

Promising climate progress: How close do net-zero ambitions take us towards the Paris Agreement goals?

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Abstract

The Paris Agreement aims to limit the increase of global mean temperature to well-below 2°C and preferably 1.5°C. This study provides a multi-model analysis of global projections of current policies and pledges, and climate pathways to implement the Paris Agreement's overall goals. In this exercise, current policies and NDCs scenarios are updated. Additionally, three main scenarios are analysed: i) a long-term strategies (LTS) scenario, which assumes the full implementation of the NDCs and the announced net-zero pledges from COP26 (in Glasgow, 2021); ii) an Expanded LTS scenario, which expands the net-zero pledges to all countries/regions; and iii) an Accelerated LTS scenario, which sees climate targets being brought forward by 5–10 years. Our findings indicate that the current net-zero pledges bring the world close to a well-below 2°C pathway, but a gap remains. Increasing ambition proves crucial to dealing with the climate challenge: expanding the global coverage of net-zero pledges and speeding up action increases consistency with the Paris goals (1.5 to 2.0°C range in model mean, 50th percentile). However, reaching the 1.5°C goal without overshoot seems increasingly unlikely, and dedicated policies are needed to reduce the reliance on fossil fuels and increase renewable energy capacity.

Introduction

The Paris Agreement aims to limit the increase of global mean temperature to well-below 2°C, and to pursue efforts to stay below 1.5°C. The agreement requires that countries regularly formulate their climate action plans in the so-called Nationally Determined Contributions (NDCs), outlining their emission targets and policy actions. Assessments of the emissions gap have been conducted already for over a decade, with the first UNEP Emissions Gap Report dating back from 2010 ¹. By now, multiple studies have shown that, when put together, the NDCs fall short of achieving the Paris Agreement goals ^{2–6}. However, since the Conference of the Parties (COP26), in Glasgow, in 2021, many countries have also set out long-term goals, notably the net-zero emissions pledges. These pledges have been evaluated in individual model studies ^{7,8}. Nevertheless, robust multi-model assessments about the effectiveness of these ambitions ⁹ and ways to further strengthen them are scarce but necessary ¹⁰.

In this study, we explore the consistency of the announced net-zero targets with the Paris Agreement, as well as opportunities to strengthen them, to achieve its overall objectives. We perform a multi-model intercomparison exercise by using eight state-of-the-art Integrated Assessment Models¹ (IAMs). These models allow us to compare the net-zero targets and their consistency with global pathways limiting global temperature to 1.5/2°C warming levels. We thus contribute to the existing body of literature by conducting a systematic evaluation of the net-zero pledges and the benefits of expanding the net-zero

coverage worldwide and accelerating action (earlier mitigation), identifying the most effective mitigation options (looking into sectors and regions) and the overall costs of mitigation. Furthermore, we explore the implementation of net-zero targets in the light of the outcomes of the first Global Stocktake ¹¹, which was concluded in 2023 during COP28, in Dubai.

We present five scenarios, from the current policy landscape to more ambitious climate action: 1) a current policies scenario; 2) an NDCs scenario; 3) a long-term strategies (LTS) scenario; 4) an expanded long-term strategies scenario; and 5) an accelerated long-term strategies scenario. Table 1 provides a brief description and underlying assumptions for all scenarios, while a full description is provided in the Methods section and the Supplementary Material.

[1] COFFEE, GCAM, GEM-E3, IMAGE, MESSAGEix, POLES, REMIND and WITCH. Short model descriptions and links to detailed documentation are available in the Supplementary Material. Model documentation for all models is available at the IAMC Wiki (IAMC).

Results

Climate policy implications for global emission pathways

Figure 1 shows the results of the models, indicating for emissions both the models mean and the models spread. The results are visible in clearly defined bands. The results for the CP scenario show that current policies worldwide are expected to more-or-less stabilise emissions, leading to an increase in global mean temperature² (Fig. 1b) between 2.6–3.4°C (model range, 50th percentile). This means that our results corroborate earlier findings showing that current policies are not yet in line with the NDCs or with long-term strategies, emphasising a clear implementation gap (Fig. 1). The NDCs scenario shows that, if more ambitious policies are not implemented after 2030, emissions at the global scale slightly decrease but remain far from reaching net-zero. This scenario would lead to a warming in the range of 2.3–2.8°C, 50th percentile.

The LTS scenario indicates that, if expressed net-zero pledges are implemented, considerably more emission reductions can be achieved. The LTS scenario leads to a greenhouse gas (GHG) emissions level of around 15–20 GtCO₂e, after 2050 (and a warming in the range of 1.8–2.1°C). However, there is still an ambition gap in meeting the long-term global climate goals and pursuing efforts to stay below 1.5°C. A key reason is that not all countries have formulated net-zero targets. Expanding the coverage of net-

zero pledges to all countries worldwide (Expanded LTS) leads to an alignment with the well-below 2°C target, with global mean temperature increase in the range of 1.4–1.8°C by 2100 (50th percentile). Still, even in this scenario it is very unlikely that we reach a 1.5°C pathway by 2100 without overshoot. Furthermore, accelerating the action to reach net-zero earlier (Accelerated LTS) drives steeper emission reductions in the short/mid-term (between now and 2060), leading to an end-of-century global mean temperature increase of 1.4–1.7°C (model range, 50th percentile). Emissions reductions in the shorter term (2030–2040) resulting from early mitigation efforts are mostly driven by gains in energy efficiency and a faster transition away from coal. Overall, this does show that several models confirm the finding that the LTS target could go a long way in closing the ambition gap if broadened to include all countries and with some acceleration. A comprehensive assessment of global mean temperature changes can be found in the Supplementary Material (Fig. SM1).

Strengthening climate policy and accelerating climate action

In order to meet the Paris Agreement goals, 158 countries (accounting for over 50% of global methane emissions) signed the Global Methane Pledge (GMP), agreeing to work together to reduce global methane emissions by 30% (from 2020 levels) by 2030¹². More recently, based on the outcomes of the recent Global Stocktake, the ambition was formulated to triple global renewable energy capacity by 2030, to double energy efficiency and to rapidly transition away from fossil fuels to achieve net-zero by 2050. Strengthening climate policy and anticipating climate action is crucial for reaching such goals. The scenarios in this study do not include dedicated interventions on methane emissions or renewables/fossils. We, therefore, evaluate such targets by exploring the policies and pledges currently put forward by countries in the context of the climate negotiations.

Our results (Fig. 2) show consistently that the more ambitious the scenario, the closer to reaching the methane and renewable energy goals. However, typically most scenarios still fall short of hitting the marks. For the GMP, both Expanded and Accelerated LTS scenarios show notable improvements in reducing methane emissions. However, while some models overreach the estimated target in 2030, models median is still above the required level (Fig. 2a). For the expansion of renewable energy capacity (Fig. 2b), the far majority of the scenarios does not reach the tripling goals by 2030 (compared to 3655 GW in 2023)¹³. The Accelerated LTS scenario reaches the target for models mean by 2035. This highlights the importance of early interventions, which in this study were operationalized by anticipating the net-zero commitments of countries. Furthermore, it indicates the need of dedicated interventions, with concrete underlying policies to drive the transformation of the system.

Energy sources should not be assessed only in terms of installed capacity, but also regard their share in the energy mix. Our results show a significant expansion of renewables and reduction of fossil fuels, abated or unabated, in the share of primary energy (Fig. 2c). In the shorter term, current pledges do not show large differences when compared to existing policies, while the more ambitious long-term strategies scenarios show considerable changes in the energy mix towards renewable energy. By the end of century, unabated fossil fuels are reduced from over 60% estimated in the current policies scenario to 35% when current net-zero pledges are accounted for (with limited coverage). With the worldwide coverage of long-term strategies this number is reduced below 20%. Coal is phased out by nearly all models, with strong phase down already in 2050. The remaining unabated fossil sources are split between oil and gas, mostly directed to the hard-to-abate sectors, such as aviation and international shipping, and industry.

In terms of renewables, while different models have different fingerprints ¹⁴, i.e. technological preferences, they all agree that a large expansion of renewable energy is projected in the climate policy scenarios. The inclusion of bioenergy in the renewable mix and to what extent bioenergy is coupled with carbon capture and storage varies per model, and per region. GCAM and REMIND are less optimistic about the employment of BECCS, MESSAGEix chooses not to further develop bioenergy without CCS, while other models employ different shares of both options. Solar and wind have high agreement across models, expanding considerably by 2100 (with MESSAGEix, REMIND and WITCH showing the highest numbers). Nuclear is an important option for some models, such as GCAM (8.5-9.0% of the energy mix in 2050 for Expanded and Accelerated LTS, respectively), POLES (around 9.0% of the energy mix in 2050 for Expanded and Accelerated LTS) and MESSAGEix (approximately 7.3% of the energy mix in 2050, for Accelerated LTS). A detailed break-down of global primary energy and the role of different energy carriers is presented in the Supplementary Material (Fig. SM2-5).

Electrification plays a big role in decarbonising the energy system. As can be seen in Fig. 3, the share of electricity strongly picks up in 2040, accounting for more than 50% of final energy for most models in Accelerated LTS, by 2050. This outcome is mostly driven by the transport and buildings sectors. The more stringent the climate target, the higher the transitions towards the electrification of the passenger fleet and the switch away from conventional fuels for heating, considerably reducing emissions.

From the global picture to regional strategies

While stabilizing global mean temperature increase is a collective effort, action on emission reductions happens at the local/regional scale. In this study, we explore ten different global regions: EU28, Eastern Europe (including Russia), Japan, Korea and

Oceania, East Asia (including China), South Asia (including India), Southeast Asia, Middle East, North America, Latin America and Sub-Saharan Africa. A more detailed analysis of major emitters, including insights from country-level IAMs, is provided in a parallel publication (Diuana et al., in preparation).

Under current policies, most regions stabilize their GHG emissions (Fig. 4). Notable exceptions are regions with high economic and population growth, i.e. South Asia, Sub-Saharan Africa, and the Middle East, which continue to increase their emissions. East Asia is projected to peak emissions in 2030 and already shows significant emission reductions (47% lower in 2100 compared to its current emission levels) in the Current Policy scenario. Moving towards more stringent scenarios, the results show developed regions to reach net-zero earlier, driven by sharp emission reductions before 2050. Developing regions show different behaviours, with some regions reaching net-zero later in the century (East Asia and Latin America), while others strongly reduce but remain positive emitters (South Asia, Southeast Asia and Sub-Saharan Africa). The main reason is that most of the individual countries in these regions either have pledged net-zero after 2050 or do not yet have a net-zero target.

Focusing on the routes to achieve the targets, it should be noted that countries and regions are inherently diverse, resulting in diverse strategies towards reaching their emission reduction targets. Around mid-century, Eastern Europe and the Middle East show an increasing deployment of renewable energy mostly coming from non-bio renewables, mainly solar and wind. South and Southeast Asia, and Japan, Korea and Oceania have higher deployment rates of non-bio renewables under the CP and NDCs scenarios, but shift towards more bioenergy once net-zero pledges come into effect, given the possibility of carbon dioxide removal. Bioenergy plays a bigger role in the energy system in EU28, North America, and Sub-Saharan Africa. For EU28 and North America, this is dominated by liquid biofuels in the transport sector, while for Sub-Saharan Africa biomass is largely employed for cooking and heating. Latin America relies more on non-bio renewables (despite Brazil's leadership in biofuel production), with a significant share of hydropower, but sees a substantial increase in bioenergy in Accelerated LTS, taking advantage of the region's potentials for BECCS. Interestingly, in East Asia accelerating climate action reduces the employment of BECCS, shifting emissions reductions to other sectors, particularly industry.

International cooperation is key for increasing ambition and closing the gap

There is a clear gap in the implementation of climate policies and pledges compared to the goals of the Paris Agreement. Current policies do not yet align with the NDCs pathways or long-term strategies, leading to implementation gaps in the shorter (2030) and mid/longer terms (mid- to second half of the century). This means that, if more ambitious policies are not implemented after 2030, emissions at best stabilise at the global scale, leading to warming substantially above the Paris goals. Moreover, while the announced long-term strategies are a big step forward compared to the 2030 NDC goals, they alone do not lead to emission pathways compatible with Paris.

Our work provides robust evidence from a multi-model analysis that moving towards Paris-aligned pathways requires a rapid expansion of renewables and moving away from fossil fuels. Early mitigation speeds up the transition away from fossil fuels and reduces the reliance on carbon dioxide removal technologies that are not mature enough for a fast ramp up in the shorter term. Such transformation of the current energy system requires dedicated policies, as the outcomes of our study show that pledges imply considerable improvement but still fall short of achieving the tripling renewable energy goals and phasing out of fossil fuels. Nonetheless, the significant emission reductions achieved in the Expanded LTS scenario highlight the importance of having long-term commitments from all countries.

International cooperation is key in bridging the emissions gap. Under Article 6, the Paris Agreement recognizes voluntary cooperation between countries to allow for higher ambition in mitigation and adaptation efforts, including the use of mechanisms such as Internationally Transferred Mitigation Outcomes (ITMOs), as well as finance, technology transfers and capacity building. Countries and regional strategies to reducing emissions are diverse and dependant on their local context. Navigating their different priorities towards effective cooperation is crucial to collectively achieving the global climate goals. Our work explores the implications of a more ambitious international setting for reaching net-zero emissions. However, further work can be done by looking at climate policy scenarios through the lens of effort-sharing, bringing in equity and justice considerations to how carbon budgets and mitigation efforts are divided across countries, and how financial transfers can help in enabling the transition.

[2] Global temperature changes are calculated for each scenario, for each model, using MAGICC (Model for the Assessment of Greenhouse Gas Induced Climate Change).

Methods

Models and scenario framework

A set of global integrated assessment models (IAMs) participates in this model intercomparison study, namely: IMAGE, COFFEE, REMIND, WITCH, POLES, MESSAGEix, GCAM and GEM-E3. Brief model descriptions can be found in the Supplementary Material, and in-depth model documentation can be found in the IAMC Model Documentation Wiki³.

Following a common modelling protocol (see Supplementary Material for the details), global models implement the following scenarios:

Current policies (CP) scenario

Current policies are defined as currently implemented policies adopted by governments (through legislation) or non-binding targets backed by effective policy instruments. Ambitions and pledges are not considered current policies and therefore are not included in this scenario. Cut-off date for current policies included in this study: October 2022.

After 2030, the ambition levels remain at least constant throughout the rest of the time frame. In order to keep ambition levels after 2030, the following extension method was used: the equivalent carbon price in 2030 was extrapolated to 2100, using the GDP growth rate of the different model regions, following ⁸. This equivalent carbon price represents the value of carbon that would yield the same marginal emission reductions as the current policies in a region. If a region has a zero-carbon price while implementing the current policies in 2030, a minimum carbon price of 1\$/tCO₂ in 2030 was assumed. This represents an equivalent effort in the future.

The Climate Policies Modelling Protocol (CPMP), including all current policies considered and their respective targets used for this scenario is publicly available at: <https://doi.org/10.5281/zenodo.10009463>.

NDCs scenario

The **NDCs** scenario aims to represent the goals of the NDCs (for this study, as of October 2022). Global modelling teams implemented a set of NDCs for selected countries/regions. The ambition levels reached in the target year remain at least constant throughout the rest of the century, using the same extension method as described for the CP scenario.

Long-term strategies (LTS) scenario

For the **Long-term Strategies (LTS)** scenario, we consider the NDCs pledges and the mid-century strategy pledges (net-zero) announced around COP26 in Glasgow. Global modelling teams consider all net-zero pledges, aggregating them to their specific model regions. The methodology to define the regional net-zero target year assumed that if the countries with net-zero pledges have a share of 50% or more of total emissions in the

region, the region is set to have a net-zero target year equal to the average target year weighted by each countries' emissions.

Expanded Long-term Strategies (Expanded LTS) scenario

The **Expanded LTS** scenario considers the mid-century strategy pledges (net-zero) announced around COP26, in Glasgow, and expands their coverage to all countries/regions. In this scenario, countries can overachieve their 2030 NDC target if this is cost-effective for reaching the long-term neutrality target. For countries/regions that currently do not have established a net-zero strategy, the assumed net-zero target year is calculated based on a regression that is a function of their income level.

Accelerated Long-term Strategies (Accelerated LTS) scenario

The **Accelerated LTS** scenario builds up on the Expanded LTS scenario and anticipates the action (net-zero target year defined for each region) by 5–10 years (depending on the model's time steps).

We derive the global temperature increase of each scenario (see 'Temperature assessment', below) and compare the overall outcomes of the scenarios with 1.5/2°C benchmark scenarios.

Temperature assessment

Probabilistic temperature simulations are performed using the MAGICC (Model for the Assessment of Greenhouse Gas Induced Climate Change) model, version 7.5.3, covering all the most important greenhouse gas emissions and short-lived climate forcers. For a full list, see Table 1 of Kikstra et al. (2022). The calibration of the model is the same as used in working group III of the IPCC Sixth Assessment report. The emissions trajectories of IAM scenarios are also processed to enable the highest possible comparability in line with the IPCC methodology. Individual emissions species are harmonized to 2015 historical values, and if an emissions species is not reported for a scenario by an IAM, it is inferred from the CO₂ energy and industrial emissions pathway of the scenario. Full detail and description of the methodology applied here is described in ¹⁷.

[3] IAMC wiki: <https://www.iamcdocumentation.eu/>

Declarations

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Data availability

The underlying data is available at <https://doi.org/10.5281/zenodo.10009463> and will be made available via the ENGAGE Scenario Explorer at: <https://data.ece.iiasa.ac.at/engage/>.

Code availability

The models are documented on the Integrated Assessment Model Documentation Wiki¹⁸ and several have been published as open source code, such as REMIND¹⁹, MESSAGEix²⁰, and GCAM²¹.

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Tables

Table 1
Description of scenarios (including action after 2030)

Scenario name	Scenario description
Current policies (CP)	Current policies are defined as currently implemented policies adopted by governments (through legislation) or non-binding targets backed by effective policy instruments. Ambitions and pledges (e.g. NDCs and net-zero pledges) are not considered current policies and are therefore not included in this scenario. After 2030, the ambition levels remain at least constant until 2100. Cut-off for policy inclusion in October 2022, based on the Climate Policy Database ¹⁵ and the Climate Policy Modelling Protocol ¹⁶ .
NDCs	The NDCs scenario builds up on the current policies scenario and assumes the achievement of the NDCs, unconditional and conditional, in 2030 (further information can be found in the supplementary material). The ambition levels reached in the target year remain at least constant throughout the rest of the century.
Long-term strategies (LTS)	The long-term strategies (LTS) scenario builds up on the NDCs scenario, following the NDCs pledges until 2030. After 2030, the scenario assumes the implementation of all announced net-zero targets (countries that do not yet have a net-zero target keep the ambition levels of their NDC).
Expanded long-term strategies (Expanded LTS)	The expanded long-term strategies (Expanded LTS) scenario assumes the implementation of all announced net-zero targets and expands the net-zero coverage to all countries. Countries can overachieve their 2030 NDC target (mitigation efforts surpassing the NDC targets already in 2025) if this is cost-effective for reaching the long-term neutrality target. For expanding the net-zero coverage, countries that currently do not have established a net-zero strategy assume a net-zero target year based on the net-zero target year of countries with a similar income level.
Accelerated long-term strategies (Accelerated LTS)	The accelerated long-term strategies (Accelerated LTS) scenario builds up on the Expanded LTS scenario, anticipating all targets by 5–10 years.

Figures

Total GHG emissions

GtCO₂e

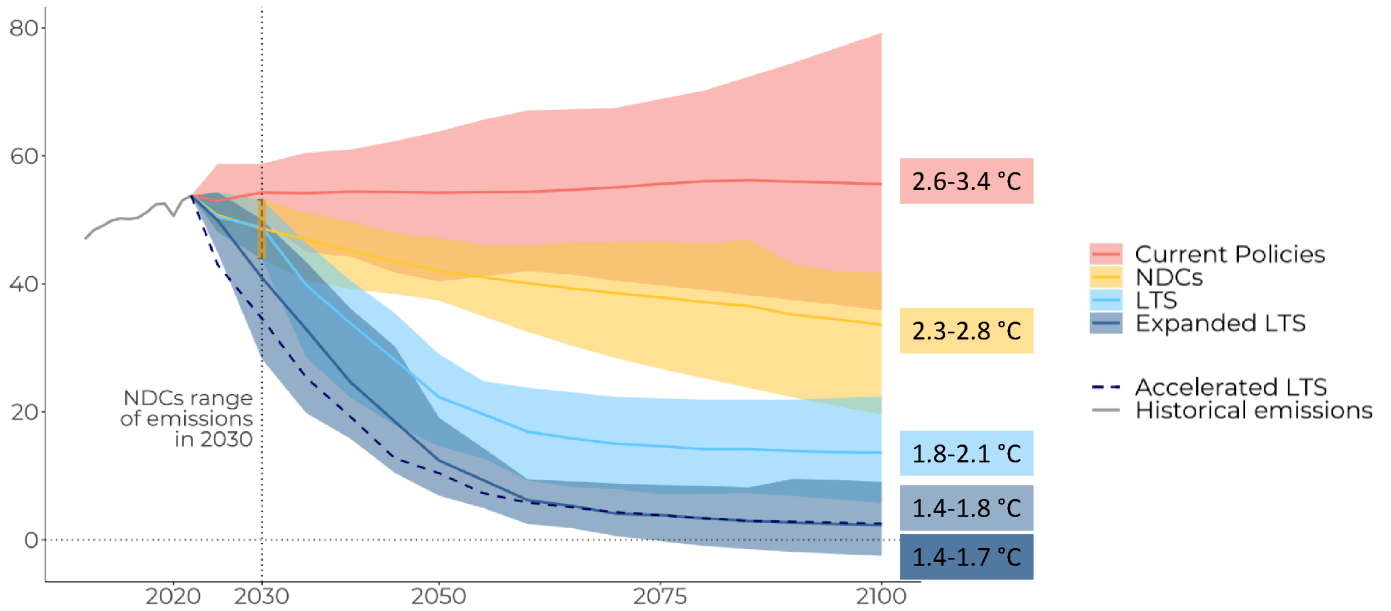


Figure 1

Global emission pathways (ribbons show model spread, lines show models mean; models range of change in mean global surface temperature per scenario, with 50% probability).

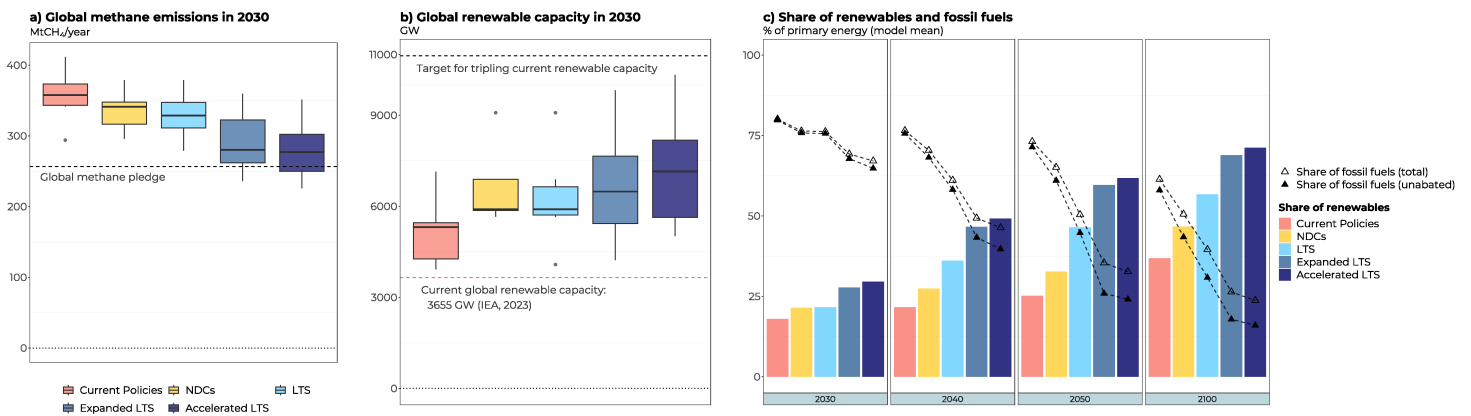


Figure 2

Performance of the climate policy scenarios: a) global methane emissions and the Global Methane Pledge; b) global renewable capacity and tripling renewable capacity for electricity generation; c) share of renewables and fossil fuels in the primary energy mix and phasing down/out of fossil fuels. Notes: renewables include biomass, with and without

carbon capture and storage. Box plots centre-line, median; box limits, upper and lower quartiles; points, outliers.

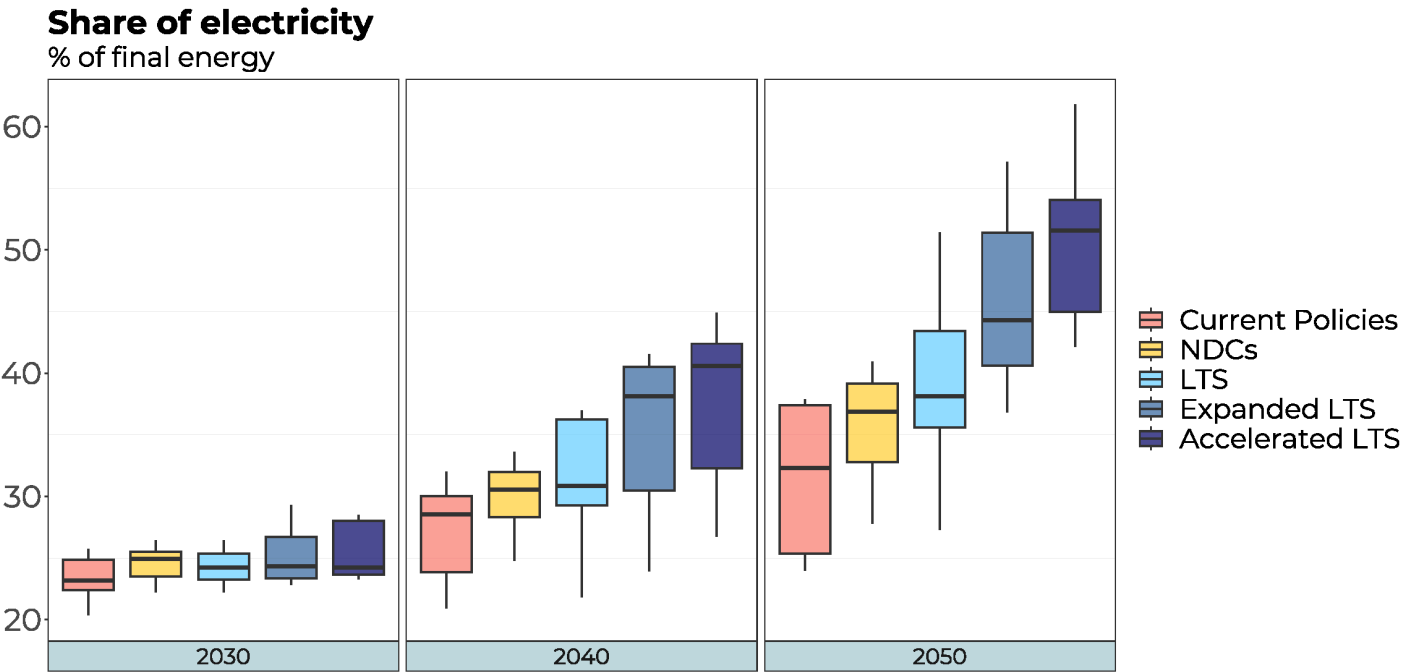


Figure 3

Share of electricity in final energy (2030-2050). Box plots centre-line, median; box limits, upper and lower quartiles.

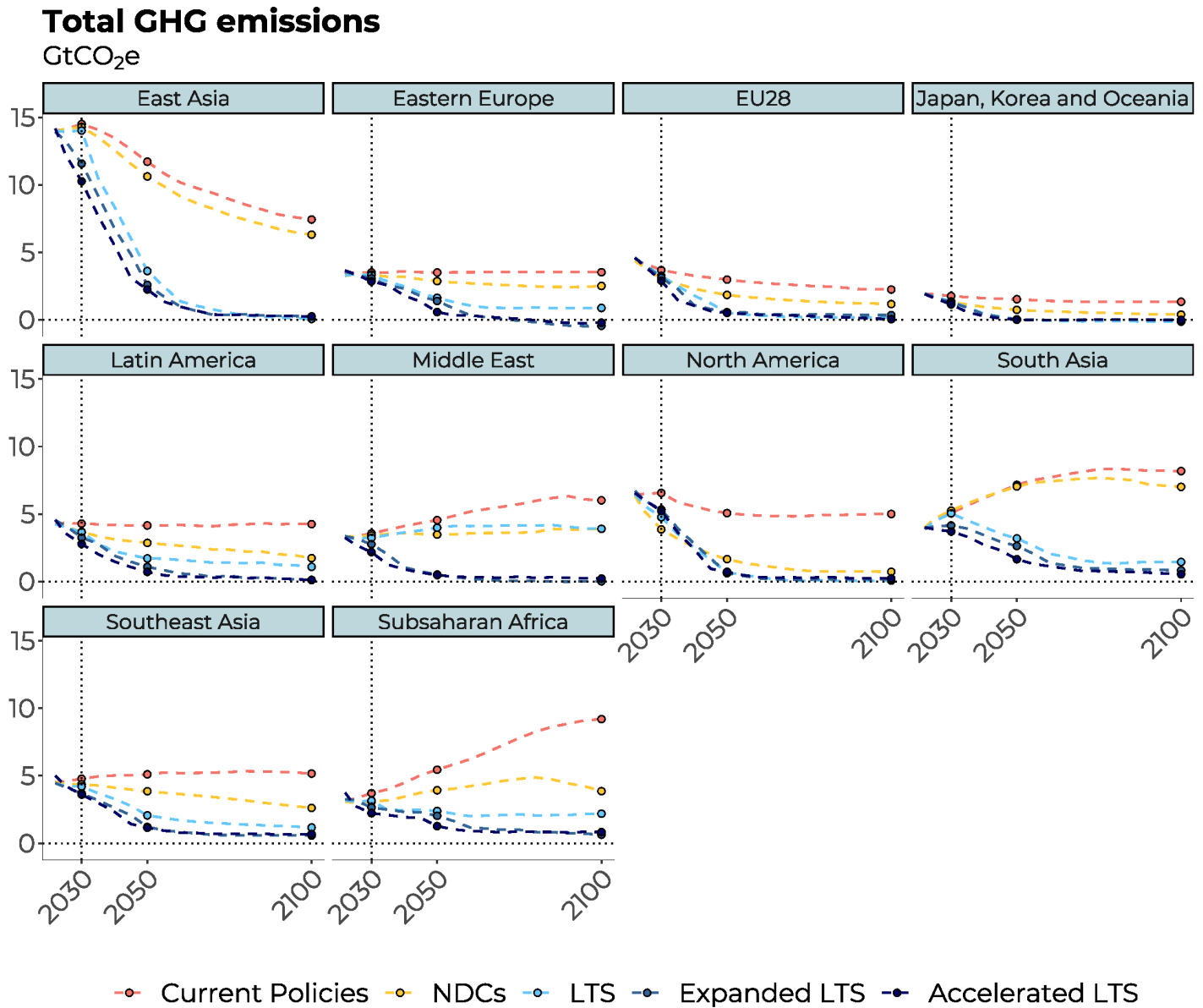


Figure 4

Regional emission pathways (2020-2100), models mean (East Asia, including China; Eastern Europe, including Russia; EU28; Japan, Korea and Oceania; Latin America; Middle East; North America; South Asia, including India; Southeast Asia; and Sub-Saharan Africa).

Renewables in the regional energy mixes

EJ/year in 2030

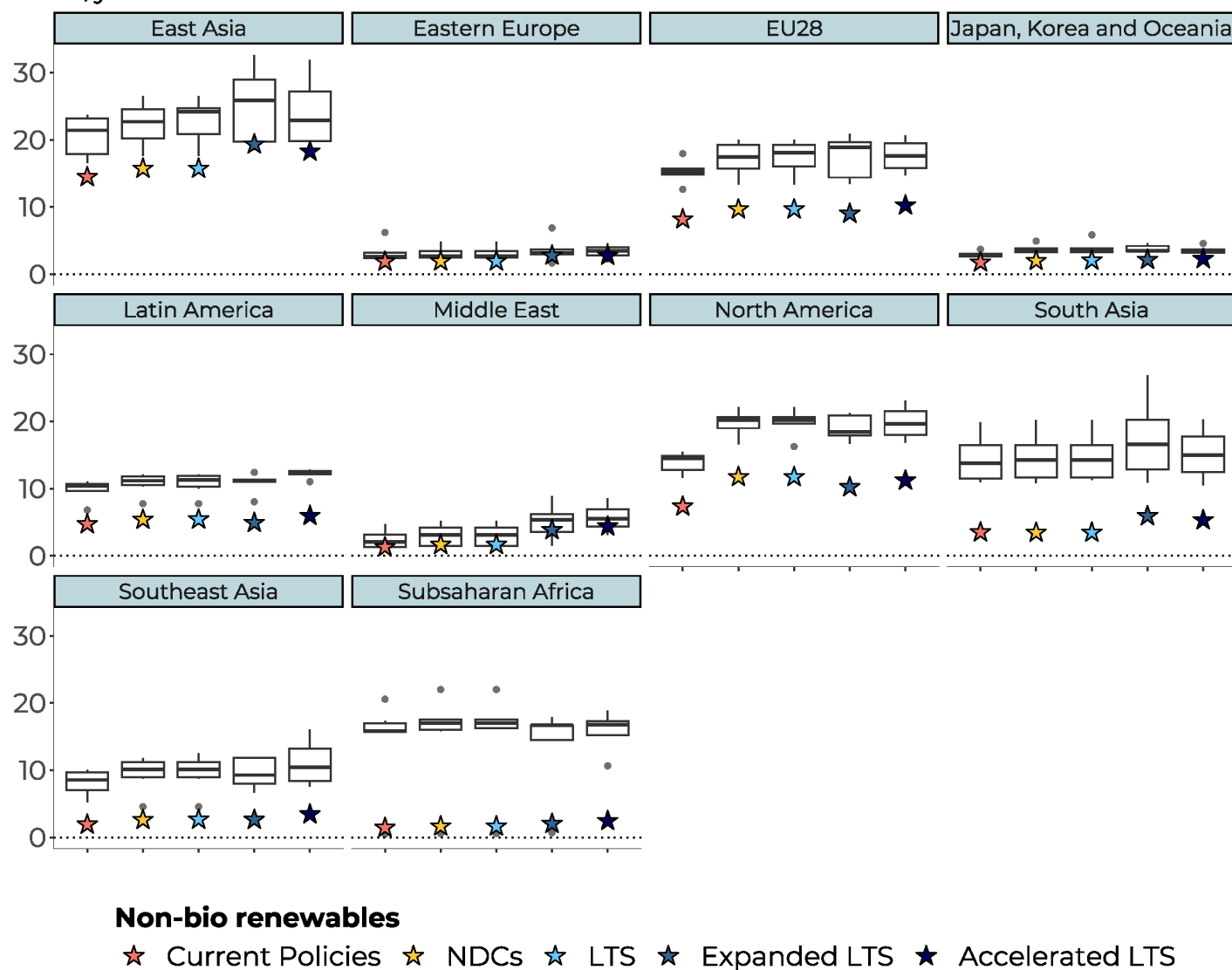


Figure 5

Regional deployment of renewables in 2030 (boxes show model spread for total renewables, stars show models-median for non-biomass renewables). Here non-biomass renewables including solar, wind, geothermal and hydro. Box plots centre-line, median; box limits, upper and lower quartiles; points, outliers.

Supplementary Files

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