assessment models generally do not explicitly model behaviour (embedding behavioural heterogeneity in e.g. stylizing behavior change through proxy indicators, price elasticity or exogenous data), hence further research is recommended in how to internalize behavior into integrative assessment studies.

Keywords: Climate mitigation; lifestyle; integrated assessment models

5.6 J. Leitao, R. Van Dingenen et al. (2015): **Assessment of co-benefits from climate and air quality policies with the TM5-FASST tool**

To be submitted to Environmental Science and Policy

Abstract: This paper makes an analysis of the LIMITS scenarios developed in a multi IAM set-up (see paper proposal Rao et al). Where Rao et al. discuss emission trends of ‘classical’ pollutants under various climate and air quality policy configurations, we evaluate here the impacts of these policy scenarios on human health and resulting premature mortalities. We quantify in particular the co-benefit of climate policies in combination with different assumed stringencies of air quality policies. This analysis is done in an ensemble-approach, using the TM5-FASST tool on the set of emission scenarios provided by the 6 participating IAMs. Where the Rao paper keeps a global overview, here we focus more on regional differences and the contribution of individual economic sectors.
Initial results indicate that health related impacts increase significantly between 2010 and 2030 if no extra efforts are made to reduce air pollution with more than 2 million additional premature deaths taking place. Improvements of air quality incurring from the application of climate policies, on top of currently decided air quality legislation, lead to almost 600 thousand lives saved globally in 2030, compared to the reference policy case. On global level, this co-benefit is close to half of what could, ideally, be achieved with stringent end-of-pipe air quality controls (in the absence of climate policies). The ideal combination of policies aiming at reducing both the air pollution and climate change could potentially have a much higher impact reducing global premature mortalities from air pollution by approximately 1.7 million cases. The largest co-benefits in terms of reductions in PM2.5 concentrations all accrue in developing countries, mainly in Asia, with almost 400 thousand lives saved in India and China

combined, where climate policies are largely beneficial in reducing the atmospheric concentrations of PM2.5.

5.7 R. Van Dingenen, J. Leitao, et al. (2015): **How do climate and air quality policies affect emissions and near-term climate forcing from air pollutants?**

Proposed Journal: Environmental Science and Policy

Abstract: Short-lived air pollutants (PM, O3) interact with radiation and consequently may have an impact on regional and global climate. Scattering species like ammonium sulphate, ammonium nitrate, and organic carbon contribute to cooling, whereas black carbon is an efficient absorber leading to a warming of the atmosphere. Further, the pollutant O3 is also a strong greenhouse gas.

Many linkages between air pollution and climate change have been elucidated by scientific research of the past 20 years In particular the role of air pollutants as short-lived climate forcers has received attention, both as an “inconvenient truth” for climate change policy making (Raes and Seinfeld, 2009) but also as an opportunity to reduce global warming and regional climate change impacts in the near term (UNEP, 2011).

In this paper we use the TM5-FASST tool to evaluate for the first time a consistent configuration of realistic combined air quality and climate policies for the years 2030 (and 2050?), focusing on near-term climate metrics of air pollutants. These scenarios were developed in the LIMITS project in a multi-model IAM set-up (ref). The project has assessed a variety of possible post 2020 climate architectures, putting them in relation with the likelihood of achieving 2°C, and devising climate mitigation strategies and evaluating economic consequences. Simultaneously, consistent air pollutant emission scenarios were developed for different degrees of stringency (Rao et al., paper in preparation).

We specifically evaluate the near term climate feedback of short lived pollutants whose emissions are affected by greenhouse gas abatement scenarios, as well as the climate impact of air quality policies superimposed on climate policies.