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Introduction to the AMPERE model intercomparison studies on the economics of climate stabilization

1. Motivation and research objectives of AMPERE

Climate stabilization requires ambitious policies to transition to low carbon economies within this century. Although the international community has recognized the goal to limit global warming to 2 °C above preindustrial levels, it is uncertain what level of mitigation activity can be expected over the coming decades. International climate policy to date has been fragmented and focused on the short term, and the emissions abatement commitments made for 2020 at the conferences of parties in Copenhagen and Cancun do not set a trajectory for climate stabilization unless they are followed by substantially increased ambitions (Clarke et al., 2014). What does the lack of near-term ambition imply for the possibility of still achieving ambitious climate goals? What are the challenges and opportunities for unilateral action by some regions if stringent international climate policies still took decades to emerge?

These questions are addressed in this special issue of Technological Forecasting and Social Change by drawing upon the results of twelve global energy-economy, computable general equilibrium and integrated assessment models that participated in the EU-funded AMPERE project (www.ampere-project.eu). AMPERE stands for "*Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates*", and has brought together 22 European and international research institutes to gain a better understanding of the mitigation challenges ahead. AMPERE conducted several model intercomparison studies on the implications of short-term climate action for the achievability of long-term targets (Riahi et al., 2014-in this issue), the implications of regional climate policies and staged accession to a global climate regime (Kriegler et al., 2014a-in this issue), the costs and benefits of the climate policy options faced by the European Union (Capros et al., 2014), and model diagnostics (Kriegler et al., 2014b-in this issue). The purpose of involving a wide range of models with different structures and assumptions was to improve the robustness of findings by identifying and diagnosing differences in model results. To this end, modeling work on mitigation pathways for the 21st century can be seen as a mapping exercise exploring consequences of different courses of action in a range of plausible environments. All mapping exercises have limitations, but will be useful as long as navigation is served better with than without them. If maps are known to be imperfect, it can help to consult a number of them to identify robust and uncertain features of the space to navigate. The multiplicity of results and assumptions in model comparison exercises thus provides a more comprehensive picture and can warn users against too much confidence in a single number or action. The key findings of the AMPERE project were summarized for decision makers and stakeholders in (Kriegler et al., 2014c). A database of the scenarios developed in the AMPERE studies has also been made available (The AMPERE consortium, 2014).

2. Overview of the special issue

This special issue primarily discusses two of the AMPERE model intercomparison studies, with several articles dedicated to either. They both examine the impact of near-term policies on mitigation pathways throughout the 21st century. One study on delayed action (Riahi et al., 2014-in this issue) looks at how global emission targets for the near term (until 2030) affect the cost and attainability of long-term climate targets under different assumptions about technology availability. The other study (Kriegler et al., 2014a-in this issue) investigates scenarios of staged accession, in which early movers unilaterally advance their climate policy in the near term whereas other regions phase in equivalent policies after 2030. The two studies examine these issues from various angles, using two sets of scenarios run by multiple models and analyzed in a total of 17 articles. Finally, one of the articles in this special issue is dedicated to diagnosing the behavior of the various models employed by AMPERE (Kriegler et al., 2014b-in this issue).

The basic structure of the climate policy scenarios investigated in the studies on delayed action and staged accession is shown in Fig. 1. Delayed action is conceptualized as moderate mitigation effort until 2030 followed by the adoption of a long-term climate target which would have implied more stringent near-term action if it had been adopted immediately (Fig. 1A). To adhere to the same climate target, characterized in terms of an emission budget for the 21st century, the delayed adoption of the target leads to a steeper decline of emissions until mid-

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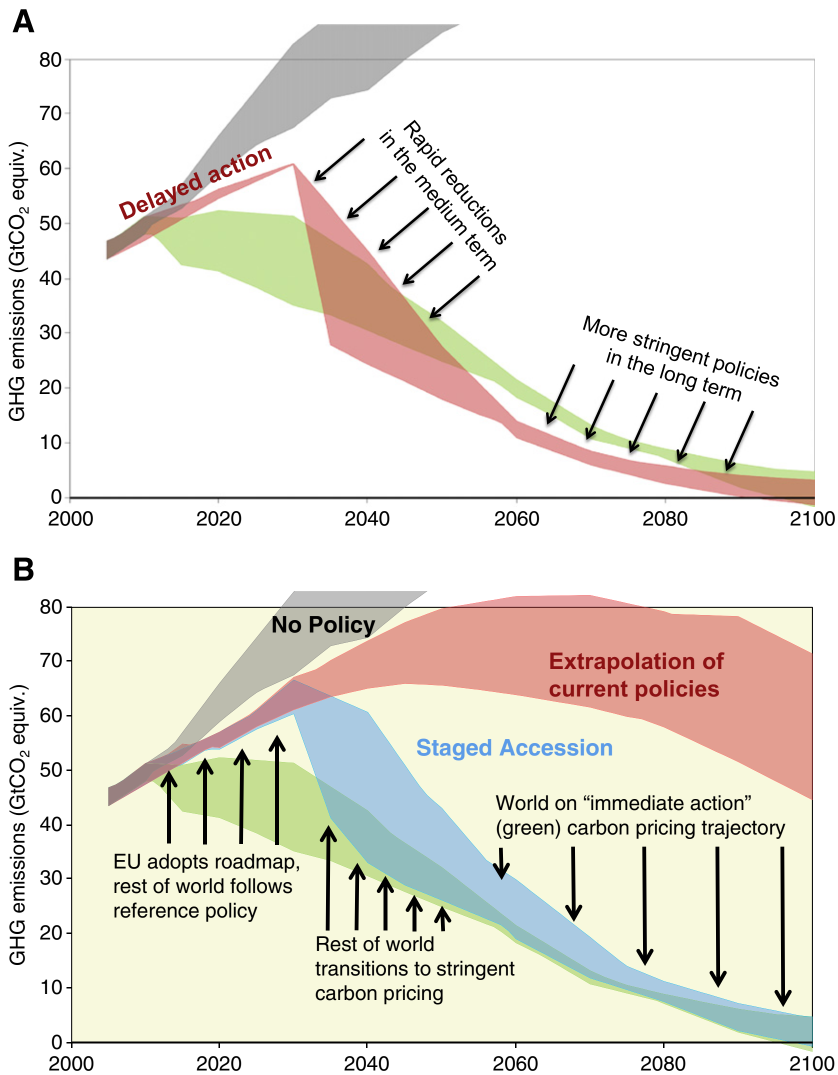

Fig. 1. Greenhouse gas emission pathways in the studies on delayed action (Panel A) and on staged accession (Panel B). Both studies feature roughly equivalent benchmark cases of no climate policy (gray funnel) and immediate climate policy for a 2 °C target (green funnel). The delayed action scenarios represented by the red funnel in Panel A adhere to the same emissions budget as the optimal climate policy case, thus compensating higher near-term emissions with deeper emission cuts in the long run. The staged accession scenarios (blue funnel in Panel B), on the other hand, shift from following the pathway of current policies until 2030 to the long-term emissions pathway of the immediate climate action case. Source Panel A: Riahi et al, 2014.

century, and lower emissions in the long run compared to immediate action on the target. The study on staged accession formulated a reference policy case of fragmented regional action based on an extrapolation of current policies and pledges. This reference scenario was used as an anchor to formulate a period of staged accession where front runner regions embark on mitigation compatible with the long-term target early on, while the rest of the world follows their reference policy until 2030 and then transition to the immediate action trajectory until 2050 (Fig. 1B). While the study on delayed action examines the dynamics of different mitigation paths adhering to the same carbon budget, the staged accession scenarios include a relaxation of carbon budgets as acceding regions do not compensate their higher near-term emissions.

Near-term policies are very relevant for long-term climate targets because of the long-lived nature of prominent greenhouse gases and the inertia of energy systems, in which investments in the near term can impact the path of the energy economy for subsequent decades. It can also be argued that without some countries demonstrating near-term success with economical emissions reduction, a concentrated global effort is unlikely to emerge. The implications of delayed action for the attainability of climate targets have been investigated before by a number of individual model studies (Keppo and Rao, 2007; Bosetti et al., 2009a; Krey and Riahi, 2009; van Vliet et al., 2009;

Vliet et al., 2012; Rogelj et al., 2013a,b; Luderer et al., 2013a) and a few model comparison studies (Clarke et al., 2009; Jakob et al., 2012; Luderer et al., 2013b). The AMPERE study on delayed action is the most comprehensive model comparison on the topic to date. It is the first to focus on 2030 as interim policy horizon, on the pure impact of delay (without consideration of climate policy fragmentation), and on the combined effects of delay and technology availability. Staged accession to a global climate policy regime has been investigated in the context of regionally differentiated mitigation action characterized by early movers and late adopters (Clarke et al., 2009; Jakob et al., 2012; Bosetti et al., 2009b; Calvin et al., 2009; Edmonds et al., 2008; Richels et al., 2009). The AMPERE study on staged accession provides a comprehensive multi-model analysis of trade-offs for early movers as well as late adopters. It is the first to evaluate these trade-offs relative to a reference policy rather than a no-policy baseline, to focus on the EU and China as front runners, and to consider that late adopters may not be willing to fully compensate excess emissions in the near term. Taken together, the two AMPERE studies constitute the most extensive exploration to date of the implications of near-term climate policy for the attainability of climate targets, and vice versa the implications of long-term climate policy objectives for near-term policy choices, using a large set of state-of-the art energy-economy and integrated assessment models. As such, they are part of a large-scale community effort to explore the space of future mitigation pathways, including complementary model comparison studies such as the project EMF27 on the role of mitigation technologies by the Stanford Energy Modelling Forum (Kriegler et al., 2014d; Krey et al., 2014; Blanford et al., 2014). Around 1000 new emissions scenarios have been produced in the context of this effort since 2010, 380 of which were developed in the two AMPERE studies presented here. The AMPERE scenarios have been collected in a database (The AMPERE consortium, 2014), and have contributed to the 5th Assessment Report of Working Group 3 of the IPCC (Clarke et al., 2014; AR5 senario database, IPCC, 2014).

2.1. Articles relating to the AMPERE study on delayed action

An overview of the study on delayed action, assessing the implications of near-term emission targets for the cost and attainability of long-term climate goals, is provided by (Riahi et al., 2014-in this issue). Nine energy-economy, computable general equilibrium and integrated assessment models (DNE21+, GCAM, IMACLIM, IMAGE, MERGE-ETL, MESSAGE-MACRO, POLES, REMIND, WITCH) participated in this study and provided a wealth of data that allows for insights into the economic and technical challenges of adhering to stringent emission budgets after aiming for more lenient emission targets in 2020 and 2030. These near-term targets follow the stringency of the national pledges from the Copenhagen Accord and Cancún Agreements. The analysis finds that such a near-term path would be insufficient to prevent further lock-in of energy systems into fossil fuels and would thus increase the post-2030 mitigation challenge compared to immediate action inducing strong near-term mitigation efforts. A lack of near-term shifts to low-carbon energy results in a need for substantially accelerating the rate of low-carbon energy deployment after 2030 in order to still meet stringent long-term climate goals. This becomes yet more challenging if technology choices are limited. For instance, carbon capture and storage (CCS) and the large-scale deployment of bioenergy may become indispensable for attaining a 2 °C temperature target if near-term policies follow the current pledges.

The issues of a lock-in into fossil fuel energy systems and the challenge of rapid energy system transition are discussed in two cross-cutting articles (Bertram et al., 2014-in this issue; Eom et al., 2014-in this issue) that identify robust results across participating models as well as some key model differences. Bertramet al., 2014-in this issue focus on the carbon lock-in implied by following the Copenhagen pledges until 2030. They find that near-term excess emissions mainly from the power sector have to be compensated by deeper emissions cuts particularly from final energy consumption after 2030. The difficulties in meeting a stringent long-term cumulative emissions target after 2030 are not only due to a lower remaining emissions budget but also due to capital stock inertias. For example, expansion of coal power capacity until 2030 leads to a significant amount of stranded capacities. Eom et al., 2014-in this issue focus on the energy system transition required in order to attain stringent long-term climate goals after following moderate near-term policies. They find that the largest shift to non-emitting technology would have to occur between 2030 and 2050 and that this shift would have to be larger if near-term emissions are higher or if technological capabilities to generate negative emissions, such as bioenergy combined with CCS, are limited.

Five articles add model-specific perspectives to the study on the implications of near-term emission targets, drawing from the particular strengths of individual participating models. The relationship between near-term emission targets and coal power capacity lock-in is analyzed in further depth by Johnson et al., 2014-in this issue based on the MESSAGE model results. They examine the stranded capacities created once an emissions budget is implemented. The analysis suggests a need for strengthening near-term emission targets, early deployment of CCS retrofits and improved energy efficiency in order to minimize stranded coal power capacities after 2030. The dynamics of low-carbon technology diffusion under different assumptions about policy timing and the existence of technology constraints is examined by Iyer et al., 2014-in this issue based on the GCAM model results. They find that the expansion of CCS and renewable energy technologies is more crucial for rapid and economical decarbonization than the expansion of nuclear power or bioenergy, although all of these options increase in relevance as stringent policy is delayed. Also focusing on the role of technology, Criqui et al., 2014-in this issue look at the POLES model results to characterize the potential impacts of technology availability, learning effects and technology breakthroughs. They find that a mix of technologies is required to achieve stringent climate goals, but that CCS and a large bioenergy potential are particularly important.

In addition to the availability of energy supply options, energy efficiency improvements on the demand side play an important role, particularly with regards to the affordability of climate policy. Examining the timing and economic benefits of energy efficiency improvements with the IMACLIM model, Bibas et al., 2014-in this issue find that energy efficiency alleviates the impact of energy and emissions constraints on household energy consumptions. This leads to higher economic growth and lower climate policy costs, if energy efficiency policies in industrialized countries are combined with technology transfers to developing regions. However, there is a trade-off between short- and long-term costs. Increasing energy efficiency reduces long-term costs, but is triggered by stringent near-term climate policy at high short-term costs. Since the potential for energy demand reductions and low-carbon energy supply differs between economic sectors, Sano et al. (2014) decompose the emission reductions needed to adhere to long-term climate goals based on the DNE21+ model results. They find a large potential for carbon intensity reductions in the power sector and a large potential for energy intensity improvements among passenger cars, whereas the potentials in the iron and steel sectors are lower. With these technological potentials, adhering to stringent emission budgets even after less stringent near-term policies is found to be feasible, albeit at very high carbon prices and economic costs.

2.2. Articles relating to the AMPERE study on staged accession to a global climate regime

An overview of the second study of this special issue, based on scenarios of staged accession, is provided by Kriegler et al., 2014a-in this issue. Eleven energy-economy, computable general equilibrium and integrated assessment models (DNE21+, GCAM, GEM-E3, IMACLIM, IMAGE, MERGE-ETL, MESSAGE-MACRO, POLES, REMIND, WITCH, WorldScan) participated in this study and provided global and regional results for a range of scenarios that represent different international climate policy dynamics. The focus is on front runner scenarios, in which the EU or a coalition of the EU and China embark on immediate ambitious climate action whereas the rest of the world follows moderate climate policies and accedes to a global climate regime between 2030 and 2050. The study explores the trade-offs between early and late adoption of stringent mitigation action and assesses the extent to which the initial stage of unilateral action leads to carbon leakage and low-carbon technology diffusion from the early movers to the rest of the world. The majority of models finds only limited carbon leakage and cost mark-ups for early action by the EU. The economic challenges of front runner action can be greater for China. Whereas the early movers fulfill their share of adhering to a long-term emissions budget, the other regions catch up only after substantial delay and do not compensate for their initially higher emissions. Although this makes it unlikely that initially envisaged climate targets are strictly met, staged accession can still effectively limit global warming.

Europe, as the most plausible early mover on stringent near-term climate action, receives particular attention in this study. As the willingness to implement stronger climate polices may hinge on whether such policies can support the achievement of other non-climate objectives, Schwanitz et al. (2014)-in this issue looked into the potential for co-benefits for Europe. They analyzed results from a range of participating models and found that immediate strong climate action would increase energy security by reducing fossil fuel demand and diversifying energy supply, and that it would lead to a phasing out of coal, with substantial associated health benefits. The co-benefits for air quality are analyzed in further detail by Bollen, 2014-in this issue using the WorldScan model. Bollen, 2014-in this issue finds a significant reduction of air pollutant emissions from stringent near term mitigation policies, offsetting a substantial portion of near-term mitigation costs by reducing the cost of air pollution policies in both the EU27 and energy importing Non-Annex I countries. Bollen, 2014-in this issue also finds terms-of-trade effects to have a potentially significant impact on the avoided costs of air pollution policies, and therefore also on the value of the co-benefits of climate policies.

Different channels of carbon leakage from early mover to late adopter regions are assessed by three articles relying on individual model results. Arroyo-Curras et al., 2014-in this issue look at the response of global energy markets to different sizes and compositions of early mover coalitions — EU alone, EU and China, EU and USA. Based on results from the REMIND model, they find that leakage via the ‘energy market channel’ is limited to below 16% of the emissions reduction in the early mover regions. Carbon leakage via the migration of energy-intensive industries due to concerns about competitiveness (‘the industry channel’) is the focus of Paroussos et al., 2014-in this issue who use the GEM-E3 model results to analyze the impacts of unilateral climate policy on different industrial sectors. They find that chemicals and metals are the EU industries prone to the highest leakage rates. If the USA joins a coalition with the EU, industrial leakage from the EU is only slightly reduced, but if China joins as a coalition partner, leakage drops to a fraction of what it is in the case of the EU acting alone. Another potential channel of carbon leakage is land use for bioenergy production, on which Otto et al., 2014-in this issue provide insights from an analysis of results of the IMAGE model. They find that increased demand for bioenergy due to climate policy leads to higher land-use emissions, primarily in the near term, but that in the long run, this effect is significantly smaller than the leakage in the fossil fuel markets.

Aside from carbon leakage, strong climate policy in some regions can help reduce emissions in other regions through the diffusion of low-carbon technologies. This possibility is assessed by Marcucci and Turton, 2014-in this issue, who analyzed the impact of regional climate policies on the deployment and development of electricity generation technologies in a number of models participating in the AMPERE study. They find that moderate regional climate policies can indeed promote global technological learning in low-carbon electricity, but that the additional learning effect of strong unilateral action by some early movers does not lead to significant additional deployment outside the early mover regions. They conclude that these findings may depend on the maturity of learning technologies and the extent to which technology diffusion is supported by dedicated policies.

2.3. Articles cutting across the two AMPERE studies

In addition to the articles examining aspects of either of the two AMPERE studies, two articles analyze the scenarios from both studies regarding the dynamic response of fossil fuel markets to climate policy (Bauer et al., 2014-in this issue) and their climate outcomes (Schaeffer et al., 2014-in this issue).

Bauer et al., 2014-in this issue look at fossil fuel market responses to delayed mitigation as well as initially fragmented action with staged accession to a global policy regime. Using results from all participating models, they find that a delay of strong climate policy and resulting lock-in into coal use clearly distorts fossil fuel markets relative to immediate climate action that minimizes such a lock-in. Importantly, the overall use of fossil energy in the 21st century is reduced in a delayed action scenario because excessive use of coal in the near term has to be compensated with stronger reductions in oil and gas consumption in the long run. The effects of unilateral climate policy on global fossil fuel markets are less clear, with model results differing strongly and carbon leakage ranging from positive to negative because trade and substitution patterns of coal, oil, and gas differ across models.

The exploration of the climate consequences of delayed action and staged accession by Schaeffer et al., 2014-in this issue adds critical insights into the transient and long-term temperature response to mitigation scenarios that go beyond the stylized assumption of immediate action with full regional flexibility of emission reductions. Using the coupled carbon-cycle/climate model MAGICC6, they generate a consistent set of probabilistic climate outcomes from the emissions data provided by all of the energy-economy and integrated assessment models involved in the two AMPERE studies. They also evaluate the consistency of MAGICC projections with the recent climate change projections by large-scale Earth System Models (CMIP5) (Taylor et al., 2012). While the delayed action scenarios reach similar temperature outcomes compared to the immediate action scenarios in 2100, they can have a higher peak temperature and substantially higher warming rates until 2050. The staged accession scenarios come out at somewhat higher temperature levels due to the absence of a strict emissions budget, but also allow for global warming to be contained by the end of the century.

The remaining article (Kriegler et al., 2014b-in this issue) in the special issue focuses on model diagnostics to better understand differences among model results in model comparison studies such as conducted by AMPERE. This is of crucial importance for assessing the robustness of results and the implications for climate policy analysis. Kriegler et al., 2014b-in this issue introduce diagnostic indicators characterizing the response of energy-economy and integrated assessment models to carbon price signals. The indicators were developed on the basis of a separate multi-model study with eleven models, including ten of the models that participated in the other AMPERE studies presented in this special issue (AIM-Enduse, DNE21+, GCAM, GEM-E3, IMACLIM, IMAGE, MERGE-ETL, MESSAGE-MACRO, POLES, REMIND, and WITCH). Based on these diagnostic indicators, Kriegler et al., 2014b-in this issue identify characteristic model behavior in terms of weaker emissions response, smaller reliance on carbon intensity reductions compared to energy intensity reductions and less extensive energy transformations vs. larger emissions response, larger reliance on carbon intensity reductions and more extensive energy transformations. They also provide indicators to explain differences in mitigation cost estimates in terms of differences in carbon prices and the economic impact of higher carbon prices. These insights help to improve our understanding of the model differences observed in the other articles of this special issue but will also be useful for further model diagnostic and evaluation exercises by the integrated assessment modeling community.

3. Conclusions

The AMPERE studies presented in this special issue constitute the most comprehensive model comparison studies on the relationship between near-term climate policy choices and long-term climate policy objectives to date. The articles contained in the special issue provide a wealth of information on emissions reduction rates, low-carbon deployment rates, carbon lock-ins, fossil fuel market impacts, trade-offs for early movers and late adopters, co-benefits of early action, carbon leakage, and climate outcomes in settings of delayed action and staged accession to a global climate policy regime. We hope that the reader will find this special issue an important resource to explore the implications of near-term policy choices for addressing the long-term challenge posed by climate change.

Acknowledgments

The AMPERE studies presented here owe the robustness of their findings to the dedicated participation of twelve international modeling teams hosted by CIRED (IMACLIM model; France), CPB (WorldScan model; The Netherlands), EDDEN (POLES model; France), FEEM (WITCH model; Italy), ICCS (GEM-E3 model; Greece), IIASA (MESSAGE model; Austria), NIES (AIM-Enduse model; Japan), PBL (IMAGE model; The Netherlands), PIK (REMIND model; Germany), PNNL (GCAM model; USA), PSI (MERGE-ETL model; Switzerland), and RITE (DNE21+ model; Japan). The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007–2013) under grant agreement no. 265139 (AMPERE).

References

Arroyo-Curras, T., Bauer, N., Kriegler, E., Schwanitz, V.J., Luderer, G., Aboumahboub, T., Giannousakis, A., Hilaire, J., 2014. Carbon leakage in a fragmented climate regime: the dynamic response of global energy markets. Technol. Forecast. Soc. Chang. 90 (PA), 192–203 (in this issue).

Bauer, N., Bosetti, V., Calvin, K., Hamdi-Cherif, M., Kitous, A., McCollum, D.L., Méjean, A., Rao, S., Turton, H., Paroussos, L., Ashina, S., Wada, K., van Vuuren, D.P., 2014. CO_2 emission mitigation and fossil fuel markets: dynamic and international aspects of climate policies. Technol. Forecast. Soc. Chang. 90 (PA), 243–256 (in this issue).

Bertram, C., Johnson, N., Luderer, G., Riahi, K., Isaac, M., Eom, J., 2014. Carbon lock-in through capital stock inertia associated with weak near-term climate policies. Technol. Forecast. Soc. Chang. 90 (PA), 62–72 (in this issue).

Bibas, R., Méjean, A., Hamdi-Cherif, M., 2014. Energy efficiency policies and the timing of action: an assessment of climate mitigation costs. Technol. Forecast. Soc. Chang. 90 (PA), 137–152 (in this issue).

Blanford, G.J., Kriegler, E., Tavoni, M., 2014. Harmonization vs. fragmentation: overview of climate policy scenarios in EMF27. Clim. Chang. 123 (3–4), 383–396.

Bollen, J., 2014. The value of air pollution co-benefits of climate policies: analysis with a global sector-trade CGE model called WorldScan. Technol. Forecast. Soc. Chang. 90 (PA), 178–191 (in this issue).

Bosetti, V., Carraro, C., Sgobbi, A., Tavoni, M., 2009a. Delayed action and uncertain stabilization targets: how much will the delay cost? Clim. Chang. 96, 299–312.

Bosetti, V., Carraro, C., Tavoni, M., 2009b. Climate change mitigation strategies in fast-growing countries: the benefits of early action. Energy Econ. 31 (S2), S144–S151.

Calvin, K., Patel, P., Fawcett, A., Clarke, L., Fisher-Vanden, K., Edmonds, J., Kim, S.H., Sands, R., Wise, M., 2009. The distribution and magnitude of emissions mitigation costs in climate stabilization under less than perfect international cooperation: SGM results. Energy Econ. 31 (S2), S187–S197.

Capros, P., Paroussos, L., Fragkos, P., Tsani, S., Boitier, B., Wagner, F., Busch, S., Resch, G., Blesl, M., Bollen, J., 2014. European decarbonisation pathways under alternative technological and policy choices: a multi-model analysis. Energy Strateg. Rev. 2 (3–4), 231–245.

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S., Tavoni, M., 2009. International climate policy architectures: overview of the EMF 22 international scenarios. Energy Econ. 31 (S2), S64–S81.

Clarke, L., Jiang, K., Akimoto, K., Babiker, M., Blanford, G., Fisher-Vanden, K., Hourcade, J.-C., Krey, V., Kriegler, E., Löschel, A., McCollum, D., Paltsev, S., Rose, S., Shukla, P.R., Tavoni, M., van der Zwaan, B., van Vuuren, D.P., 2014.

Assessing transformation pathways. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Criqui, P., Mima, S., Menanteau, P., Kitous, A., 2014. Mitigation strategies and energy technology learning: assessment with the POLES model. Technol. Forecast. Soc. Chang. 90 (PA), 119–136 (in this issue).
Edmonds, J., Clarke, L., Lurz, J., Wise, M., 2008. Stabilizing CO2 concentrations with incomplete international cooperation. Clim. Pol. 8, 355–376.
Eom, J., Edmonds, J., Krey, V., Johnson, N., Longden, T., Luderer, G., Riahi, K., Van Vuuren, D., 2014. The impact of near-term climate policy choices on technology and emissions transition pathways. Technol. Forecast. Soc. Chang. 90 (PA), 73–88 (in this issue).
IPCC, 2014. WGIII AR5 Scenario Database accessibleaccessible at https://secure.iiasa.ac.at/web-apps/ene/AR5DB.
Documented in: Krey, V., Masera, O., Blanford, G., Bruckner, T., Cooke, R., Fisher-Vanden, K., Haberl, H., Hertwich, E., Kriegler, E., Müller, D., Paltsev, S., Price, L., Schlömer, S., Ürge-Vorsatz, D., van Vuuren, D., Zwickel, T., 2014. Annex II: Metrics and Methodology, Section A.II.10: Scenario Data. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Iyer, G., Hultman, N., Eom, J., McJeon, H., Patel, P., Clarke, L., 2014. Diffusion of low-carbon technologies and the feasibility of long-term climate targets. Technol. Forecast. Soc. Chang. 90 (PA), 103–118 (in this issue).
Jakob, M., Luderer, G., Steckel, J., Tavoni, M., Monjon, S., 2012. Time to act now? Assessing the costs of delaying climate measures and benefits of early action. Clim. Chang. 114 (1), 79–99.
Johnson, N., Rao, S., McCollum, D., Krey, V., Riahi, K., Rogelj, J., 2014. Stranded on a low-carbon planet: implications of climate policy for the phase-out of coal-based power plants. Technol. Forecast. Soc. Chang. 90 (PA), 89–102 (in this issue).
Keppo, I., Rao, S., 2007. International climate regimes: effects of delayed participation. Technol. Forecast. Soc. Chang. 74 (7), 962–979.
Krey, V., Riahi, K., 2009. Implications of delayed participation and technology failure for the feasibility, costs, and likelihood of staying below temperature targets—greenhouse gas mitigation scenarios for the 21st century. Energy Econ. 31 (S2), S94–S106.
Krey, V., Luderer, G., Clarke, L., Kriegler, E., 2014. Getting from here to there — energy technology transformation pathways in the EMF27 scenarios. Clim. Chang. 123 (3–4), 369–382.
Kriegler, E., Riahi, K., Bauer, N., Schwanitz, V.J., Petermann, N., Bosetti, V., Marcucci, A., Otto, S., Paroussos, L., Rao, S., Currás, T.A., Ashina, S., Bollen, J., Eom, J., Hamdi-Cherif, M., Longden, T., Kitous, A., Méjean, A., Sano, F., Schaeffer, M., 2014a. Making or breaking climate targets: the AMPERE study on staged accession scenarios for climate policy. Technol. Forecast. Soc. Chang. 90 (PA), 24–44 (in this issue).
Kriegler, E., Petermann, N., Krey, V., Schwanitz, V.J., Luderer, G., Ashina, S., Bosetti, V., Eom, J., Kitous, A., Méjean, A., Paroussos, L., Sano, F., Turton, H., Wilson, C., Van Vuuren, D.P., 2014b. Diagnostic indicators for integrated assessment models of climate policy. Technol. Forecast. Soc. Chang. 90 (PA), 45–61 (in this issue).
Kriegler, E., Riahi, K., Petermann, N., Bosetti, V., Capros, P., van Vuuren, D.P., Criqui, P., Egenhofer, C., Fragkos, P., Johnson, N., Paroussos, L., Behrens, A., Edenhofer, O., The AMPERE Consortium, 2014c. Assessing Pathways Toward Ambitious Climate Targets at the Global and European Levels: A synthesis of Results From the AMPERE Project. (available at http://ampere-project.eu).
Kriegler, E., Weyant, J.P., Blanford, G.J., Krey, V., Clarke, L., Edmonds, J., Fawcett, A., Luderer, G., Riahi, K., Richels, R., Rose, S.K., Tavoni, M., van Vuuren, D.P., 2014d. The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies. Clim. Chang. 123 (3–4), 353–367.
Luderer, G., Pietzcker, R.C., Bertram, C., Kriegler, E., Meinshausen, M., Edenhofer, O., 2013a. Economic mitigation challenges: how further delay closes the door for achieving climate targets. Environ. Res. Lett. 8 (2013), 034033.
Luderer, G., Bertram, C., Calvin, K., De Cian, E., Kriegler, E., 2013b. Implications of weak near-term climate policies on long-term mitigation pathways. Clim. Chang. http://dx.doi.org/10.1007/s10584-013-0899-9.
Marcucci, A., Turton, H., 2014. Induced technological change in moderate and fragmented climate change mitigation regimes. Technol. Forecast. Soc. Chang. 90 (PA), 230–242 (in this issue).
Otto, S., Gernaat, D., Isaac, M., Lucas, P.L., van Sluisveld, M.A., van den Berg, M., van Vliet, J., van Vuuren, D.P., 2014. Impact of fragmented emission reduction regimes on the energy market and on CO2 emissions related to land use: a case study with China and the European Union as first movers. Technol. Forecast. Soc. Chang. 90 (PA), 220–229 (in press).
Paroussos, L., Fragkos, P., Capros, P., Fragkiadakis, K., 2014. Assessment of carbon leakage through the industry channel: the EU perspective. Technol. Forecast. Soc. Chang. 90 (PA), 204–219 (in this issue).
Riahi, K., Kriegler, E., Johnson, N., Bertram, C., den Elzen, M., Eom, J., Schaeffer, M., Edmonds, J., Isaac, M., Krey, V., Longden, T., Luderer, G., Méjean, A., McCollum, D.L., Mima, S., Turton, H., Van Vuuren, D.P., Wada, K., Bosetti, V., Capros, P., Criqui, P., Hamdi-Cherif, M., Kainuma, M., Edenhofer, O., 2014. Locked into Copenhagen pledges — implications of short-term emission targets for the cost and feasibility of long-term climate goals. Technol. Forecast. Soc. Chang. 90 (PA), 8–23 (in this issue).
Richels, R.G., Blanford, G.J., Rutherford, T.F., 2009. International climate policy: a ‘second best’ solution for a ‘second best’ world? Clim. Chang. 97, 289–296.
Rogelj, J., McCollum, D.L., O'Neill, B.C., Riahi, K., 2013a. 2020 emissions levels required to limit warming to below 2 degreess. Nat. Clim. Chang. 3, 405–412.
Rogelj, J., McCollum, D.L., Reisinger, A., Meinshausen, M., Riahi, K., 2013b. Probabilistic cost estimates for climate change mitigation. Nature 493, 79–83.
Sano, F., Wada, K., Akimoto, K., Oda, J., 2014. Assessments of GHG emission reduction scenarios of different levels and different short-term pledges through macro- and sectoral decomposition analyses. Technol. Forecast. Soc. Chang. 90 (PA), 153–165 (in this issue).
Schaeffer, M., Gohar, L., Kriegler, E., Lowe, J., Riahi, K., van Vuuren, D.P., 2014. Mid- and long-term climate projections for fragmented and delayed-action scenarios. Technol. Forecast. Soc. Chang. 90 (PA), 257–268 (in this issue).
Schwanitz, V.J., Longden, T., Knopf, B., Capros, P., 2014. The implications of initiating immediate climate change mitigation — a review of the potential for co-benefits. Technol. Forecast. Soc. Chang. 90 (PA), 166–177 (in this issue).
Taylor, K.E., Stouffer, R.J., Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. Bull. Am. Meteorol. Soc. 93, 485–498.
The AMPERE consortium, 2014. AMPERE Scenario Database. https://secure.iiasa.ac.at/web-apps/ene/AMPEREDB.
van Vliet, J., den Elzen, M.G.J., van Vuuren, D.P., 2009. Meeting radiative forcing targets under delayed participation. Energy Econ. 31 (S2), S152–S162.
van Vliet, J., Berg, M., Schaeffer, M., van Vuuren, D.P., Elzen, M., Hof, A., Mendoza Beltran, A., Meinshausen, M., 2012. Copenhagen Accord pledges imply higher costs for staying below 2 °C warming. Clim. Chang. 113, 551–561.

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