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Summary

While the international community has agreed on the long-term target of limiting global warming to no more than 2°C above pre-industrial levels, only a few concrete climate policies and measures to reduce greenhouse gas (GHG) emissions have been implemented. We use a set of three global integrated assessment models to analyze the implications of current climate policies on long-term mitigation targets. We define a weak-policy baseline scenario, which extrapolates the current policy environment by assuming that the global climate regime remains fragmented and that emission reduction efforts remain unambitious in most of the world's regions. These scenarios clearly fall short of limiting warming to 2°C. We investigate the cost and achievability of the stabilization of atmospheric GHG concentrations at 450 ppm CO₂e by 2100, when countries follow the weak policy pathway until 2020 or 2030 before pursuing the long-term mitigation target with global cooperative action. We find that after a deferral of ambitious action the 450 ppm CO₂e is only achievable with a radical up-scaling of efforts after target adoption. This has severe effects on transformation pathways and exacerbates the challenges of climate stabilization, in particular for a delay of cooperative action until 2030. Specifically, reaching the target with weak near-term action implies (a) faster and more aggressive transformations of energy systems in the medium term, (b) more stranded investments in fossil-based capacities, (c) higher long-term mitigation costs and carbon prices and (d) stronger transitional economic impacts, rendering the political feasibility of such pathways questionable..

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Implications of weak near-term climate policies on long-term mitigation pathways

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Abstract

While the international community has agreed on the long-term target of limiting global warming to no more than 2°C above pre-industrial levels, only a few concrete climate policies and measures to reduce greenhouse gas (GHG) emissions have been implemented.

We use a set of three global integrated assessment models to analyze the implications of current climate policies on long-term mitigation targets. We define a weak-policy baseline scenario, which extrapolates the current policy environment by assuming that the global climate regime remains fragmented and that emission reduction efforts remain unambitious in most of the world's regions. These scenarios clearly fall short of limiting warming to 2°C.

We investigate the cost and achievability of the stabilization of atmospheric GHG concentrations at 450 ppm CO₂e by 2100, when countries follow the weak policy pathway until 2020 or 2030 before pursuing the long-term mitigation target with global cooperative action. We find that after a deferral of ambitious action the 450 ppm CO₂e is only achievable with a radical up-scaling of efforts after target adoption. This has severe effects on transformation pathways and exacerbates the challenges of climate stabilization, in particular for a delay of cooperative action until 2030. Specifically, reaching the target with weak near-term action implies (a) faster and more aggressive transformations of energy systems in the medium term, (b) more stranded investments in fossil-based capacities, (c) higher long-term mitigation costs and carbon prices and (d) stronger transitional economic impacts, rendering the political feasibility of such pathways questionable.

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1. Introduction

In the Copenhagen Accord, the international community agreed on the long-term target of limiting the increase of global mean temperature to no more than 2°C, relative to pre-industrial levels. The subsequent Cancun and Durban climate conferences reaffirmed this target. Reaching the 2°C target with high likelihood implies a tight limit on future anthropogenic greenhouse gas (GHG) emissions. Various reports have concluded that pledged national 2020 reduction targets fall short of the reductions required to meet the 2°C target in an inter-temporally cost-optimal way (UNEP 2010, 2011; Rogelj et al. 2010, 2011).

So far, model-based research on the implications of weak near-term policies in the context of ambitious long-term mitigation targets is in its infancy. The EMF-22 study explored how international participation affects the attainability of different climate targets and concluded that a failure to develop a comprehensive, international approach will constrain efforts to meet ambitious climate targets (Clarke et al. 2009). As part of the same project, Calvin et al. (2009) analyzed the implications of low stabilization in the context of fragmented climate policy regimes on energy and land-use systems. The RECIPE study explored the implications of a delay in climate mitigation, by one or several world regions, in terms of global costs and feasibility as well as incentive structures (Jakob et al. 2012; Luderer et al. 2012a). (van Vliet et al. 2012) explored the high and low ends of the possible realizations outlined by the Copenhagen Pledges and their implications for the achievability of the 2°C target. Even the ambitious ends of the 2020 pledges resulted substantial cost increases compared to the least-cost pathways with immediate action. Van Vliet et al. concluded that with weaker emissions reductions in 2020, keeping global warming below 2°C is unlikely.

This study uses three integrated assessment models to advance the understanding of future climate agreements. It goes beyond the simple assessment of the gap between near-term emission reduction pledges and reductions implied by pathways with optimal timing by exploring the consequences of agreeing on low stabilization targets only after 2020 and 2030. The study design is described in Section 2. Since a number of energy and climate policies are already under way, this study defines a weak policy scenario as the pessimistic, low end of the plausible near-term climate policies and extrapolates their level of ambition to the medium- to long-term future. Section 3 analyzes implications of weak and immediate

action scenarios for emission pathways. In Section 4, we study how the timing of mitigation affects energy system transformations. In Section 5, we explore the economic implications of weak near-term action. Section 6 discusses the results and conclusions.

2. Study design

This study is based on a subset of the scenarios conducted in the RoSE study (Kriegler et al. 2013a, this issue). The subset consists of the following five harmonized scenarios:

A. *No-policy baseline scenario (BASELINE)*

In this counter-factual scenario, the development of a world without any climate policies after 2010 is considered. The models have been harmonized using the RoSE default assumptions (cf. Kriegler et al., this issue) for (1) population scenarios, (2) regional GDP growth, and (3) fossil resources.¹

B. *Weak-policy baseline scenario (WEAK-POL)*

This scenario is designed as a reference scenario that includes weak climate policies. It is meant to represent the unambitious end of current short- and long-term climate policy trends. It was constructed by considering existing climate policies, a weak interpretation of the 2020 Copenhagen Pledges, and an extrapolation of these targets beyond 2020 based on emissions intensity (GHG emissions per unit of GDP). Three country groups are considered: industrialized countries (Group I), developing countries without excluding resource exporters (Group II), and fossil resource exporters of the former Soviet Union and Middle East (Group III). Climate policy is assumed to remain fragmented, with no emissions trading between regions until 2020. Limited trading of emissions between industrialized and developing countries is allowed after 2020. It is assumed that resource-exporting countries will not adopt any binding targets.

Furthermore, it is assumed that land-use emissions will not be subject to carbon pricing. A detailed description of the assumptions and methodology used in the WEAK-POL scenario assumptions is provided in the supplementary material (SM2). Section 3 presents the resulting emission and energy system pathways, as well as the climate outcomes.

¹ This scenario is identical to BAU DEF presented in the RoSE synthesis paper (Kriegler et al. 2013a, this issue).

C. Immediate action (IMMEDIATE)

This scenario considers immediate, globally coordinated, cooperative climate policies that are aimed at stabilizing GHG concentrations at 450ppm CO₂e by 2100. Temporary overshooting of the concentration target is permitted.² The 450 ppm CO₂e target is consistent with a greater-than-50% likelihood that temperatures will stabilize below 2°C (Meinshausen et al. 2011). This scenario incorporates full “what,” “where,” and “when” flexibility. A global carbon market is established, and emission reductions are distributed in a cost-optimal way across time and across various source sectors and GHGs.

D. Weak action until 2020 (WEAK-2020) and weak action until 2030 (WEAK-2030)

The WEAK-2020 and WEAK-2030 scenarios assume that the adoption of a global agreement aimed at stabilizing GHG concentrations at 450ppm CO₂e by 2100 will be delayed until 2020 or 2030, respectively. Before this, countries will follow the WEAK-POL baseline without anticipating future climate policies that are more stringent. Once the agreement is adopted, a global carbon market is installed, thus ensuring a cost-efficient regional allocation of emission reduction efforts.

This study used three state-of-the-art integrated assessment models. Since socio-economic drivers and fossil fuel availability are harmonized, differences in the results (discussed in the subsequent sections) reflect different structural assumptions, particularly in terms of the dynamics of energy, land-use and climate systems³. Detailed descriptions of the models are available in the supplementary materials provided by Kriegler et al. (this issue). Notable model characteristics that are particularly relevant for this study are listed in the paragraphs below. The present scenarios assumed that all the low-carbon technologies represented in the models were available. In particular, technologies for combining bioenergy with carbon capture and storage (BECCS) are available in all three models.

GCAM is a multi-regional market equilibrium model. It includes a detailed representation of the energy system and of the agriculture-land-use system, and captures the interactions of these two sectors (Wise et al. 2009). The model is dynamic-recursive, thus assuming that

² This scenario is identical to 450 DEF presented in the RoSE synthesis paper (Kriegler et al. 2013a, this issue).

³ While the climate modules of all three models are calibrated to a climate sensitivity of 3°C for a doubling of CO₂ concentrations relative to pre-industrial levels, they differ in terms of other characteristics, such as the carbon cycle response, or transient climate response.

economic agents are myopic. Technological innovation is exogenously prescribed. Capital stock in the electricity and refining sectors are assumed to be long-lived. However, premature retirement of capital is allowed when the market price does not cover operating costs. GCAM includes no explicit constraints on the expansion of capital stock from period to period or the retirement of capital stock. In the GCAM version used for RoSE, biomass availability is limited to ~210 EJ/yr globally.

REMIND is an energy-economy model composed of a macro-economic growth module coupled with an energy system module with considerable detail in the representation of capital stocks in energy supply technologies (Bauer et al., this issue; Leimbach et al. 2010; Luderer et al. 2012c). The model is solved as an inter-temporal optimization problem, thus assuming perfect foresight by economic agents. Technological innovation in wind and solar energy supply technologies are treated endogenously via global learning curves, which give rise to path dependencies and technology spillover effects. The premature retirement of coal- and gas-fired power plants before the end of the technical lifetime is assumed to be possible, but is constrained to 4%/yr of installed capacity. The rapid ramp-up of technologies is subject to a cost penalty (i.e., “adjustment costs”), which scales with the square of the rate of change in new capacities. In the REMIND version used for RoSE, biomass availability is limited to 200 EJ/yr.

Similar to REMIND, **WITCH** is an optimization model that assumes the perfect foresight behavior of economic agents. It integrates a macro-economic growth model and an energy system module that characterizes power-generating investments and final energy uses (De Cian et al. this issue, 2012; Bosetti et al. 2006). WITCH characterizes the endogenous nature of technical progress in the energy sector and accounts for international and inter-temporal technology externalities generated by research and development (R&D) investments and technology deployment. R&D investments enhance energy efficiency and facilitate the penetration of innovative low-carbon technologies in power generation as well as final energy use (breakthrough technologies). Further cost-reductions related to learning-by-doing are considered for the breakthrough technologies as well as for wind power. Early retirement of power generating technologies is allowed without specific limitations.

3. Emissions pathways with weak near-term climate policies

This section explores the emission pathways of the WEAK-POL scenario and the various 450 ppm stabilization scenarios for emission pathways, and analyses their implications for changes in global mean temperature radiative forcing. Despite the unambitious near-term policies in the WEAK-2020 and WEAK-2030 scenarios, all the models find it feasible to reach the target by 2100 even if cooperative, ambitious action is delayed until 2020 or even 2030, albeit with more aggressive emission reductions within a rather short time frame.

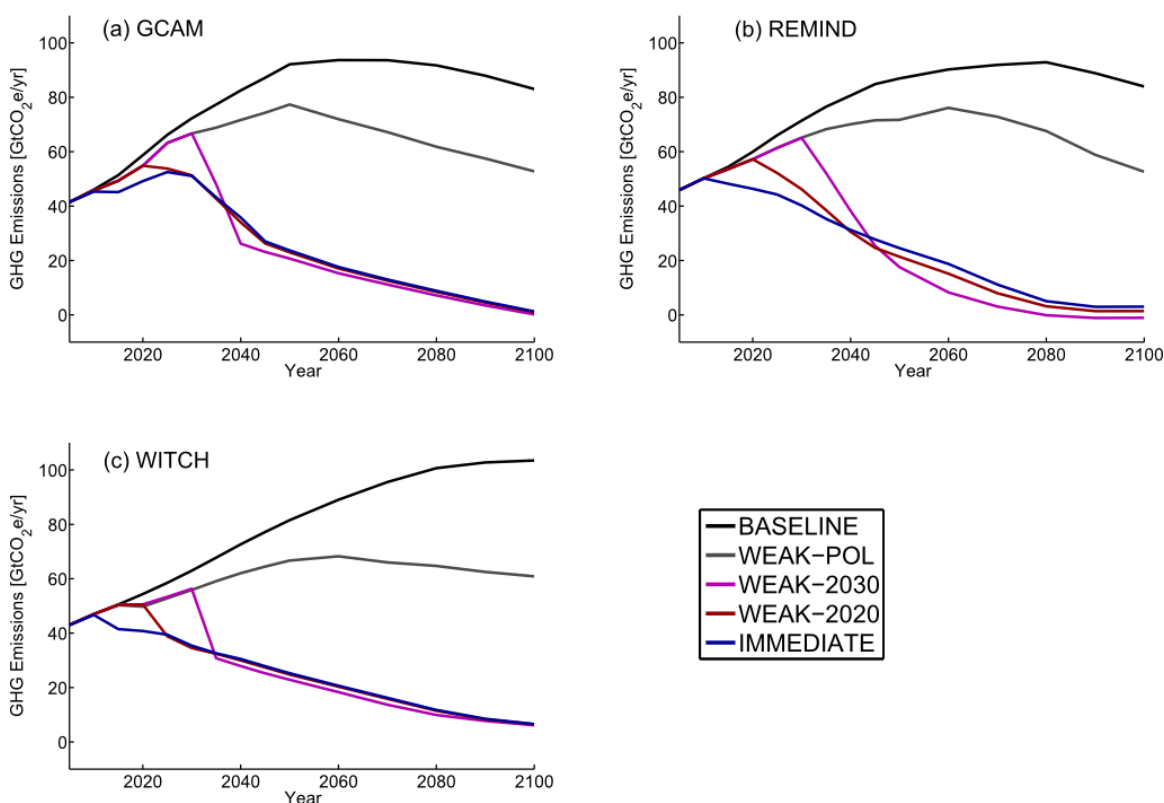


Figure 1: Global CO₂ emission trajectories for the BASELINE, WEAK-POL, WEAK-2020, WEAK-2030, and IMMEDIATE policy scenarios.

The climate policies assumed in the WEAK-POL scenario result in a significant decrease of emission reductions relative to the BASELINE scenario without climate policies. Global emissions are between 3% (REMIND) and 8% (WITCH) below the baseline level in 2020 and between 16% (REMIND) and 18% (WITCH) below baseline levels in 2050.⁴ Due to the

⁴ Although reference GDP, population, and fossil fuel availability have been harmonized across models, baseline emissions still differ across models, reflecting different structural and technology assumptions.

fragmented nature of climate policy in the WEAK-POL scenario, regionally differentiated carbon prices emerge (see supplementary material, Figure SM 2.1). In 2030, carbon prices in the industrialized countries are between two (REMIND and WITCH) and three-times (GCAM) higher than those in developing countries in 2030. As a consequence, the highest relative reduction of cumulative emissions between 2010 and 2050 occurs in the industrialized countries (Group I), while the developing countries (Group II) achieve relatively lower reductions (Figure SM3.1). Resource exporting countries (Group III) slightly increase their emissions compared to the baseline as a result of carbon leakage, wherein the overall consumption of fossil resources in Group III increases as prices decrease due to the climate policies undertaken in the other countries two country groups.

The emission reductions realized in WEAK-POL are far smaller than what is required to achieve 450 ppm CO₂e stabilization (Figure 1). Cumulated Kyoto gas emissions from 2010 to 2100 are between 5,500 and 5,800 Gt CO₂e, 20-25% below baseline levels. This compares to cumulative budgets in the range of 2,100-2,300 Gt CO₂e in the 450 ppm CO₂e stabilization scenarios. The resulting forcing levels in 2100 lie between 5.3 (WITCH) and 5.9 W/m² (GCAM), roughly 1 W/m² below baseline levels. Global mean temperature continues to rise throughout the century, reaching about 3.5°C by 2100. The climate policies assumed to be implemented in this scenario are thus much too weak to achieve the 2°C target.

The three models show different emissions trajectories for the IMMEDIATE scenario. In REMIND and WITCH, emissions peak in 2010 and decline gradually at a rate of 1–3%/year. The GCAM trajectory is characterized by a late and high peak, with emissions remaining above 2005 levels until 2035, with a higher rate of emissions reductions afterwards. This is because of the more rapid deployment of BECCS in future years, which allow for negative emissions. In the WEAK-2020 scenario, global GHG emissions peak between 50 GtCO₂ (WITCH) and 57 GtCO₂e (GCAM), which is 22–33% higher than the emissions levels in the IMMEDIATE scenario. The different emission patterns in the IMMEDIATE scenario affect the size of the gap between IMMEDIATE and the weak action scenarios in 2020 and 2030.

Despite the higher emission levels in the WEAK-POL scenarios compared to IMMEDIATE, all three models find it feasible to achieve the 450 ppm CO₂e stabilization level by 2100 even when cooperative action does not start until 2020 or even 2030. With the exception of the WEAK-2020 scenario in GCAM, the delayed introduction of ambitious and cooperative climate policies results in much more aggressive emission reductions than in the

IMMEDIATE scenario. For WEAK-2030, GCAM reduces emissions by about 60% between 2030 and 2040, WITCH by about 50%, and REMIND by 40%. However, the aggressive reductions required after the transition from the weak to the ambitious climate policy regime would imply structural changes in energy supply and demand at an unprecedented pace, causing potentially severe economic impacts, as discussed in Sections 4 and 5.

Due to the long residence time of GHGs in the atmosphere, the effects of anthropogenic emissions on the climate are primarily a function of the cumulative emissions budget (Meinshausen et al. 2009). Limiting GHGs to specified level consequently constrains total GHG emissions throughout the coming century. This property also holds for the various stabilization scenarios considered in this study: we find that the GHG budget reaching 450 ppm CO₂e by 2100 is almost independent of the timing of mitigation action (Figure SM3.1).⁵ Therefore, emissions reductions after the adoption of the climate stabilization target are steeper in the weak near-term climate policy scenarios, while long-term emission levels tend to be lower than in the case of immediate action (Figure 1).

The models differ regarding the point in time at which the WEAK-2020 scenario catches up with the emission levels of the immediate action scenario. While the emissions gap between these two scenarios closes by 2025 in WITCH and 2030 in GCAM, in the REMIND WEAK-2020 emissions do not reach the level of the IMMEDIATE scenario until 2040. According to all the models, the difference in long-term emissions between the WEAK-2020 and the IMMEDIATE scenarios are rather small (well below 1 GtCO₂/yr). In other words, the additional effort to compensate for excess emissions before the crossover point is moderate.

The discrepancy with the immediate action scenario is much larger in the WEAK-2030 scenario than in the WEAK-2020 scenario. By 2030, emissions in REMIND and WITCH are approximately 70% above those of the immediate action case. For GCAM, the difference is 31%. Emission reductions after the adoption of the climate target are much steeper than the IMMEDIATE scenario and even the WEAK-2020 scenario. GCAM and WITCH feature emission reduction rates up to 10%/year between 2030 and 2040, with emissions dropping below the level of the immediate action and WEAK-2020 scenarios. This reflects different assumptions on the rate at which fossil-based capacities can be retired, and new, low-

⁵ The cumulative budgets for the weak actions scenarios are slightly higher than in the immediate action scenario. Due to carbon cycle dynamics, a smaller share of emissions that occur early in the century remain airborne, compared to emissions that occur at a later point in time.

carbon energy technologies are phased-in. Path dependencies in the REMIND energy system are more pronounced than in WITCH and GCAM (cf. Section 4.2); therefore, emissions reductions after 2030 are not as steep as in GCAM and WITCH. As a result, the excess in cumulative emissions until 2050 in the WEAK-2030 scenario compared to the IMMEDIATE scenario is higher in REMIND than in WITCH and GCAM (Figure SM3.1). To make up for the excess near-term emissions, the long-term emissions in the REMIND WEAK-2030 scenario are considerably lower than in the IMMEDIATE and WEAK-2020 scenarios.

For the IMMEDIATE, WEAK-2020, and WEAK-2030 scenarios, a 2100 forcing level of 2.6 W/m² is prescribed as a climate target, but no limit on the overshooting is defined. Moreover, the models use different climate system representations. Therefore, the scenarios are not equivalent in terms of the transitory climate effects. Differences in near-term emissions have an effect on the peak levels of radiative forcing and temperature (Figure 2). In all three models, weak action results in higher radiative forcing in the near-term. This difference is the greatest in REMIND, where radiative forcing peaks at 3.2 W/m² in the IMMEDIATE scenario, and at 3.6 W/m² in the WEAK-2030 scenario. The resulting higher rates of temperature change, higher peak CO₂ concentrations as well as temperature overshooting may have implications for climate impacts, including the likelihood of triggering tipping points.

The overshooting of forcing also results in a slight peak in global mean temperatures. This effect is more pronounced in the WEAK-2020 and WEAK-2030 scenarios than in the IMMEDIATE scenario. As a result, the 2°C level is temporarily exceeded in REMIND and WITCH.

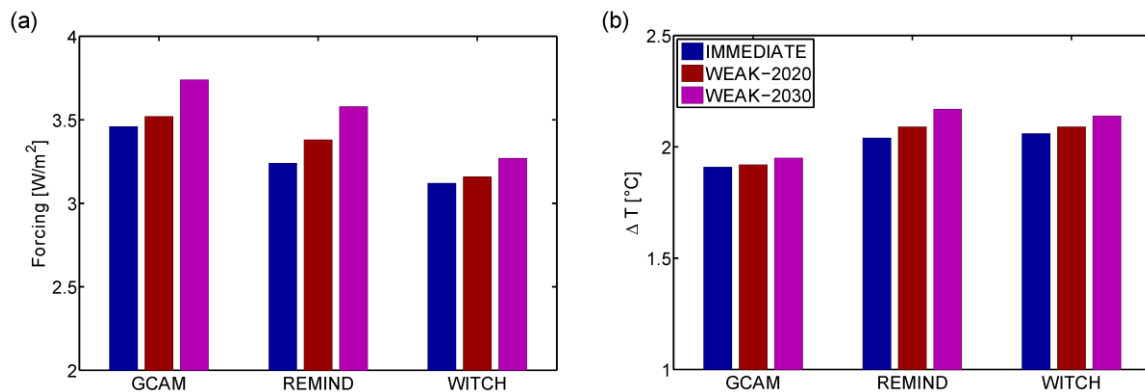


Figure 2: (a) Maximum radiative forcing and (b) maximum transient global mean temperature increase in 2010-2100.

4. Implications for the transformation of energy systems

Due to its dominant share in emissions, the energy system has to bear the bulk of the climate mitigation effort. This section analyses the effect of weak policies on global energy systems, and implications of delayed cooperative action on the energy system transformation.

4.1. Primary energy supply

The effect of weak climate policies on primary energy supply is depicted Figure 3 (right row). In all three models, the adoption of weak climate policies results in a sizable reduction in conventional coal use in the medium- and long-term. By 2050, coal use without CCS is 80 EJ (REMIND), 90 EJ (WITCH) and 130 EJ (GCAM) lower than in the baseline. Reductions in oil and gas are less significant. For all models, energy supply from biomass and nuclear is higher than the baseline. GCAM projects considerable deployment of carbon capture and storage (CCS) already in the first half of the century. The decrease of primary energy demand caused by weak climate policies is the most pronounced in WITCH, where R&D investments can improve energy efficiency.

The consumption of fossil energy in the IMMEDIATE scenario is substantially lower than in the weak action scenarios (Figure 3, left). In particular, coal use without CCS declines immediately after 2010 and a gradual but substantial phase-in of low-carbon energy carriers and technologies occurs simultaneously. In 2020, fossil energy use without CCS is 60 EJ (GCAM), 80 EJ (WITCH), and 100 EJ (REMIND) lower than in the weak action

scenarios (Figure 3, right). By 2030, the gap in fossil energy-use widens to between 180 (GCAM) and 240 EJ (REMIND). Similarly, low carbon energy deployment in the immediate action scenario exceeds that of the weak action scenarios by 40 EJ (WITCH), 60 EJ (GCAM), and 110 EJ (REMIND). The diversity of energy system transformations found in the model results shows that there are several alternative pathways with different technology choices towards the same common long-term climate target.

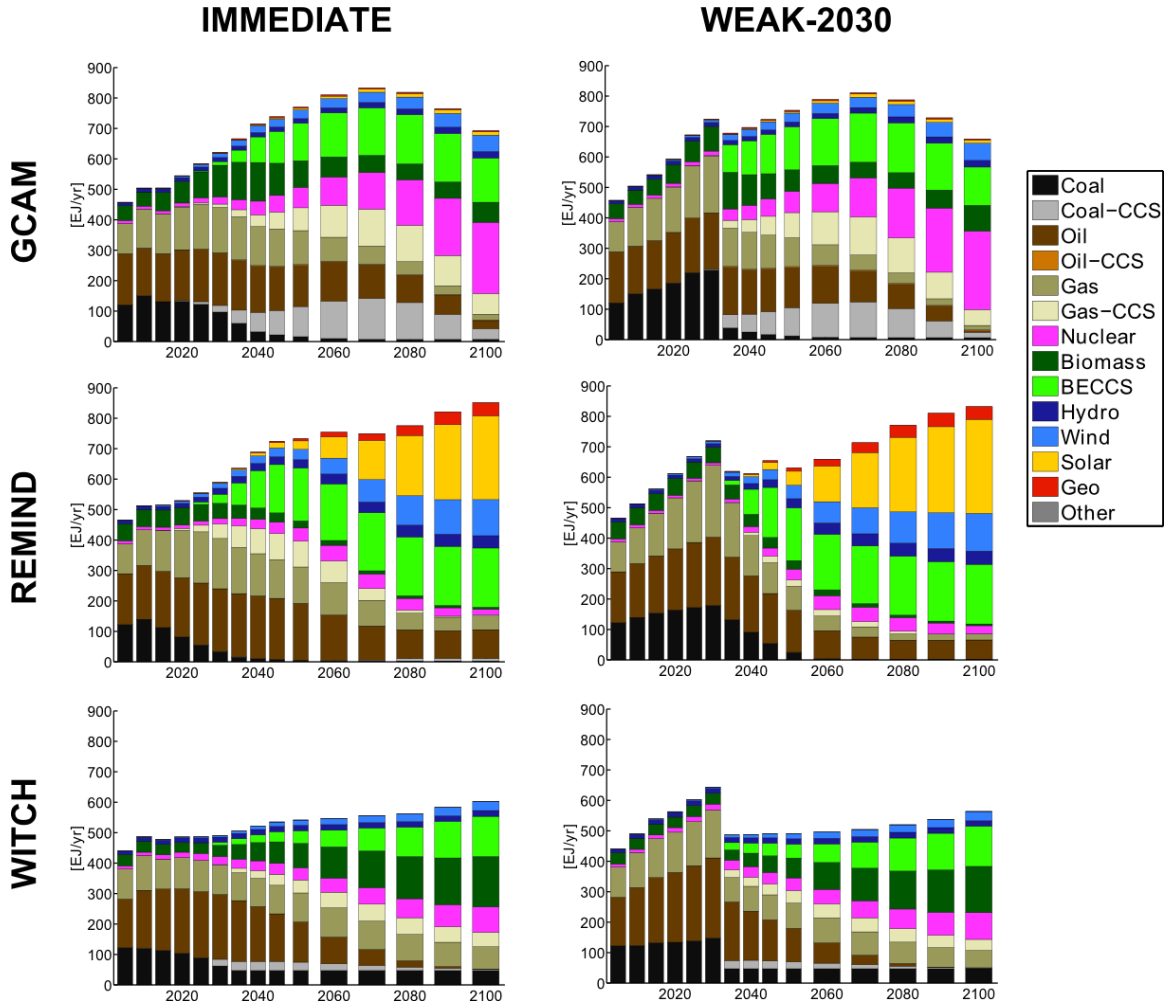


Figure 3: Primary energy supply in the IMMEDIATE (left) and WEAK-2030 (right) scenarios.

In case of a delay of ambitious cooperative action, the divergent development between the weak action and immediate action scenarios prior to target adoption poses a two-fold challenge for the development of the energy system after target adoption. First, at the time of target adoption, the energy system’s capital stock is characterized by higher fossil capacities and fewer low-carbon capacities. Second, in order to reach the same stabilization target, the excess emissions from the weak policy period must be compensated by lower cumulative emissions during the remainder of the century (see also Figures SM4.2 and SM 4.3).

Climate policy renders many pre-existing fossil installations unprofitable, resulting in early retirements of capacities. In IMMEDIATE, for example, a substantial volume of fossil

capacities for electricity generation are stranded, as shown in Figure 4. While the models agree that unused capacities increase in the WEAK-2020/WEAK-2030 scenarios, they exhibit different timing and scale in terms of the retirement and replacement of excess fossil capacities. This is particularly evident in the WEAK-2030 scenario. In GCAM and WITCH, the introduction of a high, globally uniform carbon price results in the sudden retirement of a major share of conventional fossil capacities. As a consequence, coal, oil, and gas use in the WEAK-2030 scenario fall to levels below those of the IMMEDIATE scenario by 2035 (Figure 3). REMIND is characterized by stronger path dependencies and a slower phase-out of fossil fuels, reflecting the assumption of moderate premature retirement of coal- and gas-fired power plants (see Section 2). Conventional fossil energy use in the WEAK-2030 scenario remains above that of the IMMEDIATE scenario until 2050. The supplementary materials (SM5) provide a detailed discussion of stranded investments under different climate-policy-timing scenarios.

Moreover, patterns regarding the phase-in of low-carbon technologies after weak near-term action differ across models. In GCAM, weak near-term climate policy results in more rapid and aggressive deployment of bioenergy with CCS (BECCS) after adoption of the climate target. Among the three models, GCAM is most optimistic about the availability of CCS storage potentials (see also Kriegler et al., this issue). Furthermore, nuclear energy and natural gas, in combination with CCS, are deployed at a higher level than in the IMMEDIATE scenario.⁶ By contrast, the use of coal with CCS is lower because the carbon price applied to the residual emissions is higher in the WEAK scenarios, which drives up the cost of coal with CCS. In REMIND, the higher carbon prices after 2030 in the weak action scenarios result in higher electrification and deployment of non-biomass renewables compared to the IMMEDIATE scenario. Differences in bioenergy use are small, since all stabilization scenarios result in biomass deployment close to the maximum potential. In WITCH, the deployment of BECCS, nuclear, and wind increases slightly. The reduction of energy demand relative to the baseline scenario is more pronounced in WITCH than in the other models, (see Section 4.2).

⁶ In GCAM, BECCS and Gas CCS deployment in the weak action cases is lower than in the immediate action cases after 2080. For both technologies, the cost of electricity generation is higher in the WEAK action cases after 2080, due to higher bioenergy prices in the case of BECCS and the higher carbon prices applied to residual emissions in the case of Gas CCS.

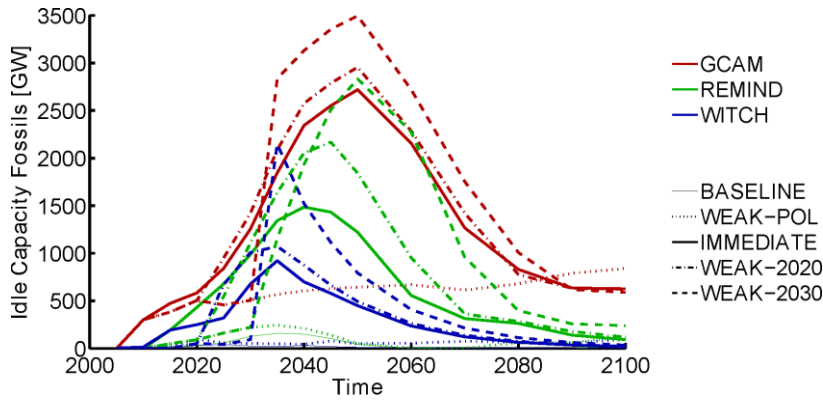


Figure 4: Global fossil electricity generation capacities that become unused in different climate policy scenarios.

4.2. Energy demand reductions and decarbonization of supply

Energy-related emission reductions can be achieved by reducing total final energy demand, by reducing the amount of CO₂ emitted per unit of final energy produced (carbon intensity), or through a combination of both. From a meta-perspective, energy system transformations can thus be characterized in terms of the relative contributions of these two factors. Figure 5 presents the final energy demand and carbon intensity for the climate stabilization scenarios as well as the WEAK-POL and BASELINE scenarios. The models agree that the adoption of a stringent climate policy target results in a strong reduction of energy demand relative to the baseline—which is particularly significant in the short-term—as well as a strong and continuous decarbonization trend. Nevertheless, differences across models exist in the relative importance of demand reduction and decarbonization and the pace at which they can be achieved.

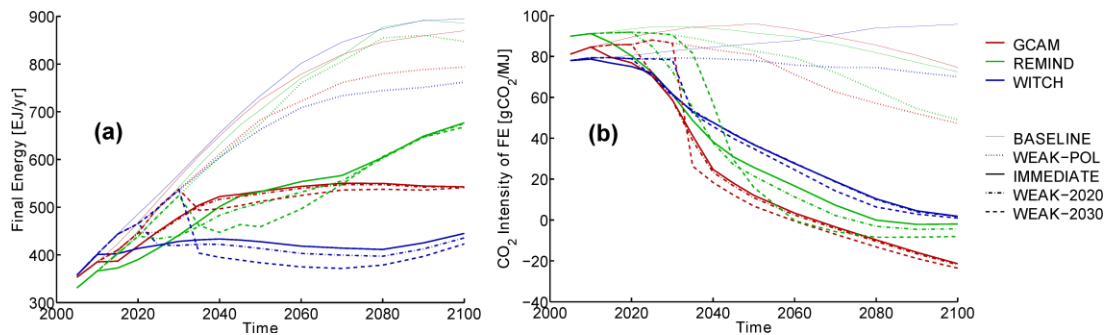


Figure 5: Global (a) final energy demand and (b) carbon intensity of final energy across the different scenarios.

The adoption of ambitious cooperative action results in an abrupt increase of carbon prices (cf. Section 5). The energy supply in GCAM is most responsive to this price shock, with very high decarbonization rates after target adoption. Early retirement of existing fossil capacities (see Section 4.1 and SM5) and rapid up-scaling in the deployment of carbon-free technologies enable a fast reduction of carbon intensity. This pattern is particularly prominent in the WEAK-2030 scenario. Energy demand reductions, by contrast, are less important than in the other two models.

In WITCH, carbon intensity is reduced at a lower rate and long-term carbon intensity levels are higher than in the other two models. In the climate policy scenarios, a substantial level of energy-related emissions remain, and the deployment of bioenergy in combination with CCS is considerably smaller than in GCAM and REMIND. While WITCH is less optimistic about supply-side decarbonization options, it features a larger contribution from the reduction of final energy demand, with a more pronounced contraction of final energy. Induced innovation provides an additional channel for demand side energy intensity improvement, which, along with the substitution between capital and energy in the macro-economic production function, reduces the amount of final energy per unit of output produced and in a more pronounced contraction of final energy (see also De Cian et al., this issue).⁷

The decarbonization of the REMIND energy system is characterized by longer transition time scales after climate target adoption. This is due to the constraint on the rate of premature retirement of fossil capacities, which is assumed to be limited to 4%/yr, and the cost penalty for fast up-scaling of low-carbon options. The contribution of reductions in energy demand is sizeable, but smaller than in WITCH. As in the other two models, the price shock arising from the high carbon prices in the WEAK-2030 scenario results in a short-term contraction of final energy demand to a level below that in the other two stabilization scenarios.

5. Carbon prices and climate policy costs

The IMMEDIATE action scenario describes an optimal pathway towards the prescribed climate stabilization target, and therefore results in the lowest cumulative discounted

⁷ The mechanism of R&D in energy efficiency is not represented in REMIND and GCAM.

mitigation costs. Weak near-term action results in a deviation from the least-cost pathway, and thus has a different carbon price and mitigation cost pattern. This section analyzes the implications of the timing of mitigation efforts on the evolution of carbon prices and costs.

Figure 6a presents the intertemporally aggregated global climate policy costs expressed as a fraction of global economic output.⁸ The mitigation costs, aggregated over 2010–2100, amount to 1.4% (REMIND), 1.5% (GCAM), and 2.5% (WITCH) of global economic output in the IMMEDIATE scenario.⁹ By contrast, climate policy costs amount to a few tenth of a percent for a continuation of weak, fragmented climate policies throughout the century (WEAK-POL scenario). The differences in mitigation costs reflect differences in the responsiveness of models to climate policies (Kriegler et al. 2013b). In GCAM and REMIND, more emissions reduction options are available at lower cost levels, while abatement options are more scarce and costly in WITCH.

A delay of comprehensive emission reductions results in an increase in aggregated costs that is relatively small for WEAK-2020, but more significant for WEAK-2030. For this scenario, aggregated costs are between 11% (GCAM) and 45% (REMIND) higher than in the IMMEDIATE scenario. The differences in cost penalties for delayed action relate directly to differences in short-term flexibilities and path-dependencies between GCAM (high short-term flexibility), WITCH (medium short-term flexibility) and REMIND (stronger path dependencies).

⁸ It is important to note that we quantify the costs of reducing emissions, but do not consider the benefits of avoided climate damages.

⁹ In REMIND and WITCH, mitigation costs are calculated as consumption losses relative to the baseline. In GCAM, mitigation costs were calculated as the area under the marginal abatement cost curve (Calvin et al. 2009b). A discount rate of 5% was used for the intertemporal aggregation of mitigation costs.

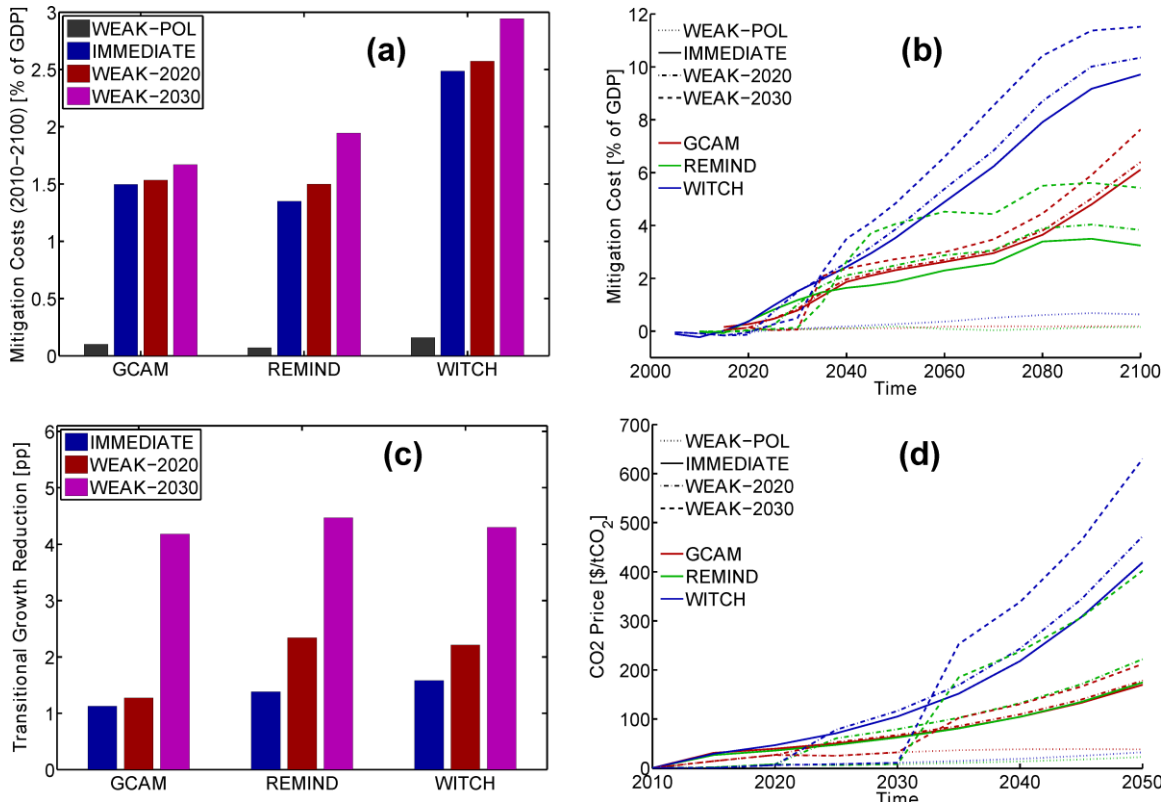


Figure 6: Economic effects of climate policies. (a) Mitigation costs aggregated and discounted from 2010–2100 and expressed as a fraction of GDP; (b) relative mitigation costs over time; (c) transitional reduction of income growth; and (d) CO₂ price trajectories. REMIND and WITCH report consumption losses as a mitigation cost metric, GCAM the area under the marginal abatement cost curve.

Regarding the evolution of costs over time, all models indicate a continuous increase in global mitigation costs as a fraction of GDP for the climate policy scenarios (Figure 6b). This means that climate policies reduce the rate of income growth relative to the baseline. In the IMMEDIATE scenario, the introduction of climate policy in a transitional growth reduction of 1.6 percentage points or less (Figure 6c). In the WEAK-2030 scenario, the radical emission reductions within a relatively short period of time result in a marked jump in policy costs. As shown in Figure 6c, the reduction of income growth rates in the decade after climate policy adoption is considerably higher for the WEAK-2020 scenario than for IMMEDIATE, and more than doubles for WEAK-2030.

Carbon prices quantify the marginal costs of emissions reductions. Due to their influence on energy prices, CO₂ prices affect the incidence of mitigation costs on households, businesses,

and industry. CO₂ prices are also an important driver of the distribution of mitigation costs among nations under a global cap and trade system (Luderer, DeCian, et al., 2012). Figure 6d depicts the evolution of carbon prices over time. In the IMMEDIATE scenario, carbon prices are approximately 30\$/tCO₂ in 2015 and increase nearly exponentially over time. The transition from fragmented, unambitious climate policy to a cooperative, ambitious climate policy regime results in an abrupt increase of carbon prices (Figure 6b). To compensate for weak near-term action, carbon prices after target adoption are higher than in the IMMEDIATE scenario. For the WEAK-2030 scenario, carbon prices jump from 10-30 \$/tCO₂ in 2030 to between 100 \$/tCO₂e (GCAM) and 250 \$/tCO₂ (WITCH) in 2035.

6. Discussion and conclusions

Our analysis shows that continuing climate policies at the current level of ambition would fail to have a significant impact on climate change and warming. In particular, such weak policies are insufficient to stabilize GHG emissions at a level that is consistent with the long-term target of limiting global temperature increase to no more than 2°C, relative to pre-industrial levels. At the same time, our analysis suggests that mitigation pathways reaching 450 ppm CO₂e by 2100 are possible with the abatement flexibility in the models, even with a further delay of cooperative and comprehensive mitigation action.

However, our results show that weak near-term action exacerbates the 450 ppm CO₂e challenge, which requires fundamental transformations even if it started immediately. The impacts of delaying comprehensive action until 2020 are noticeable, and become very substantial if action is delayed until 2030. In delayed action scenarios we observe a steep increase of carbon prices during the transition from unambitious, fragmented climate policies to an ambitious coordinated climate regime, more radical decarbonization rates of energy supply, more ambitious reductions of final energy demand, and greater stranded investments resulting from the early retirement of fossil capacities. The contraction of mitigation action to a short time horizon imposes a major shock to economic systems, and reduces income growth markedly in the decade after target adoption. For reasons of political acceptability, the phase-in of climate policies will presumably have to be slower in the real world than in the stylized scenarios considered here, thus further increasing the long-term mitigation challenges. In summary, in view of the rapid decarbonization rates and strongly increased mitigation challenges observed in the WEAK-2030 scenario, it can be expected that the political and social acceptability of 2°C mitigation pathways with a

prolonged delay of action will be called into question. The determination of acceptability is, of course, a political question and outside the scope of this paper.

Our study reveals several areas of further research needs. The scenarios considered in this study all assume that the full set of mitigation technologies represented in the models is available. Some of these technologies, such as CCS, are not yet fully mature. Other supply-side options, such as large-scale bioenergy use or nuclear power, face public opposition. The effect of weak action in the case of incomplete technology portfolios is yet to be explored. The models exhibit a high degree of flexibility in reacting to the carbon price shock in the weak near-term action scenarios. Different assumptions regarding path-dependencies explain some of the differences in the results of the three models used in this study. More research is required to explore path-dependencies and inertias in energy systems and land-use, in order to qualify the plausibility of such developments. More detailed studies on the interrelation between the representation of path dependencies and the impact of unambitious near-term action are required, ideally by comparing a larger number of structurally different models. Finally, our results show that for a given long-term stabilization target, weak near-term action results in higher overshooting of GHG concentrations and global mean temperatures than immediate action, as well as higher rates of climate change. Further climate impact research is required to clarify the incremental impacts that result from such overshooting pathways.

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