



Net0Pathways through impRoved IAMs across Sectors, diMensions, and scAles

Deliverable 6.4

Synthesis report, final database and visualization of the updated impact assessment of EU and global climate policies, and of the statistical downscaling results

28 July 2026

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Abstract

This deliverable presents the scenario protocol developed in Work Package 6 (WP6) of the PRISMA project for quantifying the full cost of rolling back climate ambition under a disrupted and asymmetric global climate regime. The protocol defines four core scenarios, Meet Aspirations, Asymmetric Roll-Back, Late Reawakening, and Staying Alive, implemented across all PRISMA Integrated Assessment Models (WITCH, IMAGE, OPEN-PROM, GEM-E3, MESSAGE, IMACLIM, and REMIND) under Shared Socioeconomic Pathways 2 (SSP2). The scenarios are structured around three research questions addressing the cost of regionally differentiated rollback in climate ambitions, the feasibility and cost of late reawakening of this ambition, and the value of low-regret clean energy strategies under weakened climate policy. Model outputs in terms of energy and emission projections are downscaled from multi-country regions to indicative ranges at the national level. Scenario data is reported in the IAMC tabular time-series format, made available through the PRISMA Scenario Explorer (<https://prisma.apps.ece.iiasa.ac.at/>), and deposited on Zenodo for long-term archival (<https://zenodo.org/records/19207562>). Code used to produce the analysis and figures in this deliverable is available upon request. The current public instance of the Scenario Explorer is live and has been linked from the project website. The Scenario Explorer infrastructure is built on the open-source ixmp4 backend and connected to the pyam Python package for scenario analysis and is made available under the Creative Commons Attribution license (CC-BY). The WP6 scenario dataset will be released upon completion of vetting and model intercomparison activities. Preliminary results across key indicators point to three main findings. First, delayed carbon ambition imposes a broad set of consequences: it breaches the 2.0°C (50%) carbon budget before mid-century, and delays electrification and renewable penetration significantly. Second, a late reawakening of climate ambition after 2035 can be sufficient to preserve long-run temperature outcomes, staying below the 2.0°C (50%) carbon budget and converging with the more climate stringent scenario in renewable capacity and electrification by 2070, but at the cost of a compressed and expensive transition in a single decade. Third, maintaining strategic investments in renewables and electrification technologies under weakened climate policy cannot substitute for carbon pricing on the emissions trajectory, but it preserves supply chains, learning curves, and deployment momentum to the point where installed solar and wind capacity ultimately exceeds even the ambition pathway by end of century. Despite its structural benefits, this remains a low-regret strategy that falls short of what is needed on the climate dimension: cumulative emissions remain far above the 2.0°C carbon budget, and no amount of clean investment can compensate for the absence of carbon pricing in driving the deep and rapid decarbonization that temperature targets require.



1. Introduction

1.1 Task description

Task 6.4 (Policy synthesis - impact assessment of updated national, EU, and international climate policies; Lead: CMCC, Partners: all partners) is responsible for providing a general framework of climate policy design for implementation by IAMs across the PRISMA consortium. This deliverable provides this IAM climate policy framework committed to in T6.4, centred on Nationally Determined Contributions NDCs (2030/2035) and long-term strategies (LTS/climate neutrality pledges). It meets the requirements of T6.4 by: (i) providing a peer-reviewed, pre-registered protocol that all PRISMA modelling teams can implement; (ii) reflecting the current policy landscape including the weakening of multilateral climate action observed since 2025; (iii) serving as the basis for WP2.4 (EU-focused model comparison) and WP3.4 (innovation and finance) deep-dive analyses; and (iv) presenting preliminary results from first-round model submissions that validate the scenario design. The task also leads the downscaling of energy and emission projections from global IAMs to national-level ranges, and coordinates the release of scenario data and methods in line with FAIR principles in coordination with WP1 (Wilkinson et al., 2016).

1.2 Context

The current context for scenario design is one of unprecedented disruption to multilateral climate governance. The international climate policy landscape has undergone a profound shift since 2025. The withdrawal of the United States from the UNFCCC and the Paris Agreement (UNFCCC, 2015; IEA, 2024), combined with the rollback of national decarbonization policies across several major economies, has called into question the capacity of multilateral climate governance to maintain the ambition needed for temperature stabilization. Threats to core decarbonization instruments, including the European Union Emissions Trading System and the phasing out of clean energy incentives in key markets, are creating new uncertainties for investors and policymakers. At the same time, the geopolitics of the energy transition is reshaping global climate action along a fundamental divide between fossil-fuel-dependent economies, which are scaling back climate commitments, and electro-states, which continue to decarbonize driven by industrial strategy and energy security imperatives rather than international pressure alone.

Against this backdrop, quantifying the full cost of rolling back climate ambition has become a pressing research and policy question. The costs of inaction are not symmetric: regions that delay action the most will face the largest penalties when global ambition eventually resurfaces, as infrastructure lock-in and stranded fossil assets compound the challenge of catching up. At the same time, even under weakened policy frameworks, some decarbonization strategies continue to advance because of their economic and energy security rationale, most notably the rapid deployment of renewable energy and end-use electrification. Identifying which decarbonization strategies can advance without strong climate governance, and which cannot, is the central question motivating PRISMA WP6 Task 6.4: *The Full Cost of Rolling Back Ambition: Asymmetric Net-Zero Transitions in a Disrupted and Uncertain Climate Regime*.



1.3 Dissemination

For the dissemination of pathways developed under the PRISMA project, the reporting standards defined by the Integrated Assessment Modeling Consortium (IAMC) (Huppmann et al., 2021) and the web-based Scenario Explorer infrastructure developed at IIASA are used. The IAMC has been developing and maintaining tabular time-series data reporting standards for more than fifteen years; these standards have been widely adopted in the integrated assessment modelling community for sharing and disseminating scenario information, and have been used in IPCC Assessment Reports (AR5, SR1.5, AR6) and numerous Horizon Europe projects including CD-LINKS, ENGAGE, NAVIGATE, ARIADNE, ECETF, and openENTRANCE.

This document is organized as follows. Section 2 describes narrative, regional classification of countries, scenario protocol, research questions, and cross-cutting modelling guidelines. Section 3 describes the scenario data infrastructure, covering the IAMC data template, the PRISMA Scenario Explorer, and the national downscaling methodology. Section 4 presents first-round preliminary results across key indicators, discussed through the lens of the three research questions. Section 5 provides a description of the link to other WP in the PRISMA project, while Section 6 summarises the timeline of the task.

2. Scenario Description

2.1 Narrative

The unprecedented weakening of multilateral climate action, exemplified by the US withdrawal from the UNFCCC and the Paris Agreement as well as the rollback of national policies and threats to pillars of decarbonization such as the EU ETS, is creating profound uncertainties about the capacity to implement regional decarbonization strategies. Though these rollbacks might be temporary, some institutional changes are likely to lead to a protracted weakening of climate ambition, possibly followed by a sudden revitalisation of climate policies in pursuit of climate stabilization. Despite such a politically volatile context, some decarbonization strategies, in particular renewables, electricity storage, and end-use electrification, continue to advance given their favourable economics, but in a regionally differentiated way which reflects political priorities and fossil fuel endowments.

The main goal of PRISMA Task 6.4 scenario protocol is to analyse the implications of regionally differentiated roll-backs on the ambition of net-zero climate strategies and to quantify the climate and economic consequences of disrupted decarbonization plans and the costs of making up the lost time. Short-term pathways reflect diverging trends of technological development (fast for Renewable Energy Sources, RES, and electricity, slow or null for Carbon Capture and Storage, CCS). CO₂ removal is very limited in the short to medium term, but can pick up after net zero in the latter part of the century. This narrative directly fulfils the commitment of T6.4 to assess international climate policy provisions emerging from UNFCCC negotiations, using the US withdrawal and Paris Agreement dynamics as the central framing.

2.2 Models description



The analysis uses seven IAMs. Model names are abbreviated throughout to their short identifier; Table 2 below provides the mapping.

- WITCH (WITCH 6.0 - World Induced Technical Change Hybrid): A global optimal-growth IAM with endogenous technological change via R&D and learning-by-doing (Emmerling et al., 2016; Drouet et al., 2021). Developed at CMCC/RFF-CMCC.
- IMAGE (IMAGE 3.4 - Integrated Model to Assess the Global Environment): A simulation-based IAM with detailed land-use, energy-system, and climate modules (Stehfest et al., 2014). Developed at PBL Netherlands.
- MESSAGE (MESSAGEix-GLOBIOM-GAINS 2.1-M-R12): An energy-systems and land-use optimisation model with 12-region representation and air pollutant co-benefits (Fricko et al., 2017; Huppmann et al., 2019). Developed at IIASA.
- IMACLIM (IMACLIM 2.0): A computable general equilibrium model with detailed energy-economy interactions and international trade (Hourcade et al., 2010). Developed at CIREN.
- OPEN-PROM (OPEN-PROM 2.2): A bottom-up energy system optimisation model with detailed sectoral representation. Developed at E3Modelling.
- REMIND (REMIND-MAGPIE 3.7-4.14): A coupled energy-economy-land-use model combining the REMIND energy-economy module with the MAGPIE land-use model (Baumstark et al., 2021). Developed at PIK.
- GEM-E3 (GEM-E3 V2026): A multi-sector computable general equilibrium model with detailed energy-economy-environment interactions (Capros et al., 2013). Developed at E3Modelling/NTUA.

2.3 Regional Classification

Countries are clustered into three groups based on fossil fuel wealth (World Bank Wealth of Nations), renewable energy growth over the past decade, and GHG intensity of the economy, using a Gaussian Mixture Model (GMM) clustering approach:

- Transition leaders: low fossil fuel rents, high renewable energy growth, and low GHG intensity (e.g. Western Europe, Japan, South Korea).
- Diversifying economies: moderate fossil dependence, improving renewable growth, but still carbon-intensive production (e.g. China, USA, India, Brazil).
- Fossil-dependent economies: high fossil fuel rents, high GHG intensity, and limited RES growth (e.g. Middle East, Russia, parts of Africa).

Detailed country-to-cluster mappings and the procedure for aggregating country-level classifications to model regions are provided in the scenario protocol spreadsheet to the modelling teams. The three-cluster regional classification implements the nationally differentiated policy realism commitment of T6.4. Further details can be found in Appendix 1.

2.4 Scenario Design

The protocol defines four core scenarios, aligned with SSP2 (K. C. et al., 2024), as follows:

Meet Aspirations (Scenario 1)



All countries implement current policies, NDCs through 2030 (and where available 2035), and the existing LTS. This is a standard scenario where countries meet their long-term stated aspirations with regionally differentiated efforts and no explicit international coordination mechanisms (e.g. Article 6). The USA targets net-zero emissions in 2050. For countries without LTS targets, an exogenous carbon tax trajectory is applied to maintain a GHG emission trajectory in line with their NDCs (as in the ELEVATE project). The implementation of NDCs and LTS climate neutrality pledges as the backbone of Scenario 1 fulfils the commitment in T6.4 to assess national pledges and mid-century strategies.

Asymmetric Roll-Back (Scenario 2)

The climate mitigation aspirations of Scenario 1 are rolled back across all countries in differentiated ways. The rollback reflects two main factors: first, a general loss of momentum of climate change as a political priority; second, the geopolitics of the climate transition between fossil-fuel-exporting and electro-states. All climate milestone targets (NDCs, LTS) are moved forward in time depending on country cluster:

- Transition leaders (low fossil assets, high RES growth, low GHG intensity): targets delayed by 10 years.
- Diversifying economies (moderate fossil dependence, improving renewable growth): targets delayed by 20 years.
- Fossil-dependent economies (high fossil rents, high GHG intensity, limited RES growth): targets delayed by 30 years.

For countries with net-zero LTS targets, those are weakened to 80% of the original target (i.e. 20% residual emissions remain). On top of this scenario, a WP3 variant assumes zero international technology spillovers, increased financing costs, and higher capital costs for PV, on- and off-shore wind, and batteries, to simulate capital market fragmentation across regions and increased risk premiums.

Late Reawakening (Scenario 3)

This scenario follows Scenario 2 through 2035, then from 2040 onwards the model is free to resume the LTS targets of Scenario 1. This captures a delayed resurgence of climate ambition after a period of rollback, quantifying the costs of making up lost time.

Staying Alive, Low Regrets (Scenario 4)

This scenario follows Scenario 2 in terms of reduced policy ambition, but maintains investments in low-regret technologies at the same level as Scenario 1 throughout the century. Technologies included are:

- Solar technologies (PV and CSP).
- Wind technologies (onshore and offshore).
- Energy storage (pumped hydro, compressed air, batteries, hydrogen-based storage).
- End-use electrification, particularly electric vehicles (EVs).

Table 1 summarises the scenario naming convention.

Scenario	Description	Names
1. Meet Aspirations	All countries implement current policies, NDCs (2030/2035), and Long-Term Strategies (LTS). Carbon prices reflect near-term policies with	SSP2 - Meet Aspirations

2. Asymmetric Roll-Back	gradually increasing mitigation incentives. NDC and LTS milestones are delayed by 10 years (transition leaders), 20 years (diversifying economies), or 30 years (fossil-dependent economies). Net-zero ambitions weakened to 80% of target.	SSP2 - Asymmetric Roll-Back SSP2 - Asymmetric Roll-Back w/ High Costs
3. Late Reawakening	Follows roll-back pathway, then resumes LTS targets after a delay (around 2035–2040). Requires accelerated mitigation; infeasibilities tracked and targets shifted by 5-year periods.	SSP2 - Late Reawakening
4. Staying Alive	Same policy ambition as roll-back, but investments in renewables, storage, grid, and end-use electrification remain at Scenario 1 levels to test low-regret strategies.	SSP2 - Staying Alive

Table 1 - scenario matrix

2.5 Research Questions

Three overarching research questions structure the scenario analysis, operationalising the T6.4 commitment to compare national/international climate legislation with long-term stabilisation signposts and inform the global stocktake process of the Paris Agreement.

- RQ1 (Asymmetric Roll-Back vs Meet Aspirations scenario): What are the implications of regionally differentiated rollbacks of mitigation ambition for climate change, emissions (e.g. regional net-zero year), investments, technological innovation, energy costs, and energy security?
- RQ2 (Late Reawakening vs Meet Aspirations scenario): Is it feasible to make up the lost time and what are the costs for each region in terms of policy costs, shadow carbon prices, energy prices, and energy security? How does the extent of rollback influence the costs of regaining climate momentum?
- RQ3 (Staying Alive vs Asymmetric Roll-Back scenario): Can a focus on sectoral strategies with the strongest economic and efficiency rationale, namely RES deployment and end-use electrification, reduce the costs of rollback by closing the mitigation gap relative to Scenario 1?

2.6 Cross-Cutting Modelling Guidelines

All scenarios share the following implementation guidelines:

- Common baseline: Current Policies following the ELEVATE project's CPMP 2025.
- Land use CO₂ and non-CO₂ emissions are priced at equivalent levels to industrial CO₂ emissions; land-use non-CO₂ emissions are capped at 300 USD/tCO₂ (2010 USD).
- For perfect-foresight models, investments are fixed at scenario-specific values in Scenarios 2, 3, and 4.
- Post net-zero: modellers are free to set net-negative paths but CDR must be kept at realistic levels.

3. PRISMA scenario explorer and downscaling

3.1 PRISMA scenario explorer

The PRISMA Explorer¹ is hosted by the International Institute for Applied Systems Analysis (IIASA), to make scenario accessible to a wider audience. The database will provide results for all IAMs participating in the PRISMA consortium, namely: IMAGE, WITCH, MESSAGE, IMACLIM, OPEN-PROM, REMIND, and GEM-E3. IAMs scenarios are reported by the individual modelling teams using a common IAMC data format², which features dedicated columns for each model, scenario, region, variable, unit, and time periods. The time scale of these models spans from 2020 to 2100, with varying timesteps between models, even if reporting is a 5-year intervals. IAMs regions usually represent large economic aggregates, although some of these models provide results also for individual countries, as shown in Table 2:

Country	Covered by models:
China (often aggregated with small countries)	'REMIND-MAgPIE 3.7-4.14', 'IMACLIM 2.0', 'WITCH 6.0', 'IMAGE 3.4', 'OPEN-PROM 2.2', 'MESSAGEix-GLOBIOM-GAINS 2.1', 'GEM-E3 V2026'
United States	'REMIND-MAgPIE 3.7-4.14', 'IMACLIM 2.0', 'WITCH 6.0', 'IMAGE 3.4', 'OPEN-PROM 2.2', 'GEM-E3 V2026'
India	'REMIND-MAgPIE 3.7-4.14', 'IMACLIM 2.0', 'WITCH 6.0', 'IMAGE 3.4', 'OPEN-PROM 2.2', 'GEM-E3 V2026'
Japan	'REMIND-MAgPIE 3.7-4.14', 'IMAGE 3.4', 'OPEN-PROM 2.2', 'GEM-E3 V2026'
Brazil	'IMACLIM 2.0', 'WITCH 6.0', 'IMAGE 3.4', 'GEM-E3 V2026'
Canada	'IMACLIM 2.0', 'WITCH 6.0', 'IMAGE 3.4', 'GEM-E3 V2026'
Mexico	'WITCH 6.0', 'IMAGE 3.4', 'GEM-E3 V2026'
South Africa	'WITCH 6.0', 'IMAGE 3.4', 'GEM-E3 V2026'
Indonesia	'WITCH 6.0', 'GEM-E3 V2026'
Turkey	'IMAGE 3.4', 'GEM-E3 V2026'
Argentina	'GEM-E3 V2026'
Saudi Arabia	'GEM-E3 V2026'
South Korea	'GEM-E3 V2026'
United Arab Emirates	'GEM-E3 V2026'
EU27 (individual countries) and GBR	'OPEN-PROM 2.2', 'GEM-E3 V2026'

Table 2. Native regions covered by IAMs.

Therefore, some countries like China (virtually available from all models, although often combined with other smaller countries), India and the United States are largely represented by IAMs. However, other countries are either available only from a limited subset of models or completely missing. To increase the spatial heterogeneity of these models we use a downscaling algorithm, as described in section 3.2.

¹ <https://prisma.apps.ece.iiasa.ac.at/>

² Additional information on this data format can be found in a dedicated repository hosted by the International Institute for Applied Systems Analysis (IIASA): <https://github.com/IAMconsortium/nomenclature>



3.2 National downscaling method

This section provides an overview of the method used to downscale regional IAMs results to the country level.

We rely on the DSCALE algorithm (Sferra et al., 2026), which focuses on downscaling primary, secondary and final energy as well as emissions variables. DSCALE uses as input GDP and population projections at the country level from the Shared Socio-economics Pathway (SSP) dataset (K. C. et al., 2024). Moreover, it hinges on historical energy data from the International Energy data (IEA) (IEA, 2022) and the PRIMAP emissions database (Gütschow et al., 2024).

Energy demand is allocated from the region to the country level by considering country level GDP and population projections. In the near term, DSCALE aims at replicating existing historical trends in each country within a region, while matching the sum across countries with the regional IAM results. In the longer term, the regional IAMs boundaries will become increasingly important, and the energy intensity will become similar in all countries sharing the same level of economic development (GDP per capita). This may also lead to drastic changes in the historical trends especially in the 1.5C compatible pathways.

The secondary energy electricity is allocated by using a variety of criteria, including historical data, the economic lifetime of power plants (fossil fuels), supply cost curves (renewable energy) and governance indicators (nuclear and renewables). Primary energy is calculated from secondary energy, by using efficiency factors. Energy related CO₂ emissions are calculated by applying emissions factors to the primary energy mix.

To calculate total GHG-emissions we add:

- Non-CO₂ emissions (by using inputs from the GAINS model (Höglund-Isaksson et al., 2020), adjusted to match regional IAMs scenarios)
- Land use emissions (adjusted to account for national accounting method (Grassi et al., 2021)).
- Industrial process emissions (where the allocation from region to the country level is informed by final energy demand in the industrial sector)

The DSCALE tool can be applied to any IAMs that provide sufficient variable coverage (especially regarding the energy sector) and provides results for around 140 countries and approximately 100 variables. For the PRISMA project we have downscaled the results from 5 IAMs: IMAGE, REMIND, WITCH, MESSAGE and IMACLIM. Please note that for IMACLIM we have only downscaled CO₂ emissions, because non-CO₂ emissions are not reported by this model.

4. Preliminary results

This section presents preliminary results from the PRISMA WP6 modelling intercomparison. Section 4.1 through 4.7, with 4.8 showing the preliminary outcomes from the downscaling. Section 4.9 then discusses the results through the lens of each research question, commenting on what each indicator reveals about the costs and opportunities of regionally differentiated climate policy.

4.1 CO₂ emissions

Figure 1 shows global annual CO₂ emissions across the four scenarios for WITCH 6.0. A



single model output has been selected in this case to give a better idea of the relative CO₂ trajectories between scenarios. In Meet Aspirations world CO₂ emissions decline constantly, reaching near zero by the early 2060s and remaining at that level through 2100. Late Reawakening closely tracks the rollback path through 2035, then drops sharply and converges with Meet Aspirations by around 2065, confirming that accelerated mitigation after a decade of delay is feasible but compresses the transition into a very short window. Asymmetric Roll-Back declines more gradually and plateaus at approximately 8 GtCO₂/yr by 2080. Staying Alive manages to have lower emissions than Asymmetric Roll-Back before 2060, thanks to the strategic investments in clean technologies.

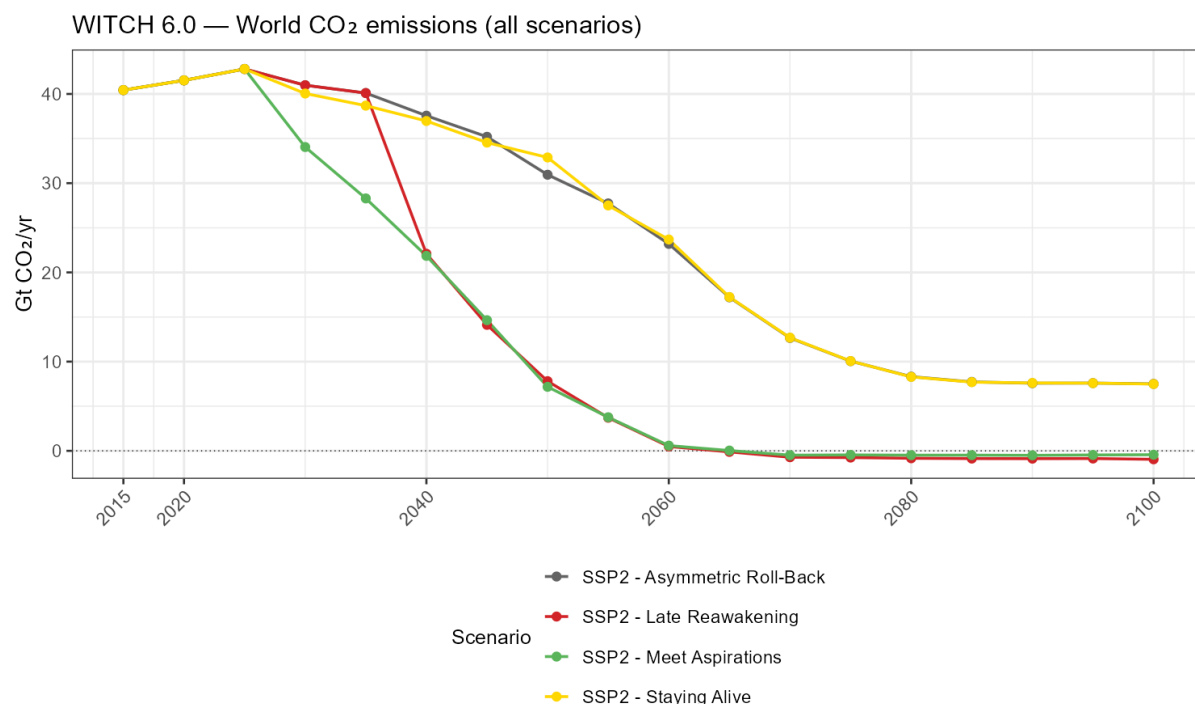


Figure 1. Annual CO₂ Emissions, World (GtCO₂/yr). Median value of the models, shaded areas show bounds of values across models, SSP2.

Figure 2 shows CO₂ emissions by PRISMA country cluster, normalized to 2020 = 1, with pairwise scenario comparisons organized by row (RQ1 top, RQ2 middle, RQ3 bottom) and by cluster column (Transition leaders, Diversifying economies, Fossil-dependent economies). The top row (RQ1) reveals a clear regional gradient in the cost of rollback. In Transition leaders, both scenarios decline sharply and the normalized gap between Asymmetric Roll-Back (black) and Meet Aspirations (green) remains moderate, reflecting the continued momentum of renewable deployment even under weakened policy. In Diversifying economies, the gap widens: Meet Aspirations moves into slightly negative territory by late century while Asymmetric Roll-Back stays around 0.1, indicating persistent emissions substantially above the ambition benchmark. In Fossil-dependent economies, the rollback penalty is largest in relative terms, then Asymmetric Roll-Back and Meet Aspirations converge at roughly 0.25 to 0.30 of 2020 levels by 2100. The model spread is widest in this

cluster, reflecting deep structural uncertainty about the pace of decarbonization in high-fossil-rent economies.

The middle row (RQ2) shows that Late Reawakening (red) tracks above Meet Aspirations through 2035 and then declines sharply, converging closely with the green line in Transition leaders and Diversifying economies by mid-century. In Fossil-dependent economies the convergence is slower but still clearly visible after 2060, as both scenarios end at comparable emission levels by 2100. This confirms that a timely recovery of ambition is sufficient to close the annual emissions gap in all three clusters, even if the delayed trajectory locks in additional cumulative emissions in the short-term decade. The bottom row (RQ3) shows that Staying Alive (yellow) consistently sits above Meet Aspirations (green) across all clusters, confirming that low-regret investment alone cannot match the ambition pathway.

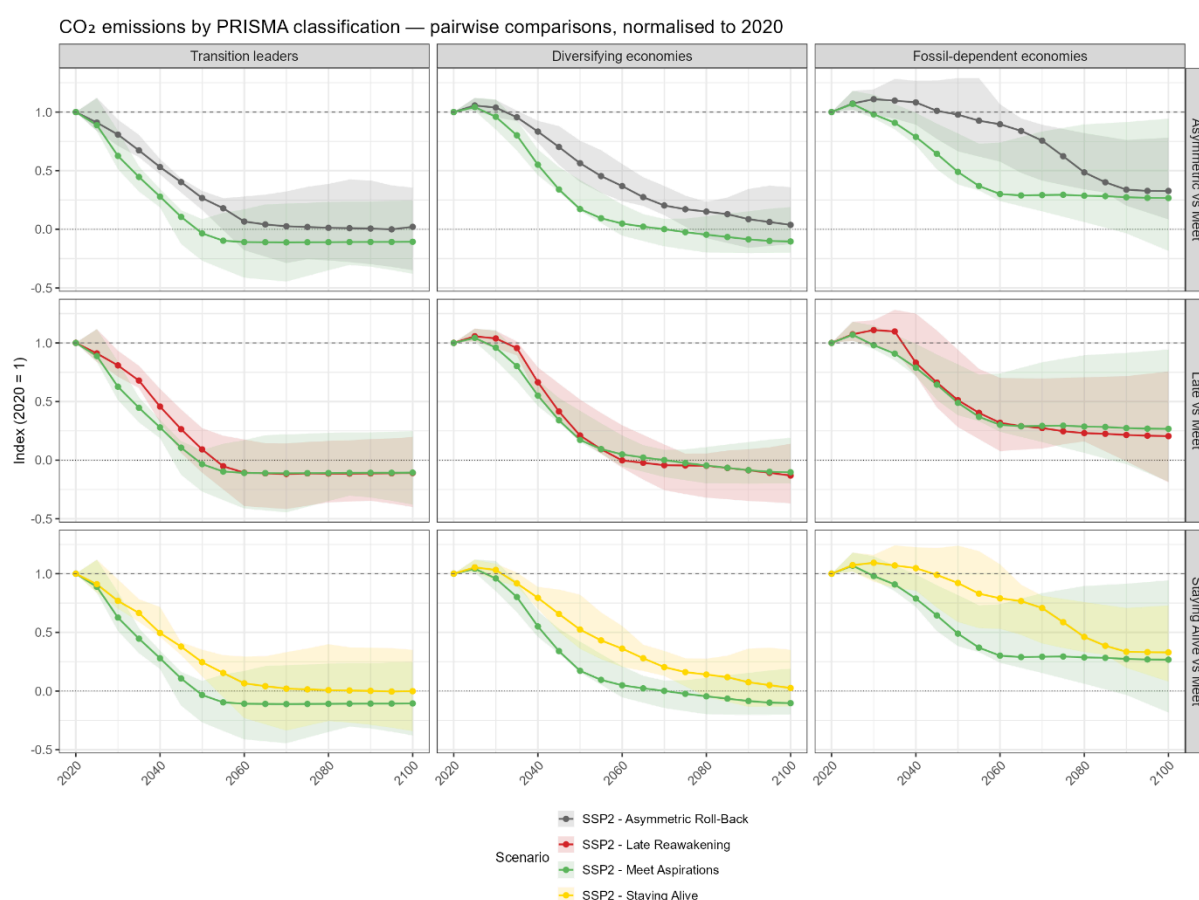


Figure 2. Annual CO₂ emissions by country cluster, normalized to 2020 level (CO₂ emissions in 2020 = 1). Transition leaders (left), Diversifying economies (middle), Fossil-dependent economies (right). Median value of the models, shaded areas show bounds of values across models, SSP2.

4.2 Cumulative CO₂ emissions

Figure 3 shows world cumulative CO₂ emissions from 2020, shown as pairwise comparisons of each scenario against Meet Aspirations. Applying a simplified transient climate response



to cumulative emissions (TCRE) approach (Rogelj et al., 2019; IPCC, 2021), and using the pre-2020 cumulative stock of approximately 2500 GtCO₂ (Copernicus, 2026) and a sensitivity of 0.5°C per 1000 GtCO₂, we can calculate the approximate end-of-century warming contributions from CO₂ alone per scenarios. Meet Aspirations (green) accumulates approximately 1050 GtCO₂ by 2100, keeping the model median just below the 2.0°C (67%) budget line, consistent with staying within 2°C with at least two-thirds probability. Asymmetric Roll-Back (left panel, black) diverges sharply from 2030 onward, reaching roughly 1600 GtCO₂ by 2100 and breaching the 2.0°C (50%) budget line well before mid-century. The gap relative to Meet Aspirations, approximately 550 GtCO₂ at 2100, is locked in progressively and cannot be undone within the century. Late Reawakening (middle panel, red) tracks above Meet Aspirations through 2040 before bending down sharply, with the models median landing just below the 2.0°C (67%) threshold. Staying Alive (right panel, yellow) accumulates approximately 1500 GtCO₂ by 2100, a trajectory broadly comparable to Asymmetric Roll-Back, confirming that maintained clean investment under a weakened policy framework is insufficient to substantially reduce cumulative emissions and keeps the world well above the 2.0°C (50%) budget.

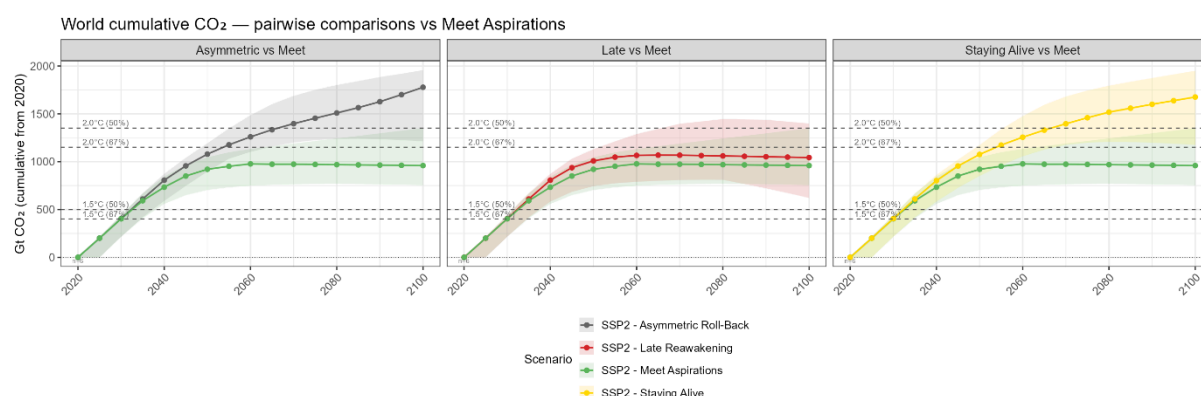


Figure 3. World Cumulative CO₂ Emissions from 2020 (GtCO₂). Pairwise comparison of each scenario versus Meet Aspirations. Median value of the models, shaded areas show bounds of values across models, SSP2.

4.3 GDP variation (%)

Figure 4 shows the percentage GDP variation (calculated using Market Exchange Rate) relative to Meet Aspirations for four modelling teams, with each panel corresponding to one scenario. The models not present in the panels have an exogenous GDP, that is not affected by variation of climate ambition within the scenarios.

All three rollback scenarios show positive GDP variation relative to Meet Aspirations in the near to medium term across most models, reflecting the short-run economic relief of reduced carbon pricing and lower mitigation costs. However, the magnitude and persistence of this gain differ substantially across scenarios and models. For Asymmetric Roll-Back (left panel), most models report a modest positive differential that peaks before 2060 and gradually erodes toward zero by 2100, with WITCH 6.0 being the clear outlier at a peak gain of roughly +5% around 2050 before converging downward.

In the Late Reawakening (middle panel), WITCH shows an initial positive gain similar to Asymmetric Roll-Back, but the GDP differential turns negative around 2045, dipping to approximately -7.5% in 2050, before recovering toward zero by 2100. This temporary

contraction below the ambition pathway captures the economic disruption of the compressed post-2035 transition, when rapid fossil capital stranding and accelerated investment surge impose costs not present in the smoother Meet Aspirations trajectory.

Staying Alive (right panel) shows similar variation with respect to Asymmetric Roll-Back, with the largest positive GDP differential in WITCH, peaking at around +5% near 2055 and remaining above zero through 2100. The large inter-model spread across all three panels is a clear signal that GDP implications of rollback scenarios are highly sensitive to model structure, particularly to how carbon pricing costs and clean energy co-benefits are represented.

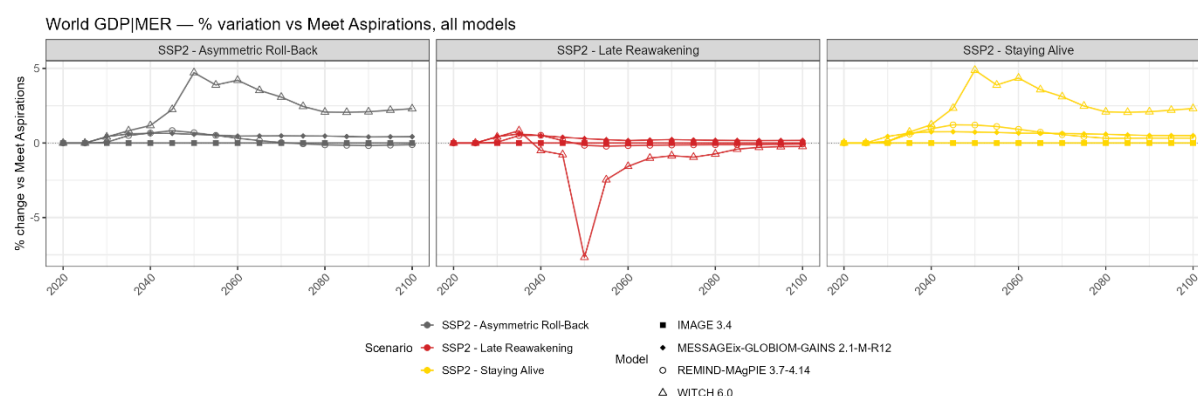


Figure 4. GDP MER Variation (% relative to baseline), World. Model values, SSP2.

4.4 Clean energy investments

Figure 5 shows world investment in solar and wind technologies as 10-year averages, now reported across all five models, given issues in the investments constraint implementation in the other models.

Asymmetric Roll-Back (left panel) shows a large and persistent solar and wind investment deficit: approximately 24% below Meet Aspirations in 2030, narrowing to 4.7% below at 2050 and 2.2% below at 2070. The gap closes over time as long-run technology economics exert pressure toward deployment even without policy support, but it never reverses, confirming that policy rollback leaves a lasting imprint on solar and wind investment even in the most technology-friendly sector. Late Reawakening (middle panel) starts essentially at parity with Meet Aspirations in 2030 (+0.7%), surges to +4.9% above by 2050 reflecting the post-2035 acceleration in the recovery pathway, and then settles back near parity at 2070 (+0.4%). The overshoot at 2050 is consistent with a compressed transition in which solar and wind are prioritized as the primary instrument of catch-up, before converging to the Meet Aspirations level as the transition matures. Staying Alive (right panel) maintains solar and wind investment above or at Meet Aspirations throughout the period: +1.2% in 2030, exactly at parity in 2050, and +0.8% in 2070. This confirms that the investment floor built into the scenario design for these technologies is functioning as intended and is sufficient to preserve parity with the ambition pathway in this specific sector, even in the absence of broader climate policy.

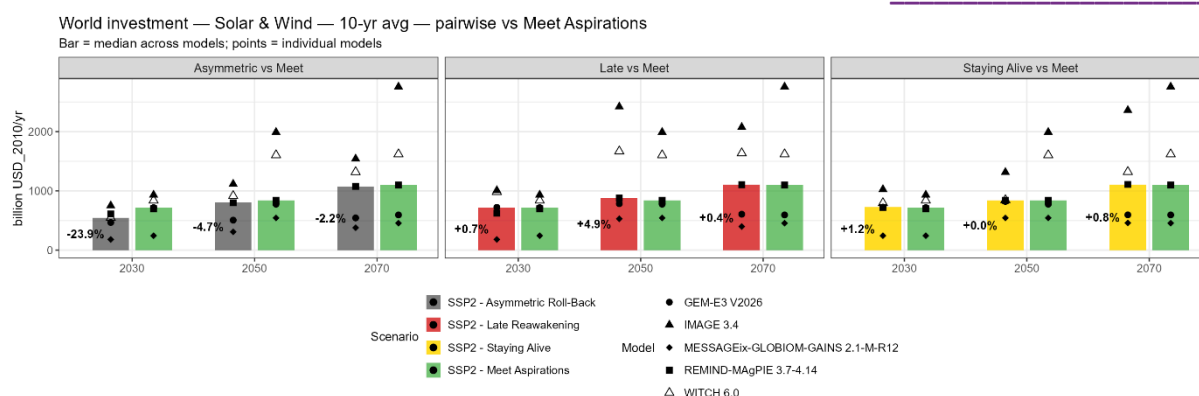


Figure 5. World investment in solar and wind technologies (billion USD 2010/yr). Ten-year averages, pairwise comparison vs Meet Aspirations; bar = model median, points = individual models, SSP2.

4.5 Solar and wind cumulative capacity

Figure 6 shows world installed solar and wind capacity across all scenarios, with shaded bands indicating model spread. All scenarios start from the same base and diverge progressively from 2030 onward. Meet Aspirations (green) follows a steep upward trajectory, reaching approximately 50000 GW by 2100. Late Reawakening (red) tracks closely with or below Meet Aspirations through 2040, reflecting the rollback period, then accelerates sharply post-2035 and ends as the highest trajectory at approximately 52000 GW by 2100, slightly above the ambition pathway. This end-of-century overshoot reflects the compressed post-2035 transition, in which rapid deployment of solar and wind is the primary recovery instrument. Asymmetric Roll-Back (grey) is the lowest trajectory throughout, ending at approximately 46000 GW by 2100. As noted for the investment variable, this value is still high in absolute terms, reflecting the long time horizon over which technology cost reductions drive deployment even without strong policy; it does not, however, imply better climate outcomes, since the timing of deployment matters critically for cumulative emissions. Staying Alive (yellow) tracks closely with Asymmetric Roll-Back through mid-century, then gradually converges toward Meet Aspirations, ending near 51000 GW by 2100. It must be noted that this variable exhibits considerable ambiguity, as the inter-model spread exceeds the inter-scenario spread across much of the time horizon, which limits the confidence with which scenario differences can be interpreted.

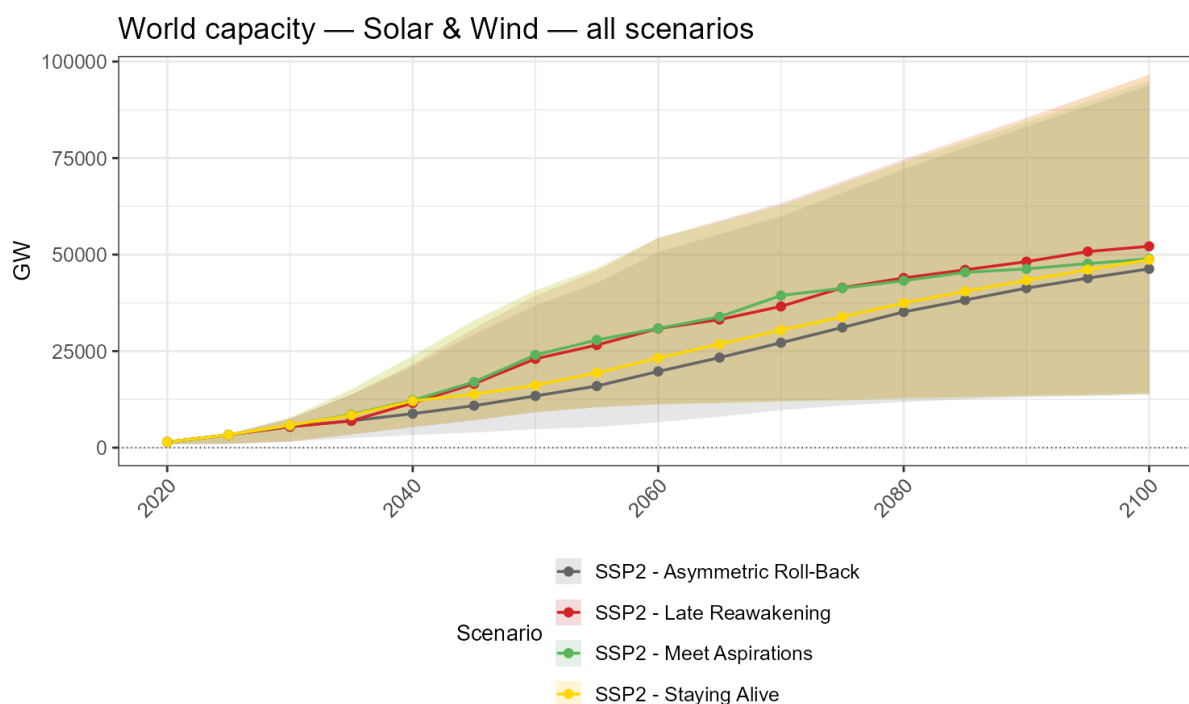


Figure 7. World installed solar and wind capacity (GW), all scenarios. Model median; shaded areas show model spread. SSP2.

4.6 Electricity share in secondary energy

Figure 7 shows the share of electricity in world secondary energy as 10-year averages, compared pairwise against Meet Aspirations. All scenarios show a broad upward electrification trend over time, reflecting the common structural shift toward electricity across the energy system regardless of policy stringency. The gap between rollback scenarios and Meet Aspirations is most visible in 2050. Asymmetric Roll-Back (left panel) reaches an electricity share 16 percentage points below Meet Aspirations at the model median, confirming that weaker climate policy measurably slows the electrification of the energy system. Late Reawakening (middle panel), despite tracking Asymmetric Roll-Back through 2030, it nearly reaches the level of Meet Aspirations by 2050, demonstrating that the post-2035 policy acceleration drives rapid electrification gains within a relatively short window. By 2070 the two bars are essentially indistinguishable across the ensemble. Staying Alive (right panel) occupies an intermediate position. It narrows the electrification gap relative to Asymmetric Roll-Back, reflecting the contribution of maintained clean investment to supply-side capacity build-up, but it still falls meaningfully short of Meet Aspirations at both 2050 and 2070. This means that investments without the accompanying carbon pricing signal and electrification mandates is insufficient to drive demand-side electricity uptake at the pace required by the ambition pathway.

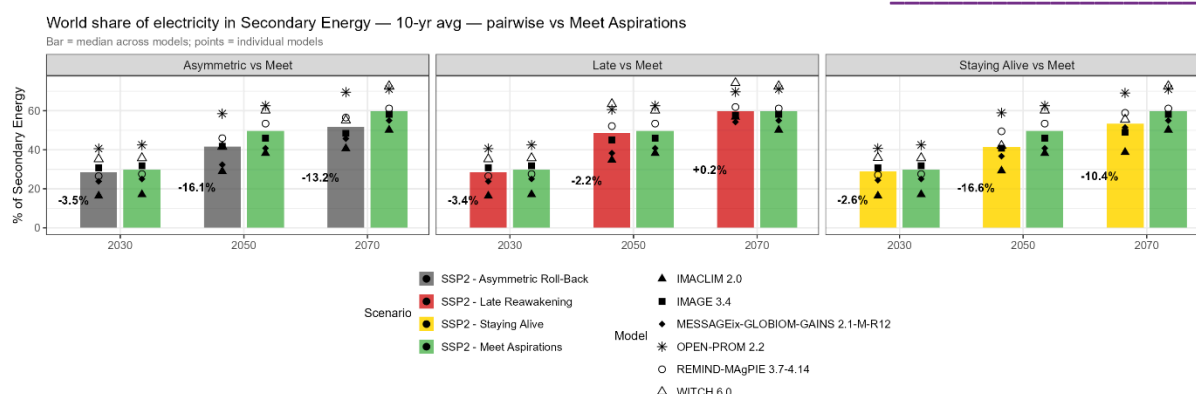


Figure 7. World Share of Electricity in Secondary Energy (%). Ten-year averages, pairwise comparison vs Meet Aspirations; bar = model median, points = individual models, SSP2.

4.7 Renewable energy share in primary energy

Figure 8 shows the share of renewables in world primary energy as 10-year averages, compared pairwise against Meet Aspirations. The percentage labels show the median gap relative to Meet Aspirations.

In 2030 the three rollback scenarios already diverge slightly from one another: Asymmetric Roll-Back and Late Reawakening both start around 15 percent below Meet Aspirations, while Staying Alive is closer at 8 percent below, reflecting the effect of maintained clean investment in the near term. By 2050 the differences become substantial. Asymmetric Roll-Back falls 39 percent below Meet Aspirations at the median, representing the clearest quantitative signal of how deeply policy rollback constrains structural renewable penetration beyond emissions alone. The gap then narrows to 26 percent by 2070, as long-run technology economics begin to close the distance even without policy, but a large deficit persists to the end of the period. Late Reawakening (middle panel) recovers sharply: the gap narrows from 15 percent in 2030 to just 4 percent by 2050 and 1 percent by 2070, effectively converging with Meet Aspirations within two decades of the policy recovery. Staying Alive (right panel) occupies a consistent intermediate position. In 2050 it stands 29 percent below Meet Aspirations, meaningfully better than the 39 percent gap of Asymmetric Roll-Back, and the deficit narrows further to 24 percent by 2070 compared to 26 percent under pure rollback. The improvement relative to Asymmetric Roll-Back confirms that maintained investment does translate into higher renewable shares, but the persistent gap with Meet Aspirations reinforces that investment alone cannot substitute for the structural pull of carbon pricing and regulatory targets.

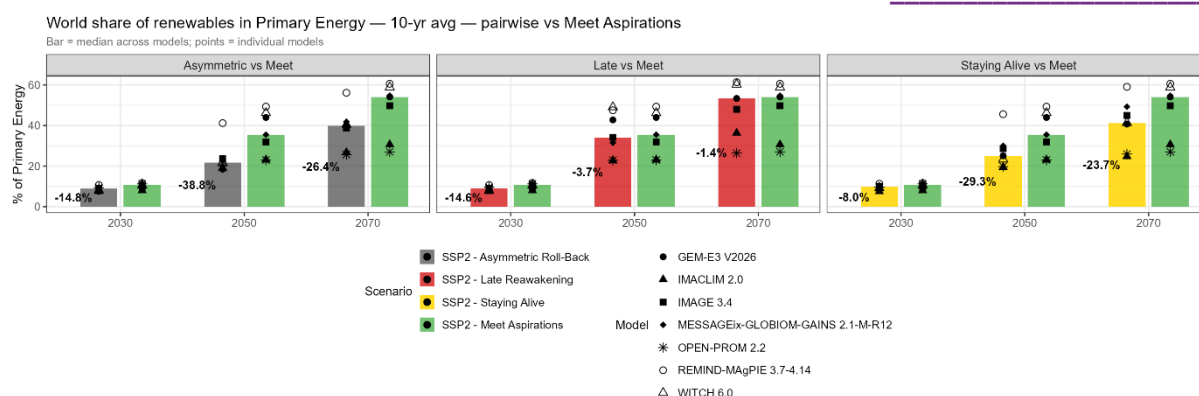


Figure 8. World share of renewables in primary energy (%). Ten-year averages, pairwise comparison vs Meet Aspirations; bar = model median, points = individual models, SSP2.

4.8 Preliminary downscaled results

This section shows the preliminary downscaled results from IAMs regions to the country level. To streamline the analysis, we show a couple of countries for each representative group:

- Transition leaders: Japan and Germany
- Diversifying economies: India, Brazil
- Fossil-dependent economies: Russia, Saudi Arabia

4.8.1 Transition Leaders

This section presents the results for selected countries among the transition leaders: Germany and Japan. Figure 9 below shows the result across models and scenarios for Japan in terms of Emissions (by type of gas) and primary energy (by technology).

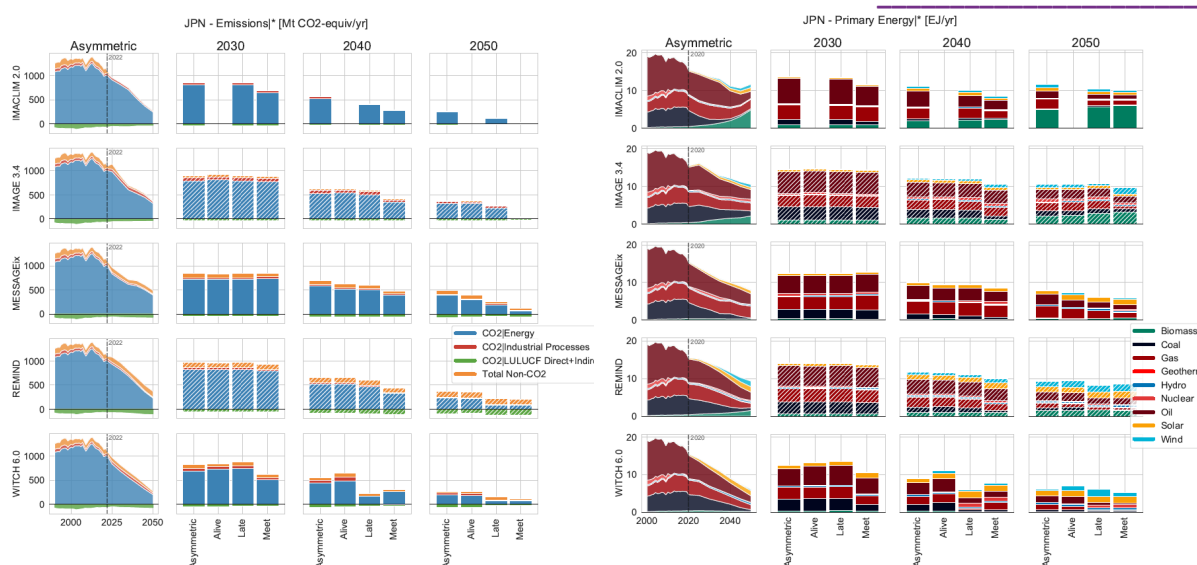


Figure 9. Emissions (left) and Primary energy (right) in Japan across models, and scenarios: downscaled results (solid bars) vs native IAM regions (bars with stripes)

The figure compares the observed historical country-level data with the downscaled Asymmetric rollback scenario. For the other scenarios, we show results for selected time periods: 2030, 2040 and 2050. The figure shows both downscaled results (solid bars) and native IAMs results (bars with stripes).

The left-hand panel shows emissions by gases, including energy related CO₂ emissions, industrial processes, land use and total non-co₂ emissions. The right-hand panel shows the energy mix associated to each scenario.

Results show that the contribution of negative land use emission will be minor in Japan, with a good level of agreement across models. In the Meet Aspiration scenario emissions will be lowest as they will approach net zero by 2050, whereas the Asymmetric Roll-Back scenario shows emissions ranging from around 250-500 MtCO₂ by mid-century, depending on the model. The IMACLIM and IMAGE models envision higher shares of biomass in the energy mix, whereas the WITCH, REMIND and MESSAGE show a higher penetration of renewables.

We see a similar pattern in Germany (Figure 10), with emissions approaching net zero in the Meet Aspiration scenario.

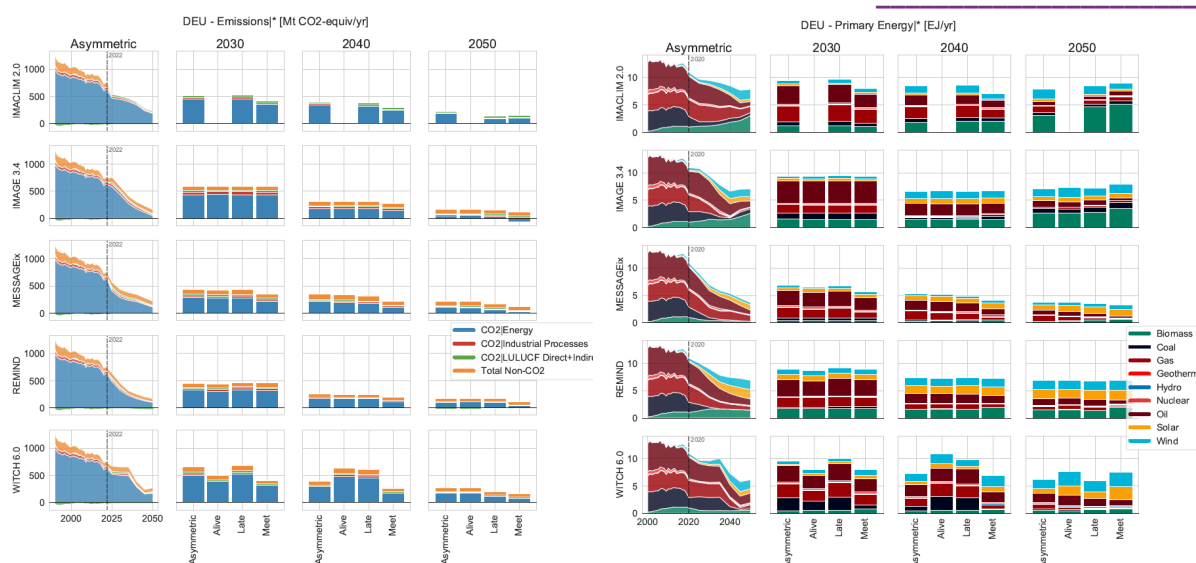


Figure 10. Emissions (left) and Primary energy (right) in Germany across models, and scenarios: downscaled results (solid bars) vs native IAM regions (bars with stripes)

This figure highlights differences about how to reduce emissions, according to the different models. Once again, the IMACLIM and IMAGE models show higher reliance on biomass, while REMIND and WITCH show increasing shares of wind and solar in the primary energy mix. The downscaled MESSAGE model results suggests that successful energy efficiency measures can effectively reduce the overall amount of primary energy, by more than 50% in 2050 compared to present day values. Finally, the contribution of the land use sector is relatively small compared to the emissions reductions achieved in the energy sector.

4.8.2 Diversifying economies

In this section we select Brazil and India as representative countries for the diversifying economies. Three (IMACLIM, IMAGE and WITCH) out of 5 models, provide results for both Brazil and Japan, while REMIND provide results for Japan. Therefore, this section also allows for a comparison of downscaled vs native regions using a common set of scenarios. Figure 11 below shows a good level of agreement, although some clear differences appear.

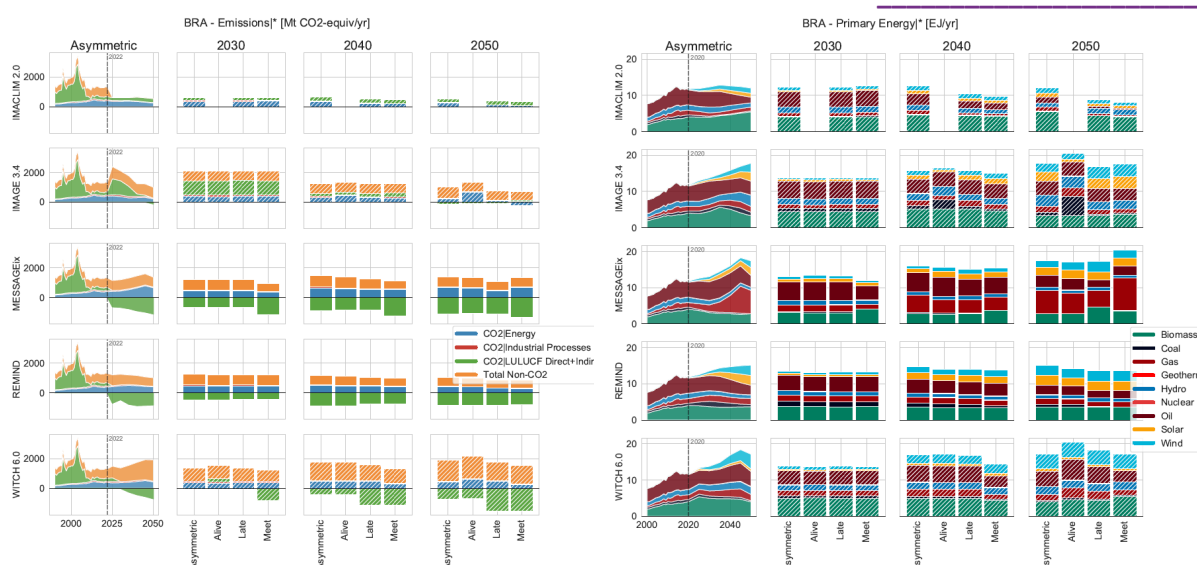


Figure 11. Emissions (left) and Primary energy (right) in Brazil across models, and scenarios: downscaled results (solid bars) vs native IAM regions (bars with stripes)

The figure shows that there is relatively high uncertainty across models regarding land use emissions in Brazil. This uncertainty seems to be driven by different model's characteristic, rather than the downscaling approach, as it persists when looking at native Brazil region of the WITCH, IMAGE and IMACLIM model (that do not rely on the DSCALE algorithm). Results suggests that the WITCH model utilize negative land use emissions, to compensate for hard-to-abate (mostly from non-CO2) emissions. We see a similar pattern in the downscaled results from MESSAGE, and to some extent also in the REMIND model (with lower reliance on negative land use emissions, as positive emissions are much lower).

Biomass will continue to supply a significant share of primary energy, especially in the IMACLIM model, whereas it will be partly substituted by gas in the MESSAGE model. Wind will be scaled up significantly in the WITCH scenarios, whereas solar will be significantly deployed in the REMIND, MESSAGE and IMAGE model. All models suggest low coal demand in all scenarios, except for the IMAGE `staying alive scenario`, showing a revival of coal use in 2050.

Regarding India (Figure 12), coal is expected to supply a large share of primary energy until 2030, whereas in the longer term it will be replaced mainly by solar and wind (IMAGE, MESSAGE, REMIND), or biomass (IMACLIM), especially in the Meet Aspirations and Late Reawakening scenarios

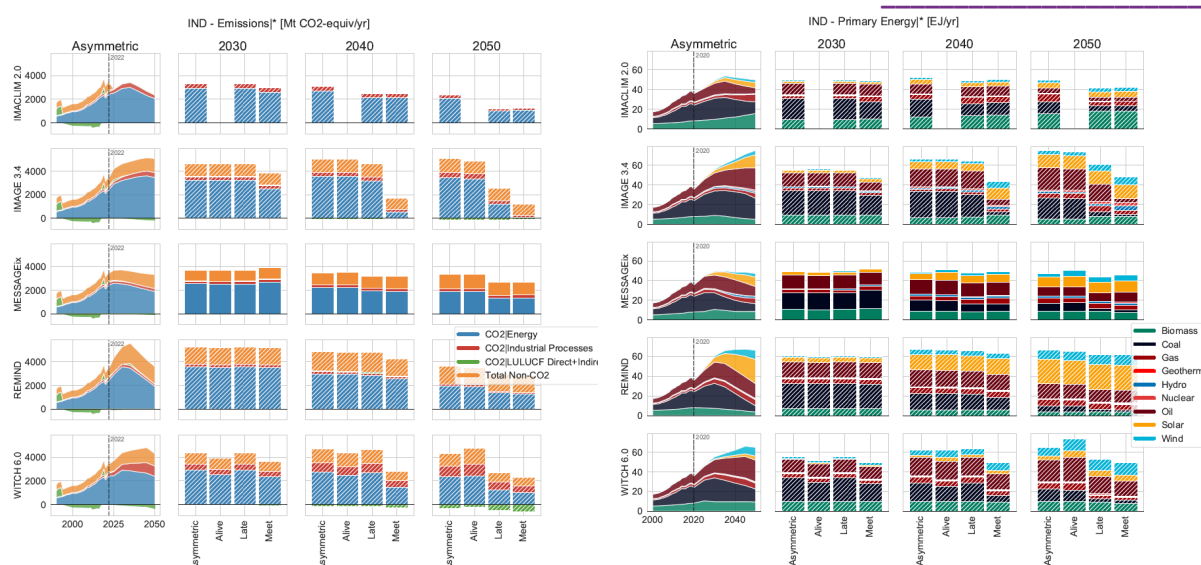


Figure 12. Emissions (left) and Primary energy (right) in India across models, and scenarios: downscaled results (solid bars) vs native IAM regions (bars with stripes)

Emissions will remain above net zero in all (including the Meet Aspirations) scenarios. The figure also shows limited abatement potential from the land use sector in India, with a high level of agreement across models. When comparing the meet aspirations and the late reawakening scenarios, some models (REMIND, MESSAGE and IMACLIM) suggest that it is feasible to make up for the lost time. However, the IMAGE model suggests otherwise, due to some locks-in effects regarding oil consumption in the transportation sector.

4.8.3 Fossil-dependent economies

This section focuses on downscaled results for Russia and Saudi Arabia as representative of the fossil-fuel dependent countries. Figure 13 below shows that all models agree that the land use emissions will continue to act as a carbon sink until 2050, which can help compensate for residual emissions.

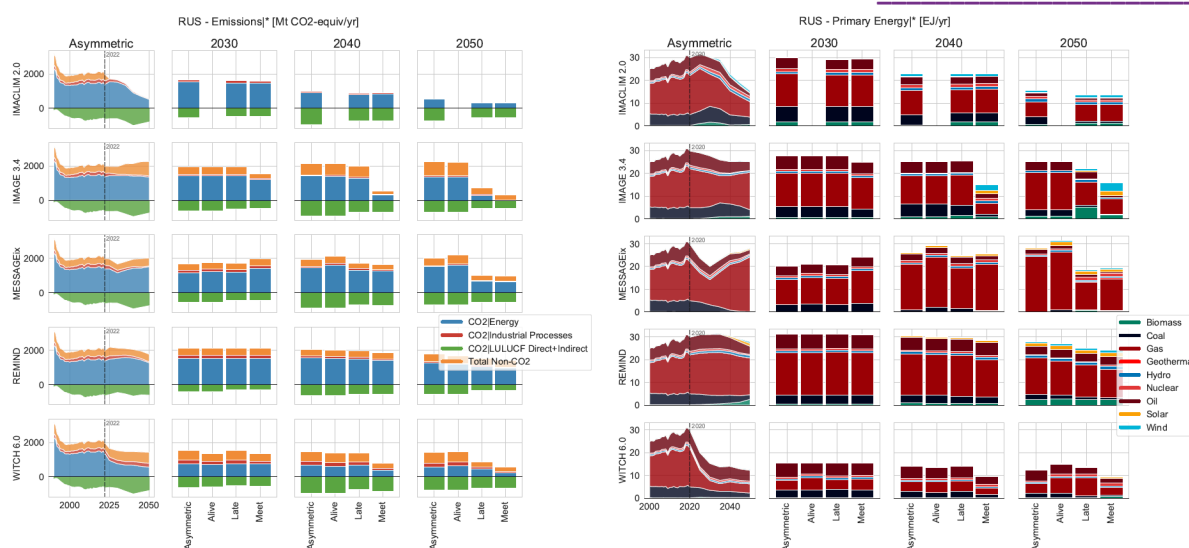


Figure 13. Emissions (left) and Primary energy (right) in Russia across models, and scenarios: downscaled results (solid bars) vs native IAM regions (bars with stripes)

The Russian economy will remain dependent on gas in all scenarios under scrutiny, with limited scope for renewable energy development. This also reduces the mitigation potential for energy related CO₂ emissions. Downscaled results from WITCH, suggest that gas could drop to roughly a third compared to current primary energy demand by 2050, and for this reason emissions could reach net zero in the late reawakening and meet aspirations scenarios.

Downscaled results for Saudi Arabia (Figure 14) show that will replace oil with gas in all models and across all scenarios.

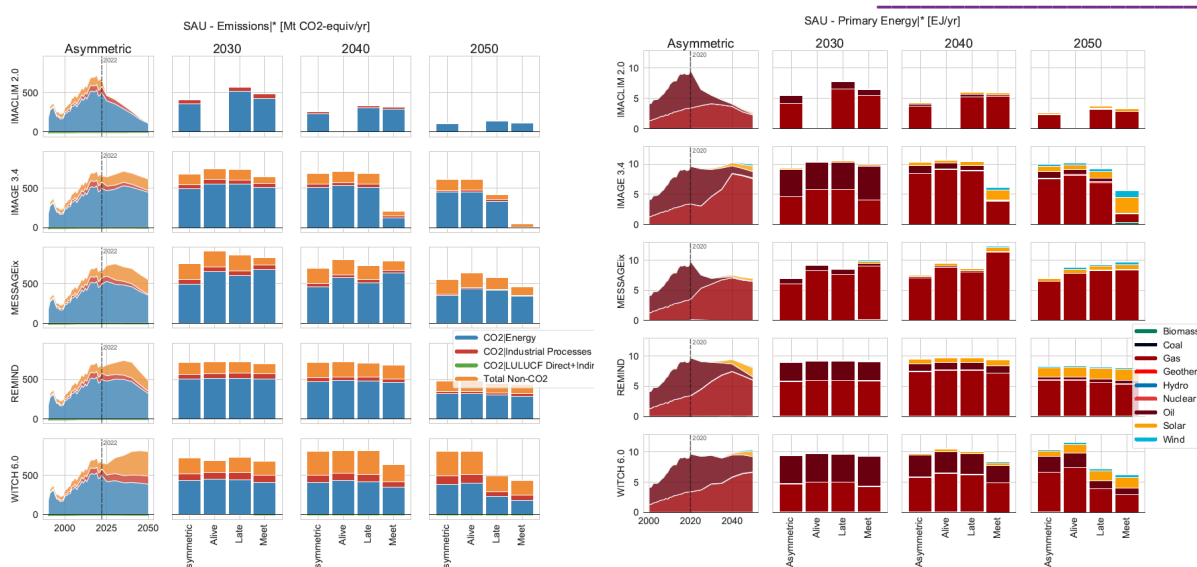


Figure 14. Emissions (left) and Primary energy (right) in Saudi Arabia across models, and scenarios: downscaled results (solid bars) vs native IAM regions (bars with stripes)

Solar energy will become increasingly important in the future, especially in the meet aspiration scenarios, according to the WITCH, IMAGE and REMIND models. Overall primary energy demand is expected to stabilize at current levels (IMAGE, REMIND, WITCH) or decline over time (IMACLIM, MESSAGE).

Due to increasing reliance on gas, Kyoto emissions will remain significantly above zero in 2050 in most model/scenario combinations. This is also exacerbated by the absence of negative emissions from the land use sector.

4.9 Discussion

RQ1: What are the full energy-economic implications of asymmetric rollback?

Asymmetric Roll-Back imposes costs that extend well beyond the emissions dimension. On the carbon budget, the scenario accumulates approximately 1600 GtCO₂ by 2100, breaching the 2.0°C (50%) budget line well before mid-century and locking in roughly 550 GtCO₂ of additional cumulative emissions relative to Meet Aspirations. Annual CO₂ emissions plateau at approximately 8 GtCO₂/yr by 2080, confirming that rollback does not eliminate decarbonization but permanently slows it. The structural dimension of this cost is equally clear: the share of renewables in primary energy falls 39 percent below Meet Aspirations by 2050, narrowing to 26 percent by 2070 but never closing, and solar and wind investment runs a 24 percent deficit in 2030 that narrows but persists through the century. Electrification also slows measurably, with the electricity share in secondary energy running 16 percentage points below Meet Aspirations at 2050. The GDP picture is more ambiguous in the near term: most models show a modest positive differential reflecting reduced carbon pricing costs, with WITCH reaching approximately +5 percent around 2050 before converging downward. This short-run gain, however, does not account for the physical costs of additional warming

or the structural gap in the energy system. The cluster analysis reveals that the most persistent divergence between Asymmetric Roll-Back and Meet Aspirations occurs in Diversifying economies, where Meet Aspirations moves into slightly negative territory by late century while Asymmetric Roll-Back remains at approximately 0.1 of 2020 levels.

RQ2: Is it feasible to make up for a decade of lost ambition, and at what cost?

Late Reawakening provides a genuinely encouraging answer on the carbon budget: the model median lands just below the 2.0°C (67%) threshold by 2100, demonstrating that a timely recovery of ambition after 2035 can largely preserve long-run temperature outcomes. Annual CO₂ emissions converge with Meet Aspirations by around 2065, and the renewable share gap narrows from 15 percent in 2030 to just 4 percent by 2050 and 1 percent by 2070. Solar and wind investment surges to 4.9 percent above Meet Aspirations by 2050, and installed capacity ends as the highest of all scenarios at approximately 52,000 GW by 2100. The electricity share is virtually indistinguishable from Meet Aspirations by 2070. The cost of this recovery is real, however. The compressed post-2035 transition requires rapid fossil capital stranding and an accelerated investment surge that, in WITCH, drives the GDP differential to approximately -7.5 percent relative to Meet Aspirations in 2050 before recovering toward zero by 2100. The decade of delay is therefore not free: it trades a manageable long-run cost for a concentrated and potentially disruptive near-term adjustment burden.

RQ3: Can low-regret strategies substitute for climate policy?

Staying Alive cannot substitute for climate policy. Cumulative emissions reach approximately 1500 GtCO₂ by 2100, broadly comparable to Asymmetric Roll-Back and well above the 2.0°C (50%) threshold, confirming that maintained clean investment under a weakened policy framework is insufficient to substantially alter the carbon budget trajectory. The renewable share gap with Meet Aspirations remains at 29 percent in 2050 and 24 percent in 2070, only marginally better than the 39 and 26 percent gaps under pure rollback. What Staying Alive does deliver is a set of robust co-benefits: solar and wind investment is maintained at parity with Meet Aspirations throughout the period (+1.2% in 2030, 0.0% in 2050, +0.8% in 2070), the electricity share is meaningfully higher than under Asymmetric Roll-Back even if it falls short of the ambition pathway, and the GDP differential in WITCH peaks at +5 percent near 2055 and remains positive through 2100. Staying Alive is therefore best understood as a strategy that preserves options and reduces the cost of reactivating ambition, not as a substitute for it.

Downscaled results

The downscaled results generally confirm the findings above. By looking at the downscaled data we get a more nuanced picture, and by comparing emissions with the primary energy mix, and are able to better understand the drivers of the results.

Among the transition leaders we find that both Germany and Japan are expected to reduce their primary energy use until mid-century. In both countries, emissions will reach, or get close to, the net zero target by 2050 in the Meet Aspiration scenario, according to most models. However, an asymmetric rollback will drift both countries away from this target,



which cannot be healed by no-regret strategies alone. A Late Reawakening will be able to fill most of the emissions gap by mid-century in terms of annual emissions, but not able to compensate for the lost time in terms of cumulative emissions.

Diversifying economies like India and Brazil face very different challenges, due to their socioeconomic characteristics as well as a different energy mix. On the one hand, India is highly dependent on coal, which will be likely replaced by solar and wind in the long term, also depending on the level of climate ambition. However, none of the scenarios will be able to reach net zero by 2050.

On the other hand, Brazil will continue to use biomass in its energy mix, and it could become a net zero country by mid-century. Carbon sinks from the land use sector can (at least partly) compensate for sources of emissions in all scenarios.

An Asymmetric Roll/back would tend to increase emissions in both countries and no-regrets policies alone will not be able to replace climate policies. A Late Reawakening would reduce emissions, with Brazil even able to get close net zero by 2050 (3 out of 5 models).

Oil dependent economies like Russia and Saudi Arabia are expected to substitute oil with natural gas in the long term (with a good level of agreement across models). Emissions will remain above net zero in most scenarios by mid-century, especially in Saudi Arabia where there is limited potential for negative emissions from the land use sector. In both countries an Asymmetric Roll-back would lead to significantly higher emissions compared to the meet aspiration scenario. A Late Reawakening could reduce this gap. We also find that low regret strategies cannot substitute for climate policy in both countries.

5. Extensions for WP2 and WP3

5.1 WP2: EU-Focused Analysis

The WP6 scenarios serve as the basis for WP2 model comparison focused on the European Union. The scenarios are identical to the WP6 core scenarios, but for models featuring European policy instruments (ETS, ESR, CBAM), ETS linear reduction factors are adjusted and ETS2 is delayed in line with the weakened objectives of the roll-back scenario. All WP2 teams are required to report results for the EU27+UK region using common variable definitions.

5.2 WP3: Innovation and Finance

For WP3, one additional variant is introduced on top of Scenario 2 (Asymmetric Roll-Back with High Costs), capturing heightened financial and technological disruption:

- Financing costs increase across all regions, based on indicative markups to the cost of capital (CoC) provided by ETH, ranging from 1.5% (Western Europe, USA, Canada) to 4.9% (Ukraine region).
- International technology spillovers (both learning-by-doing and R&D) are set to zero, simulating low collaboration and trade barriers.
- Higher costs for solar PV, batteries, and wind technologies are applied based on Fragkos et al. (2026), using the NDC_LTT domestic/foreign cost ratios after 2035.



6. Data Workflow and Timeline

Model teams submit results to the PRISMA internal database (prisma-internal.apps.ece.iiasa.ac.at) following the variable template list at <https://files.ece.iiasa.ac.at/prisma/prisma-template.xlsx> and using the common region and variable definitions from the GitHub workflow repository (<https://github.com/iiasa/prisma-workflow>). The timeline for D6.4 milestones was as follows:

- March-April 2026: Two consortium calls for protocol alignment and implementation support.
- May 31, 2026: First round of scenario submissions (summary in Table 3).
- July 2026: Deliverable D6.4 submission.

Model	Submission status	SSP2 - Meet Aspirations	SSP2 - Asymmetric Roll-Back	SSP2 - Late Reawakening	SSP2 - Staying Alive
IMACLIM (CIRED)	Implementation issues	✓	✓	✓	
MESSAGEix-GLOBIOM-GAINS (IIASA)	Approved	✓	✓	✓	✓
WITCH 6.0 (CMCC)	Approved	✓	✓	✓	✓
REMIND-MAGPIE 3.6-4.14 (PIK)	Implementation issues	✓	✓	✓	✓
OPEN-PROM 2.2 (E3M)	Minor implementation issues	✓	✓	✓	✓
GEM-E3 v2026 (E3M)	Minor implementation issues	✓	✓	✓	✓
IMAGE (PBL)	Major implementation issues	✓	✓	✓	✓

Table 3. Summary of model submission status.

Appendix 1: regional classification

We use indicators on fossil fuel wealth (from the World Bank wealth of nations, to capture the fossil assets of each country), of RES growth in the past decade (to capture which countries are investing in clean energy), of GHG intensity of the economy (to capture structural economic factors).

Plotting these variables provides a first cut mapping of countries in this space. Figure A.1 highlights a negative correlation between fossil fuel assets and growth in renewable energy, further reinforced by the GHG intensity of the economies (bubble sizes). The plot already highlights geographical patterns, e.g. with resource poor, high renewable energy growth and low emission intensity areas such as Europe and Japan/South Korea, while Middle East countries sit at the other end of the spectrum. Major economies such as the US, China and India appear to be middle ground.

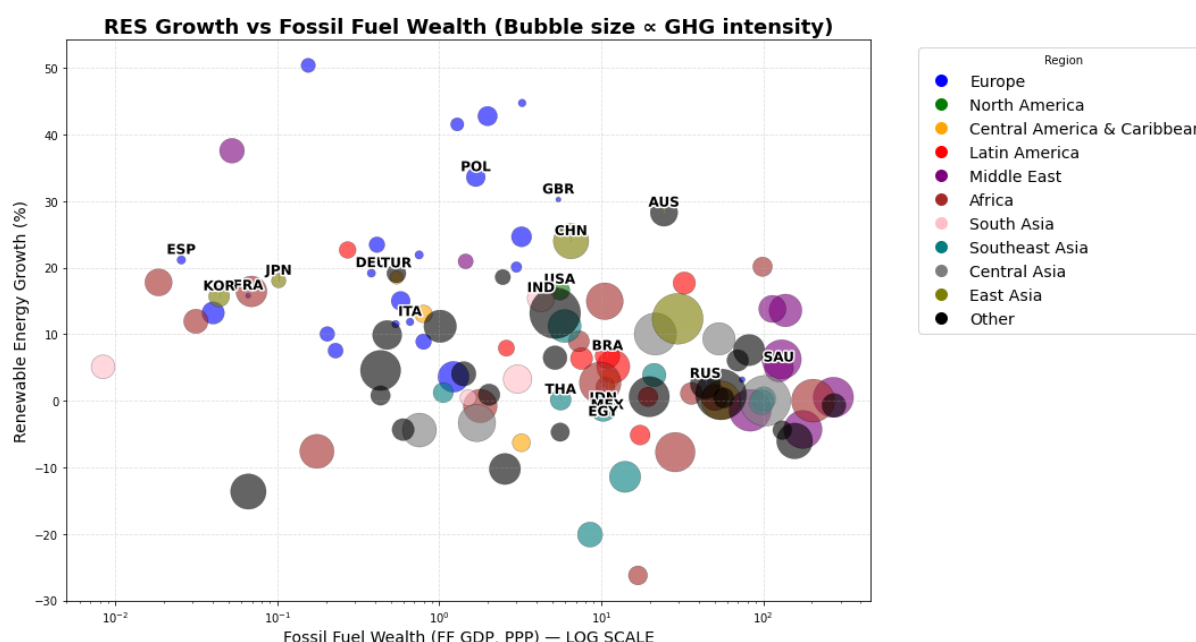


Figure A.1. Country classification by fossil fuel wealth and renewable energy growth. Each bubble represents a country; the x-axis shows fossil fuel wealth as a share of GDP (PPP, log scale); the y-axis shows past-decade renewable energy growth (%); bubble size is proportional to GHG intensity of the economy.

From this, we can classify countries based on these indicators, testing K-Means, Hierarchical Clustering and Gaussian Mixture Model (GMM) clustering methods. Using 3 clusters for interpretability (though the data suggests even 4 or 5 clusters could be viable), results in the following example (GMM cluster), which identifies Fossil-dependent economies (e.g. Economies with high fossil fuel rents, high GHG intensity, and limited RES growth), Diversifying economies (Moderate fossil dependence, improving renewables growth, but still carbon-intensive production) and Transition leaders (Low fossil fuel rents, high renewable energy growth, and low GHG intensity). Some countries are missing for missing data.

Additional dimensions can be considered, even qualitatively; for example Japan and South Korea are classified as green in this method, but they are under the strong economic and political influence of the US, and as a result they would probably need to be moved to a less proactive cluster. On the other hand, China is heavily invested in the green transition, having become the key manufacturer of clean energy technologies and exerting influence in many countries with significant FDI investments. However, this classification provides a reasonable and data-driven approach that we can use for our scenarios.

Country Clusters Based on Fossil Dependence, Renewable Growth, and GHG Intensity

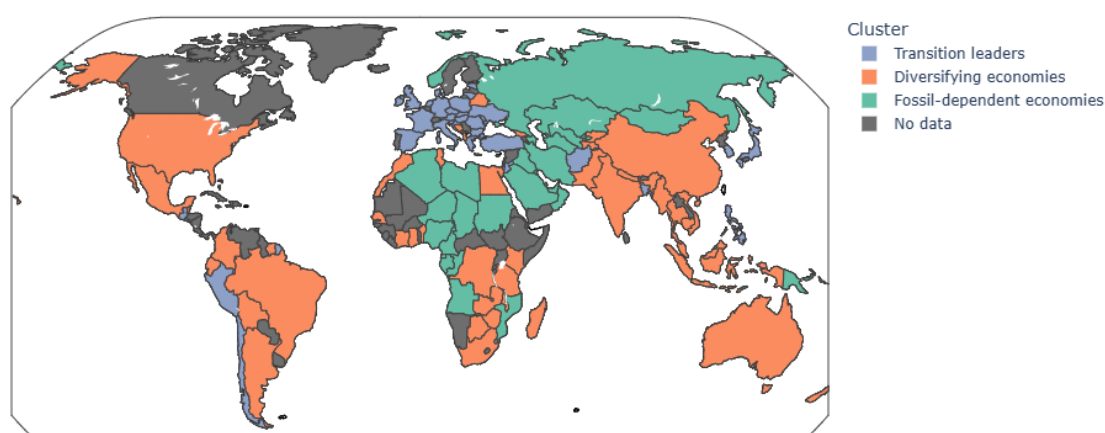


Figure A.2. World map of country clusters based on fossil fuel dependence, renewable energy growth, and GHG intensity. Transition leaders are in blue, Diversifying economies in orange, and Fossil-dependent economies in green. Grey indicates countries with insufficient data for classification.

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