A Global Roll-out of Nationally Relevant Policies Bridges the Emissions Gap

Heleen van Soest (heleen.vansoest@pbl.nl)
Netherlands Environmental Assessment Agency https://orcid.org/0000-0001-5307-5880
Lara Aleluia Reis
RFF-CMCC European Institute on Economics and the Environment
Luiz Bernardo Baptista
Centre for Energy and Environmental Economics, Universidade Federal do Rio de Janeiro https://orcid.org/0000-0002-7016-1796
Christoph Bertram
Potsdam Institute for Climate Impact Research https://orcid.org/0000-0002-0933-4395
Jacques Després
Joint Research Center https://orcid.org/0000-0002-9851-9964
Laurent Drouet
RFF-CMCC European Institute on Economics and the Environment (EIEE) https://orcid.org/0000-0002-4087-7662
Michel Elzen
PBL Netherlands Environmental Assessment Agency, 2594 AV The Hague, Netherlands https://orcid.org/0000-0002-5128-8150
Panagiotis Fragkos
E3Modelling & National Technical University of Athens
Oliver Fricko
International Institute for Applied Systems Analysis
Shinichiro Fujimori
Kyoto University https://orcid.org/0000-0001-7897-1796
Neil Grant
Imperial College London https://orcid.org/0000-0001-8671-5012
Mathijs Harmsen
Netherlands Environmental Assessment Agency https://orcid.org/0000-0001-6755-1569
Gokul Iyer
Pacific Northwest National Laboratory https://orcid.org/0000-0002-3565-7526
Kimon Keramidas
European Commission, Joint Research Centre, Calle Inca Garcilaso 3, 41092 Sevilla, Spain https://orcid.org/0000-0003-3231-5982
Alexandre Köberle
Grantham Institute, Imperial College London https://orcid.org/0000-0003-0328-4750
Elmar Kriegler
Potsdam Institute for Climate Impact Research https://orcid.org/0000-0002-3307-2647
Aman Malik
Potsdam Institute for Climate Impact Research https://orcid.org/0000-0002-7310-8448
Shivika Mittal
Imperial College London

Ken Oshiro
Kyoto University https://orcid.org/0000-0001-6720-409X
Keywan Riahi
International Institute for Applied Systems Analysis and Graz University of Technology
Mark Roelfsema
Utrecht University
Bastiaan van Ruijven
International Institute for Applied Systems Analysis https://orcid.org/0000-0003-1232-5892
Roberto Schaeffer
Universidade Federal do Rio de Janeiro, COPPE https://orcid.org/0000-0002-3709-7323
Diego Silva Herran
Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES)
https://orcid.org/0000-0001-5484-4442
Massimo Tavoni
European Institute on Economics and the Environment
Gamze Unlu
International Institute for Applied Systems Analysis https://orcid.org/0000-0003-0080-7122
Toon Vandyck
European Commission https://orcid.org/0000-0001-5927-0310
Detlef van Vuuren
Netherlands Environmental Assessment Agency https://orcid.org/0000-0003-0398-2831

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Abstract

Closing the remaining emissions gap between Nationally Determined Contributions (NDCs) and the global emissions levels needed to achieve the Paris Agreement's climate goals will likely require a comprehensive package of policy measures. National and sectoral policies can help fill the gap, but success stories in one country cannot be automatically replicated in other countries, but need to be adapted to the local context. Here, we develop a new Bridge scenario based on nationally relevant measures informed by interactions with country experts. We implement this scenario with an ensemble of global integrated assessment models (IAMs). We show that a global roll-out of these good practice policies closes the emissions gap between current NDCs and a cost-optimal well below 2 °C scenario by two thirds by 2030 and more than fully by 2050, while being less disruptive than a scenario that delays cost-optimal mitigation to 2030. The Bridge scenario leads to a scale-up of renewable energy (reaching 50%-85% of global electricity supply by 2050), electrification of end-uses, efficiency improvements in energy demand sectors, and enhanced afforestation and reforestation. Our analysis suggests that early action via good-practice policies is less costly than a delay in global climate cooperation.

Introduction

In the Paris Agreement, countries agreed to limit global warming to well below 2 °C, and if possible to 1.5 °C[1]. For implementation, the Paris Agreement relies on mitigation action at the national level. These actions are communicated via nationally determined contributions (NDCs) and long-term strategies, containing each country's pledged contribution to global mitigation. A key question is whether the collective action of all countries leads to the implementation of the Paris Agreement's climate goals[2,3]. For this, countries agreed on a global stocktake process to periodically review collective progress and to adapt efforts in order to meet the Paris Agreement's global climate mitigation goals.

Several publications have already shown that the aggregated impact of NDCs is insufficient[4,5]. In addition, global emissions implied by nationally implemented policies are, collectively, even exceeding the global emissions levels projected under current NDCs[4]. This means that current NDCs and policies need to be strengthened. The cost-optimal scenarios from global integrated assessment models (IAMs) can provide guidance on how to do this. In reality, however, it is not always possible to implement these pathways[6]. For instance, influential societal actors might be able to prevent certain measures if they go against their interests. Market distortions can also make certain measures unattractive. Other solutions might lack societal support and also the rate at which a transition can be implemented may be slowed down, such as in the case of closing coal mines and coal-fired power plants (given the impact on coal miners and coal-dependent regions and communities). At the same time, however, there is also evidence of effective implementation of climate policies[7]. Here, good practice policies are defined as successfully implemented policies in one or more countries with a noticeable impact on greenhouse gas (GHG) emissions. In some cases, these policies are not even part of the cost-optimal mix suggested by models but could be easier to implement. It has been suggested that scaling up these good practice policies to other parts of the world might in the short-term be a more feasible and convincing strategy[8-12]. Fekete et al.[7], Roelfsema et al.[8] and Kriegler et al[9] investigated the impact of replicating such good practice policies in other parts of the world by focusing on global GHG emissions and sector-level indicators related to feasibility. Although helpful as first step, this earlier work is limited by 1) the formulation of good practice policies at the global scale, and 2) being based on a single model.

Better information on such good practice policies is needed to support the UNFCCC global stocktake in 2023. Here, we build on the earlier work[7-9], also going beyond relatively abstract cost-optimal pathways as guidance for policy-making by focusing on concrete policy measures that can be implemented to close the emission gap. We do this for the first time using multiple models (both global and national) to assess a common set of reduction measures. These measures have been defined in consultation with national experts, making the scenarios more relevant. The key scenario is referred to as the *Bridge* scenario, as it aims to bridge the gap between the ambition levels set out by countries by 2030 and those consistent with the Paris Agreement. This scenario includes a set of well-defined measures that can be implemented in the

2020-2030 period and go beyond the ambition of the NDCs, and that would still allow reaching the Paris climate goals in the long-term by transitioning to a cost-optimal path towards 2 °C after 2030. The *Bridge* scenario was developed in multiple rounds. First, national modelling teams[1] responded to the proposed good practice policies (based on literature), considering whether these policies could be realistically implemented in their countries and, if not, what other target levels or years would be feasible. Second, the policy list was adjusted to further differentiate country groups, in terms of timing and stringency of the targets. Third, some national models ran the refined scenarios and provided feedback, upon which the list was further refined. As such, we eventually defined three country groups, which were found to offer enough differentiation to be nationally relevant, while still adhering to a common set of policy measures. Finally, all national and global model teams ran the agreed set of scenarios. In the context of the global stocktake, here we focus on the results at the global level and a number of large countries, while more detailed national-level results by national models can be found elsewhere[11].

[1] Covering Australia, Brazil, Canada, China, EU, India, Indonesia, Japan, Republic of Korea, Russia, United States; i.e. approximately 75% of global emissions.

Results

In order to discuss the possible impacts of the *Bridge* scenario, we compare it to four other scenarios i.e. the impacts of current policies (*CurPol*), the conditional NDCs (*NDCplus*), and the models' cost-optimal pathways towards 2 °C (starting immediately: *2Deg2020,* and with a delay: *2Deg2030*) (see Methods and Supplementary Information for more details). For the first two scenarios, the current policies and NDCs were extended beyond 2030 by assuming equivalent effort, i.e. by extrapolating the 'equivalent' carbon price in 2030, using the GDP growth rate of the different regions up to 2050 for the extrapolation (see Supplementary Information part C). For the *Bridge* scenario, the defined set of measures was implemented up to 2030 (Table 1) and a cost-optimal path towards 2 °C was implemented after 2030 (see Supplementary Information part C). A full description of the scenarios and additional results can be found in the Supplementary Information.

[Please see the supplementary files section to view Table 1.]

A bridge over the emissions gap

The model outcomes (Figure 1 and Supplementary Figures B 7 and B 8) show that the *CurPol* and *NDCplus* scenarios both fall considerably short of the emission reductions needed to implement the Paris Agreement (consistent with earlier work). In contrast, the good practice policies included in the *Bridge* scenario are able to reduce GHG emissions close to the needed levels in 2030, followed by a longer-term trajectory similar to the ambitious benchmark of *2Deg2020.* The *Bridge* scenario has a less steep reduction than the *2Deg2030* scenario in the short term, offering a pathway that largely closes the 2030 emissions gap without adding substantial challenges in the short and medium terms. Here, the emissions gap is defined as the difference between the *NDCplus* scenario and the *2Deg2020* scenario. The *Bridge* scenario closes that global emissions gap by 71% (median, range 26%–275%) by 2030, and compensates the slower start by a slightly deeper emission reduction in 2050, 106% (85%–112%). The 2030 emissions gap is closed by 17% in the USA, 49% in India, 56% in the EU and 75% in China.

Figure 2 shows the rates of GHG emissions reductions in the *Bridge* scenario, compared to the *CurPol*, *NDCplus,* and cost-optimal case (immediate: *2Deg2020* and delay: *2Deg2030*). In contrast to the increase in GHG emissions under current policies in some countries, emissions decline everywhere in the *Bridge* scenario, especially in the 2030–2050 period. In most countries, the *Bridge* scenario shows smaller reductions than the immediate action *2Deg2020* scenario in the short term (2030), and smaller reductions than the *2Deg2030* scenario in the longer term (2050). As such, good practice policies can constitute an alternate pathway in line with the Paris Agreement's climate goals, without relying on carbon pricing only as in cost-optimal scenarios, while not significantly increasing the burden in the longer term.

Which measures have the largest effect on emissions?

The emissions gap between the *NDCplus* and *2Deg2020* scenarios amounts to approximately 12 $GtCO_2e$ in 2030 (model median). The *Bridge* scenario closes this gap with 71%. The energy supply sector (through higher renewable energy share, electrification, energy efficiency improvement) is the largest contributor to emissions reductions between the *NDCplus* and *Bridge* scenarios, both in 2030 and in 2050 (Figure 3). In most models, also mitigation of non-CO_2 emissions, the transport sector (zero-carbon vehicles and efficiency improvements), and AFOLU (notably in 2030) play an important role. This indicates potential to enhance NDC ambition in specific areas.

Changes in energy and land-use systems

Figure 4 shows projected changes in energy and land-use systems under five scenarios: *CurPol, NDCplus, Bridge, 2Deg2020, and 2Deg2030*. The *Bridge* scenario significantly increases mitigation action compared to the *CurPol* and *NDCplus* scenarios. In fact, on several indicators, the prescribed policies (Table 1 and Supplementary Information part A) close the gap with the cost-optimal *2Deg2020* scenario almost completely. By 2050, the *Bridge* scenario is more ambitious than the *2Deg2020* scenario for many indicators, compensating for the delay with respect to the cost-optimal pathway. Figure 4 Panel a, for example, shows that the target to increase the renewable electricity share by 1.4% per year in the *Bridge* scenario (measure 9) leads to deployment far beyond the *CurPol* and *NDCplus* scenarios in 2050 (i.e. towards 75%, versus around 50%), but similar to the *2Deg2020* (in line with previous research[13]) and lower than the *2Deg2030*. In 2030, however, the *Bridge* scenario is similar to *2Deg2020*, so it does not increase the global trend in terms of installing renewables in the short term (it may do so regionally, however, see Baptista et al.[11]). As a result of the assumed penetration of non-fossil fueled vehicles (measure 20), the *Bridge* scenario shows a significant increase in the share of electricity in transport, even more so in *Bridge* than in *2Deg2020* (Panel b). This starts in 2030, but manifests especially in 2050. However, in some models, the target to increase non-fossil fueled vehicles actually leads to an increase of biofuel powered engines (Supplementary Figure B 1) rather than electrification (explaining the relatively large range), but less so than the *2Deg2030* scenario in 2050. Following CCS (measure 13), efficiency improvement (measure 14), and F-gas emission reduction (measure 10) targets in industry, industrial emissions (expressed as CO_2 emissions from industrial processes as well as F-gases, panel c), are projected to decrease, in *Bridge* slightly more so than in *2Deg2020* (by 2050). Because the measures in the buildings sector focus on energy efficiency improvements (measures 3-6), the share of electricity in buildings (panel D) is not projected to change significantly in the short term, but *Bridge* makes up for that by 2050. Panel E shows that the afforestation policy (measure 16) leads to slightly more afforestation in 2030, followed by a large scale-up in 2050, but not as large as in *2Deg2030*. As such, CO_2 emissions from agriculture, forestry and other land-use (AFOLU) are projected to be reduced by 38% (model median) by 2030 and by 120% by 2050 in the *Bridge* scenario, relative to 2015 levels. Supplementary Figure B 2 shows the same indicators but for the *NDCplus-convergence* scenario instead of *NDCplus*: by 2050, the *convergence* scenario is closer to the *Bridge* scenario than *NDCplus* for most indicators. Figure B 3, finally, shows the projected changes in the primary energy mix. *Bridge* sees lower total primary energy supply mainly due to the efficiency improvement and transport electrification measures, but not as low as *2Deg2020*, and a shift from fossil fuels to renewable energy sources, especially by 2050. As a result of the scale-up of renewable energy, electrification of energy demand, and efficiency improvements, CO_2 emissions from the energy sector are projected to decrease.

Costs of building the bridge

While the good practice policies may have benefits in terms of social and political acceptability, earlier work (Kriegler et al., 2018) has highlighted that a set of regulatory measures may be more costly than a comprehensive carbon pricing scheme, leading to a non-cost-optimal transition across regions and sectors. A uniform price signal ensures that mitigation happens first where costs are lowest, leading to the overall efficient outcome, in absence of other market failures. Furthermore, climate action as represented in the *Bridge* scenario implies a more gradual path for emission reductions in the period 2020-2030 compared to the immediate implementation of the cost-optimal policy (2Deg2020). This delay can further raise costs of the *Bridge* scenario, depending on the evolution of technology costs. The salience of a carbon price, however, may also raise opposition especially from low-income households facing energy poverty and food-insecurity[14], carbon-intensive regions and vulnerable trade-exposed industries that may complicate or delay its implementation[15]. Arguably, the good practice policies included in the *Bridge* scenario face lower implementation barriers and could speed up climate action compared to a scenario in which cost-optimal policy measures are pursued. A fair evaluation of the costs of the *Bridge* scenario therefore involves two comparisons: one with the immediate and cost-optimal climate policy (*2Deg2020*), and one with a delayed implementation of uniform carbon pricing, starting in 2030 (*2Deg2030*) and therefore requiring more disruptive action to meet the 2 °C target.

Our results (Figure 5) indicate that although the *Bridge* scenario raises policy costs (as expressed by GDP cost per tonne CO_2e abated relative to the Current Policy scenario) in 2050 by more than 20% (1%–38%) compared to an immediate implementation of a cost-optimal 2 °C scenario with globally uniform carbon prices (*2Deg2020*), it has lower policy costs (Figure 5a) and carbon prices (Figure 5b and Supplementary Figure B 9) in the near term (2030). The *Bridge* scenario also outperforms a delayed 2 °C scenario (*2Deg2030*, see Supplementary Information part C) with costs being more than 10% (-6%–33%) lower in 2050. As such, our analysis suggests that early but non cost optimal action is preferred over climate policy delay.

Interestingly, not all models in the ensemble agree on the size and sign of the trade-off between early and cost-optimal policy implementation. Multiple and counteracting effects are at play. Generally, good practice regulatory policies would raise costs particularly when the resulting energy system deviates strongly from the cost-optimal one. If the necessary changes are obvious, or when there are low-hanging fruits for climate policy, then a similar outcome may be achieved through regulation and carbon prices. The phase-out of coal and the scale-up of renewable power generation technologies[16-18] may be an example that comes close (Supplementary Figure B 10 shows that investments in the electricity sector are projected to shift from fossil fuels to renewables). However, for other trade-offs, such as efficiency improvements versus fuel shift, or the allocation of emission reductions across sectors, a mix of regulatory measures that leads to an outcome resembling the cost-optimal one may be more difficult to achieve. Therefore, while regulatory policies can be a pragmatic entry-point for climate policy, cost-efficiency in the medium and long-term is more easily achieved via comprehensive carbon pricing schemes across all sectors and regions to avoid inter-sectoral and inter-regional leakage[12]. The costs of delaying climate action, on the other hand, depend on technological progress and the availability and scalability of negative emission technologies (NETs) in the future, among others[19]. For three out of four models that capture economic growth endogenously, the costs of delay outweigh the additional cost of regulatory good practice policies in 2050.

An advantage of the regulatory measures as implemented in the *Bridge* scenario is that carbon prices remain at lower levels in the near term, which may facilitate public acceptability and implementation of carbon pricing schemes with a broad sector coverage. If political consensus in favour of a comprehensive pricing scheme is not found over time, then a further intensification of the good practice policies may serve as a practical way forward to close the emissions gap. At the same time, the advantages of good practice policies in terms of acceptability may be challenged if ambitious climate targets bring cost elements to the forefront of the political debate.

Hence, our results suggest that a global roll-out of good practice policies can be a useful approach to close the emission gap in the near term, while their role in climate policy in the longer term should be reconsidered in the context of a broader policy mix[20], including carbon pricing[21].

Discussion And Conclusions

Parties to the Paris Agreement were supposed to submit updated NDCs and communicate their long-term strategies to the UNFCCC in 2020. Due to the COVID-19 pandemic, these timelines have been delayed, but scaling up climate ambition and action remains necessary to keep the Paris Agreement goals within reach. As the emissions gap seems hard to close, we built a set of relevant scenarios that may provide a pathway based on successful examples of policies. The mitigation measures were defined in a two-way interaction with country experts and assumptions were adjusted for different regions if necessary. These scenarios, especially the good practice policies (*Bridge* scenario), can support the ratcheting up of mitigation ambition of NDCs.

Although the granularity of the *Bridge* scenario has improved in terms of country differentiation compared to earlier studies, some limitations remain. In most cases, we only distinguished high-income and low-/middle-income countries, and while the measures were assessed to be implementable, this might not always be the case when moving to the country-level. Therefore, Baptista et al.[11] discuss the same set of scenarios in the context of national feasibility considerations. Models implemented the set of measures in different ways. The ranges, however, do tell a robust story about the *Bridge* scenario in relation to the reference scenarios. Although set at a relatively low level, the carbon price measure was the single most effective policy in the short term. Removing it from the set of measures resulted in significantly higher emissions. However, as many countries or regions already have a form of carbon pricing, it deserves a spot in the selection of good practice policies, especially given the differentiated timelines and pricing levels assumed in the *Bridge* scenario. Finally, we have not considered the impact of the COVID-19 pandemic quantitatively, effectively assuming a full recovery without significant effect on long-term, global emissions[18]. The policy measures explored here, however, can inform governments that aim for 'green' recovery packages[22], by showing potential for ratcheting up mitigation ambition with a concrete set of measures.

We have shown that good practice policies can help to reach the 2 °C target in the long-term. They ensure closing the global emissions gap between NDCs and a cost-optimal 2 °C scenario by two-thirds (model median) by 2030. After 2030, more ambitious measures are needed. Such a *Bridge* scenario leads to lower energy sector emissions due to scale-up of renewable energy, electrification of energy demand, and efficiency improvements, and to lower land-use emissions due to afforestation—at levels and rates of change that are somewhat less than the *2Deg2020* case and less than the *2Deg2030* case. The scenario is still in a position that allows meeting the Paris goals, and, importantly, is less disruptive than *2Deg2030*. The *Bridge* scenario raises policy costs (as expressed by GDP loss per tonne of CO_2 abated relative to the *CurPol* scenario) in 2050 by approximately 20% compared to a cost-optimal 2 °C scenario (*2Deg2020*). When put in perspective of economic growth in the coming three decades, this 20% cost increase implies that annual economic growth rates in the *Bridge* would be around 0.02 percentage points below the annual GDP growth in *2Deg2020*. The *Bridge* scenario outperforms the delayed 2 °C scenario (*2Deg2030*) with global economic impacts being more than 10% lower in 2050. As such, early but non-cost-optimal action is preferred over climate policy delay. In the absence of immediate, all-encompassing and ambitious climate policy measures, therefore, a global roll-out and successful implementation of good practice policies can put the world on track to a 2 °C-compatible pathway without posing large additional challenges.

In short, acting stringently on 2 °C (*2Deg2020*) is needed, but, collectively, we are not on track (*NDCplus*). If we do not strengthen collective action until 2030, the best chance at limiting global warming may be *2Deg2030*. However, if we manage to accelerate action until 2030 (*Bridge*), major disruption can be avoided, even if we do not fully reach *2Deg2020*. These results illustrate that short-term implementation of practical regulation-based policies is preferable over delayed climate action. At the same time, the institutional set-up should aim to avoid inefficient policy lock-in, as more efficient instruments may gain political and societal support over time.

Methods

Models

Both national and global model teams followed the same scenario protocol for comparability. The global models included here are: AIM/CGE[23], COPPE-COFFEE[24], IMAGE[25], MESSAGEix-GLOBIOM[26], POLES[27], PROMETHEUS[28], REMIND-MAgPIE[29], TIAM-Grantham[30], WITCH-GLOBIOM 5.0[31]. National-level results are presented in Baptista et al.[11]

Scenarios

In line with the global stocktake, the ratcheting up mechanism has been applied in constructing the scenario protocol (see Supplementary Information part C for the full protocol text and Supplementary Information part A for the detailed lists of good practice policies). This means that the scenarios build upon one another in terms of ambition and modelling assumptions. The Current policies scenario is the least ambitious and the 2 °C scenario is the most ambitious.

The **Current policies (CurPol)** scenario incorporates middle of the road socio-economic conditions throughout the century, based on the second marker baseline scenario from the Shared Socioeconomic Pathways (SSP2)[32]. It also assumes that climate, energy and land use policies that are currently ratified are implemented (cut-off date 1 July 2019).

The **NDC-plus** scenario builds further upon the CurPol scenario and assumes that the conditional NDCs (both unconditional and conditional NDC actions) as submitted by April 2020 are implemented by 2030. After 2030, the scenario reflects continuation of effort (see below).

The **Bridging (Bridge)** scenario builds upon the CurPol scenario and assumes that certain good practice policies, which have shown to be effective in some countries[8-10], will be implemented globally from 2020 until 2030 (see Supplementary Information part A: Table A 1 lists the good practice policies while Table A 2 gives an overview of their implementation in models, with the implemented shares ranging from 53% to 94%). After 2030, the *Bridge* scenario transitions to a 2 °C scenario following a cost-effective pathway. A distinction is made between low/medium income and high income countries in terms of timing and stringency of good practice policy targets. The set of policies was defined in dialogue with national model teams, granting a more realistic scenario narrative (for more details, see the Supplementary Information). As opposed to Fekete et al.[10], carbon pricing is included as good practice policy, although it may be considered as a top-down policy of different nature than the other policies. Carbon pricing and emission trading schemes have been successfully implemented in various countries. Furthermore, previous work (Kriegler et al., 2018) highlights that good practice regulatory policies should be considered as complements to pricing-based approaches. In the simulations, the carbon price applies to all gases and sectors, hence represents an idealized view of carbon pricing schemes. It does not take the highest carbon price currently observed as starting point, but rather an approach in which countries were divided in three tiers with different carbon price levels and timelines to be most relevant to the countries represented here [insert REF]. As a variant and to analyse the effect of this measure, some models ran an additional scenario excluding the carbon price measure (see SI Figure B 6).

The **2 °C (2Deg2020** and **2Deg2030)** scenarios assume that an average temperature increase of 2 °C without overshooting is reached by 2100 in a cost-effective way (starting from 2020 in *2Deg2020* and from 2030 in *2Deg2030*). National modelling teams used a carbon budget derived from the global carbon budget of 1,000 Gt CO_2 in the period 2011-2100 (including 2011 emissions), as done in CD-LINKS (https://www.cd-links.org/) . This global carbon budget represents a high probability (66%) of keeping global warming below 2 °C. Carbon budgets have been revised since the CD-LINKS project in such a way that 1,000 Gt is even more stringent than previously. Cumulative CO_2 emissions in the 2 °C scenarios (*2Deg2020, 2Deg2030,* and *Bridge*) are not all exactly 1000 Gt, but range from 788 Gt CO_2 to 1540 Gt CO_2 (2011-2100), which is still within the range considered to be in line with 2 °C.

For the CurPol and NDC-plus scenarios, a continuation of efforts after the target year was assumed. This was implemented by extrapolating the "equivalent" carbon price in 2030, using the GDP growth rate of the different regions up to 2050. The equivalent carbon price represents the value of carbon that would yield the same emissions reduction as the NDC policies in a region. If a region has a carbon price of zero while implementing the NDC in 2030, a minimum carbon price of 1 $/tCO_2$ in 2030 was assumed. If a region has a negative carbon price in 2030, the trajectory resulting from 1 $/tCO_2$ was offset to the model's 2030 starting point. For land use, a carbon price ceiling of $200/tCO_2$ was applied.

Data availability

Model results can be found in the COMMIT database: https://db1.ene.iiasa.ac.at/COMMITDB/dsd?Action=htmlpage&page=about. Policy relevant data is available in the Global Stocktake tool: https://themasites.pbl.nl/globalstocktake-indicators/.

Code availability

The models are documented on the common integrated assessment model documentation (https://www.iamcdocumentation.eu/index.php/IAMC_wiki), and several have published open source code (e.g. REMIND: https://github.com/remindmodel/remind), visualisation tools or detailed documentation (see references). The R-script that was used to generate the figures can be found on GitHub: https://github.com/Hel1vs/Bridge

References

1. UNFCCC. *Paris Agreement: Decision 1/CP.17 - UNFCCC document FCCC/CP/2015/L.9/Rev.1*, <http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf>UNFCCC (2015).
2. Rogelj, J. *et al.* Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature* **534**, 631–639, doi:10.1038/nature18307 (2016).
3. Vrontisi, Z. *et al.* Enhancing global climate policy ambition towards a 1.5 °C stabilization: a short-term multi-model assessment. *Environmental Research Letters* **13**, 044039, doi:10.1088/1748-9326/aab53e (2018).
4. Roelfsema, M. *et al.* Taking stock of national climate policies to evaluate implementation of the Paris Agreement. *Nature Communications* **11**, 2096, doi:10.1038/s41467-020-15414-6 (2020).
5. Fujimori, S. *et al.* Implication of Paris Agreement in the context of long-term climate mitigation goals. *SpringerPlus* **5**, 1620, doi:10.1186/s40064-016-3235-9 (2016).
6. Staub-Kaminski, I., Zimmer, A., Jakob, M. & Marschinski, R. CLIMATE POLICY IN PRACTICE: A TYPOLOGY OF OBSTACLES AND IMPLICATIONS FOR INTEGRATED ASSESSMENT MODELING. *Climate Change Economics* **05**, 1440004, doi:10.1142/S2010007814400041 (2014).
7. Fekete, H. *et al.* A review of successful climate change mitigation policies in major emitting economies and the potential of global replication. *Renewable and Sustainable Energy Reviews* **137**, 110602, doi:https://doi.org/10.1016/j.rser.2020.110602 (2021).
8. Roelfsema, M. *et al.* Reducing global GHG emissions by replicating successful sector examples: the 'good practice policies' scenario. *Climate Policy* **18**, 1103–1113, doi:10.1080/14693062.2018.1481356 (2018).
9. Kriegler, E. *et al.* Short term policies to keep the door open for Paris climate goals. *Environmental Research Letters* **13**, doi:10.1088/1748-9326/aac4f1 (2018).
10. Fekete, H. *et al.* Impacts of good practice policies on regional and global greenhouse gas emissions. (NewClimate Institute, PBL Netherlands Environmental Assessment Agency and International Institute for Applied Systems Analysis, Cologne, Germany; The Hague, the Netherlands; Laxenburg, Austria, 2015).

11. Baptista, L. B. *et al. Good practice policies to bridge the emissions gap in key countries* (Submitted, 2020).
12. Bertram, C. *et al.* Complementing carbon prices with technology policies to keep climate targets within reach. *Nature Climate Change* **5**, 235–239, doi:10.1038/nclimate2514 (2015).
13. Luderer, G. *et al.* Residual fossil CO2 emissions in 1.5–2 °C pathways. *Nature Climate Change* **8**, 626–633, doi:10.1038/s41558-018-0198-6 (2018).
14. Fujimori, S. *et al.* A multi-model assessment of food security implications of climate change mitigation. *Nature Sustainability* **2**, 386–396, doi:10.1038/s41893-019-0286-2 (2019).
15. Jenkins, J. D. Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design? *Energy Policy* **69**, 467–477, doi:https://doi.org/10.1016/j.enpol.2014.02.003 (2014).
16. IRENA. Renewable power generation costs in 2019. (International Renewable Energy Agency, Abu Dhabi, 2020).
17. IEA. Renewables 2020. (IEA, Paris, 2020).
18. IEA. World Energy Outlook 2020. (IEA, Paris, 2020).
19. Daioglou, V. *et al.* Bioenergy technologies in long-run climate change mitigation: results from the EMF-33 study. *Climatic Change*, doi:10.1007/s10584-020-02799-y (2020).
20. Pahle, M. *et al.* Sequencing to ratchet up climate policy stringency. *Nature Climate Change* **8**, 861–867, doi:10.1038/s41558-018-0287-6 (2018).
21. Oshiro, K. & Fujimori, S. Stranded investment associated with rapid energy system changes under the mid-century strategy in Japan. *Sustainability Science*, doi:10.1007/s11625-020-00862-2 (2020).
22. Andrijevic, M., Schleussner, C.-F., Gidden, M. J., McCollum, D. L. & Rogelj, J. COVID-19 recovery funds dwarf clean energy investment needs. *Science* **370**, 298–300, doi:10.1126/science.abc9697 (2020).
23. Fujimori S, Masui T & Y, M. AIM/CGE [basic] Manual. 1–87 (2012).
24. COPPE/UFRJ. *Model Documentation - COFFEE-TEA*, <https://www.iamcdocumentation.eu/index.php/Model_Documentation_-_COFFEE-TEA>IAMC (2020).
25. Stehfest, E., Van Vuuren, D. P., Bouwman, L. & Kram, T. *Integrated Assessment of Global Environmental Change with Model Description and Policy Applications IMAGE 3.0*. (PBL Netherlands Environmental Assessment Agency, 2014).
26. Huppmann, D. *et al.* The MESSAGEix Integrated Assessment Model and the ix modeling platform (ixmp): An open framework for integrated and cross-cutting analysis of energy, climate, the environment, and sustainable development. *Environmental Modelling & Software* **112**, 143–156, doi:https://doi.org/10.1016/j.envsoft.2018.11.012 (2019).
27. Després, J., Keramidas, K., Schmitz, A., Kitous, A. & Schade, B. POLES-JRC model documentation – 2018 update, EUR 29454 EN. (Publications Office of the European Union, Luxembourg, 2018).
28. Fragkos, P. & Kouvaritakis, N. Model-based analysis of Intended Nationally Determined Contributions and 2 °C pathways for major economies. *Energy* **160**, 965–978, doi:https://doi.org/10.1016/j.energy.2018.07.030 (2018).
29. Aboumahboub T *et al. REMIND - REgional Model of INvestments and Development - Version 2.1.0*, <https://www.pik-potsdam.de/research/transformation-pathways/models/remind>PIK (2020).
30. Loulou R & M, L. ETSAP-TIAM: the TIMES integrated assessment model part I: model structure. *Computational Management Science* **5**, 7–40 (2008).
31. RFF-CMCC EIEE. *WITCH documentation*, <https://doc.witchmodel.org/>2019).
32. Riahi, K. *et al.* The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change* **42**, 153–168, doi:https://doi.org/10.1016/j.gloenvcha.2016.05.009 (2017).

Declarations

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Author contributions

CB and others in the REMIND(MagPIE) team developed the scenarios for the REMIND-Magpie model; RS, LBB and others in the COFFEE team developed the scenarios for the COFFEE model; PF developed the scenarios for the PROMETHEUS model; KR, BvR, GU, OF developed the scenarios for the MESSAGEix-GLOBIOM team; DSH, KO, SF developed the scenarios for the AIM team; MH, MR, DvV developed the scenarios for the IMAGE model; LD, LAR developed the scenarios for the WITCH model; JD, KK developed the scenarios for the POLES model; NG, SM, AK developed the scenarios for the TIAM-Grantham model. HvS coordinated the analysis, wrote the paper, and created the figures; TV did the analysis for the costs section; all authors contributed to the definition of the good practice policy package, the analysis, and article review.

Competing interests

There are no competing interests to declare.

Additional information

Supplementary information is available for this paper.

Correspondence and requests for materials should be addressed to HvS.

Figures

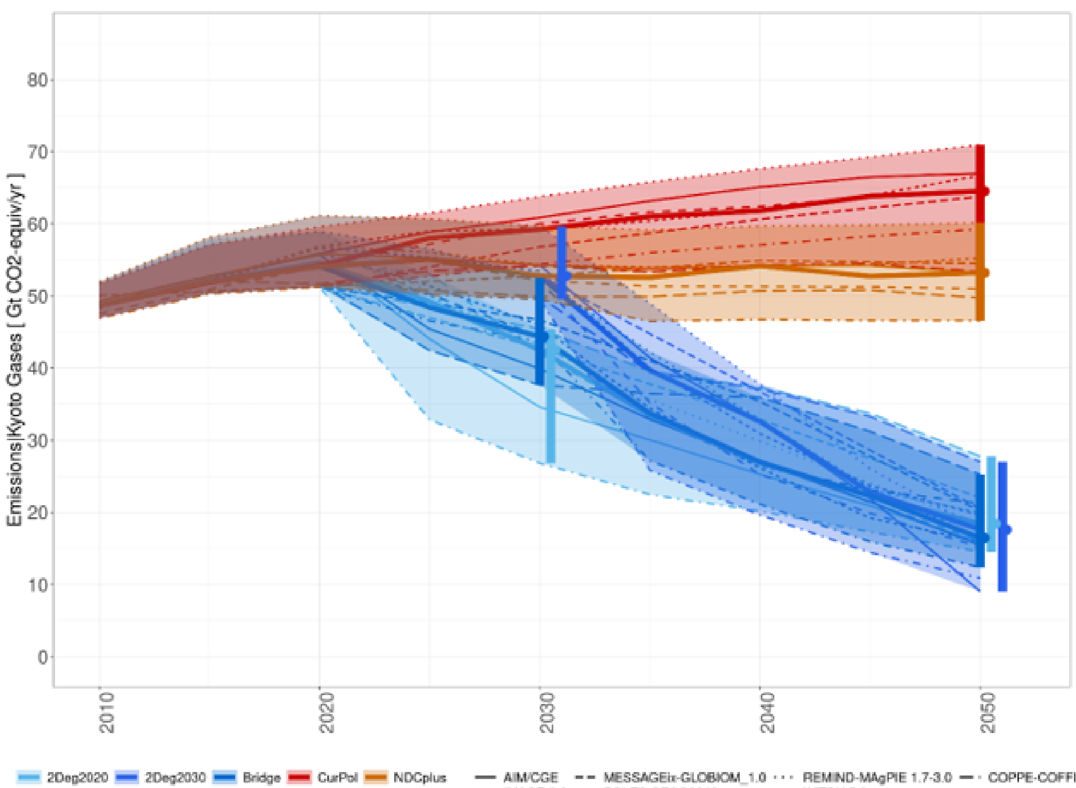
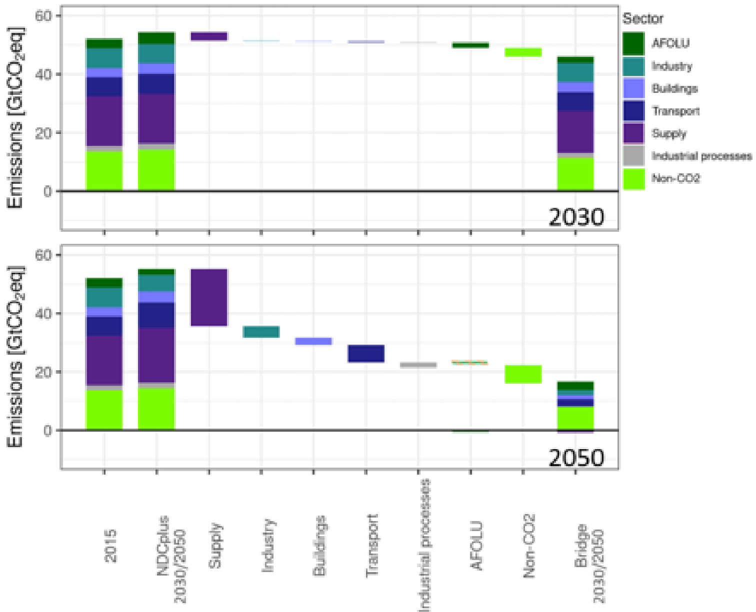


Figure 1

global GHG emissions (Gt CO2eq/year) between 2010 and 2050, as projected by the global models. Vertical bars: model range in 2050. Circles: model median in 2050. Thick solid lines: median. Projections for the Bridge scenario without the carbon tax measure are shown in Supplementary Figure B 6, for NDCplus variant NDC_2050convergence in Figure B 7, and for 2050 – 2100 in Figure B 8.

Figure 2

GHG emissions, relative to 2015 (%), per region (panel), for 2030 and 2050 (X-axis), for the CurPol, NDCplus, Bridge, 2Deg2020, and 2Deg2030 scenarios (colours). Bars indicate model median, symbols the individual model results.



	Share of sector in total GHG reduction from *NDCplus* to *Bridge* scenario (%), model range: minimum – maximum (median)						
Year	Supply	Industry	Buildings	Transport	Industrial Processes	AFOLU	Non-CO2
2030	-5.8 – 82.9 (38)	-10.1 – 14.8 (6.6)	-4.6 – 7.8 (2.4)	1 – 96.6 (8.9)	-0.2 – 5.4 (0.5)	-38.8 – 21.6 (7.8)	2.9 – 48.7 (36.3)
2050	34.6 – 49.8 (41.9)	7.9 – 31.4 (13.9)	2.9 – 9.5 (6.6)	6.5 – 20.7 (13.1)	0.1 – 8.1 (4)	-4.8 – 11.8 (4.6)	9.6 – 20.3 (16.4)

Figure 3

Contribution of each sector to emission reductions between the NDCplus and Bridge scenario (negative values denote an increase in emissions between NDCplus and Bridge, and are indicated with hashes). First bar: Emissions by sector in 2015. Second bar: emissions by sector in 2030 (upper graph) and 2050 (lower graph), under NDCplus. Third - ninth bar: emission reduction in energy supply, industry, buildings, transport, industrial processes, AFOLU (agriculture and LULUCF), non-CO2 emissions. Last bar: emissions by sector in 2030 (upper graph) and 2050 (lower graph), under Bridge. The IMAGE model is shown here as an illustrative example; full model ranges are shown in the table, while individual model results are shown in the SI (Figure B 4). In addition, Figure B 5 shows the sectoral contributions to emission reductions between the Bridge and 2Deg2020 scenarios in 2030.

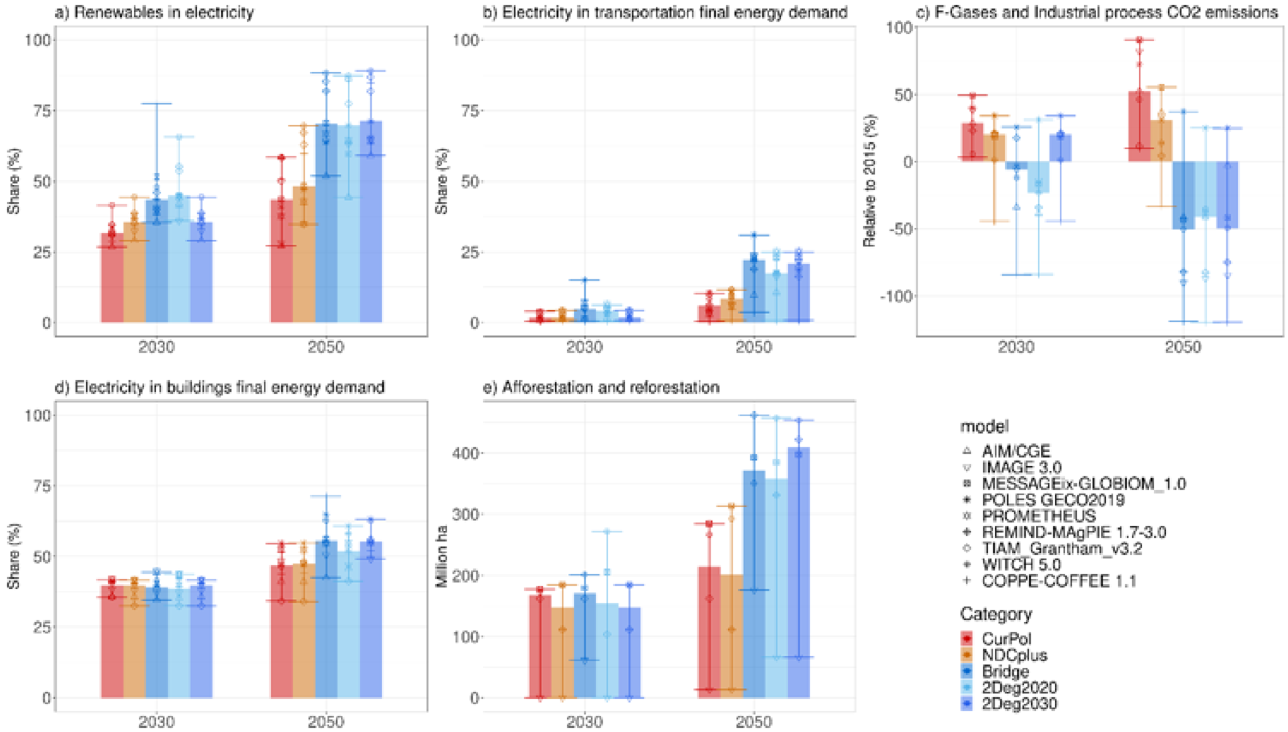


Figure 4

Projected changes in various indicators, for 2030 and 2050, for the CurPol, NDCplus, Bridge, 2Deg2020, and 2Deg2030 scenarios. Bars show model median, error bars show the full range, and symbols show individual model results. Panel a) share of renewables in electricity production (%), panel b) share of electricity in final energy demand of transportation (%), panel c) Emissions of F-gases and industrial process CO2 emissions, relative to 2015 levels (%), panel d) share of electricity in final energy demand of buildings (%), panel e) total afforestation and reforestation (million ha).

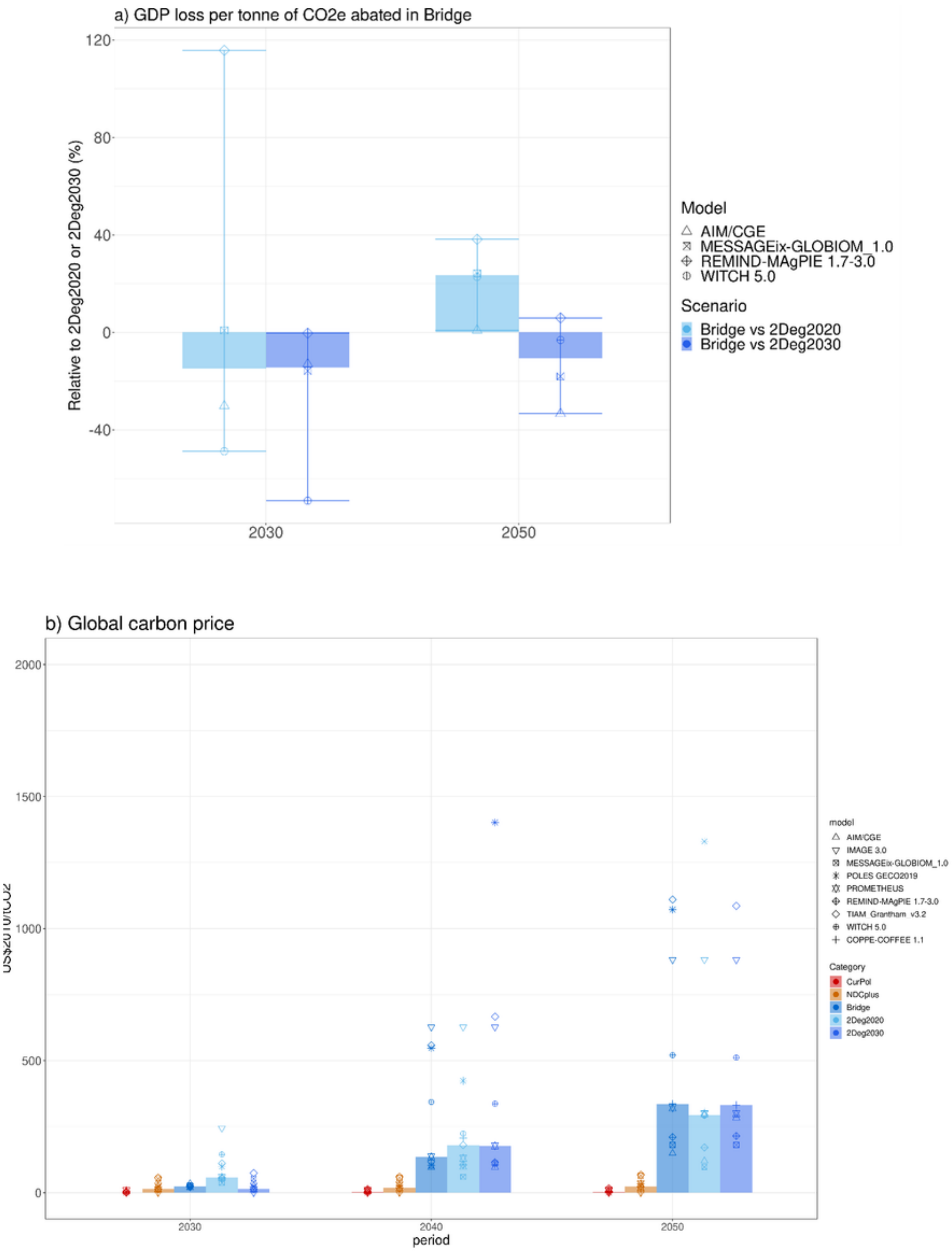


Figure 5

Panel a) GDP (in market exchange rates, MER) loss (relative to the CurPol scenario) in Bridge, relative to 2Deg2020 (light blue) and 2Deg2030 (dark blue), for 2030 (left) and 2050 (right). Panel b) Carbon price (US$2010/tCO2), in 2030, 2040 and 2050. Bars: median, error bars: full range, symbols: individual models.

Supplementary Files

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- SupplementaryInformationTableA1.xlsx
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- Table1.docx