



**The Coalition
of Finance Ministers
for Climate Action**

A new modeling approach combining bottom-up sectoral analyses with top-down macroeconomic models to understand the economic impacts of resilient and low-emissions development

World Bank

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A contribution to the 'Compendium of Practice from a Global Community of Ministries of Finance and Leading Organizations: Economic analysis and modeling tools to assist Ministries of Finance in driving green and resilient transitions'

Topic: Addressing the climate policy questions facing Ministries of Finance: the economic and fiscal impacts the green transition

June 2025

Access the full Compendium at www.greenandresilienteconomics.org

This contribution was prepared at the request of, and with guidance from, the Ministry of Finance of Denmark as Lead of the Coalition's Helsinki Principle 4 initiative 'Economic Analysis for Green and Resilient Transitions' and its Steering Group, with input from its Technical Advisory Group. The views, findings, interpretations, and conclusions expressed are those of the authors. While many Coalition members and partners may support the general thrust of the arguments, findings, and recommendations made in this contribution, it does not necessarily reflect the views of the Coalition, its members, or the affiliations of the authors, nor does it represent an endorsement of any of the views expressed herein by any individual member of the Coalition.

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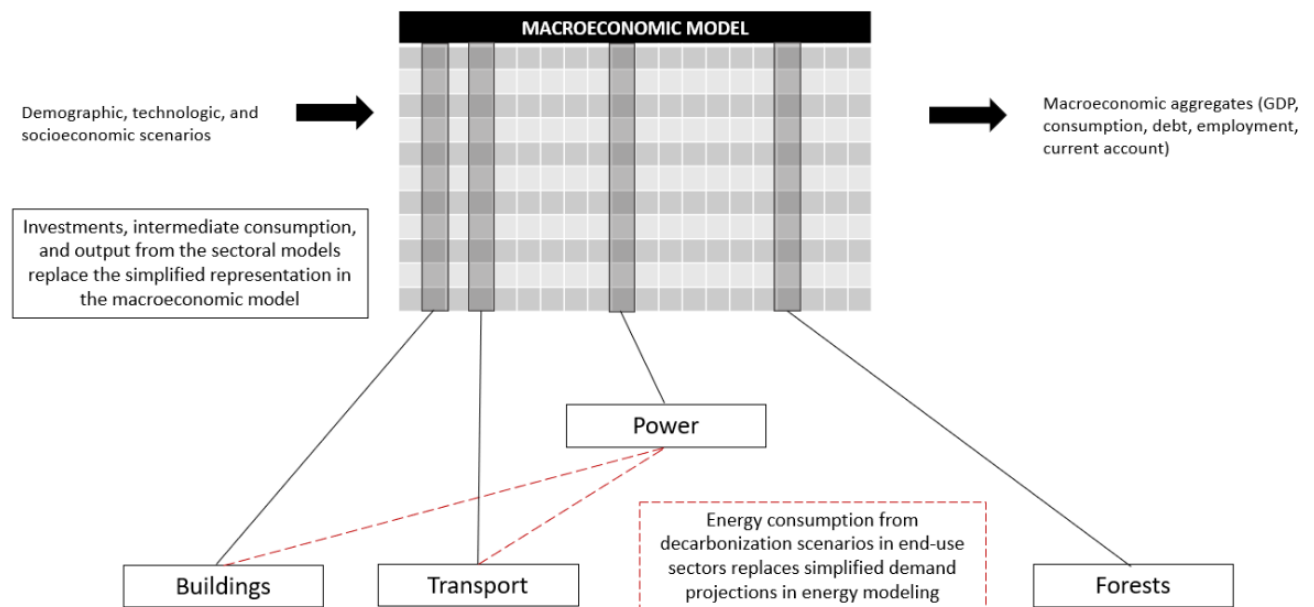
This note provides a high-level overview of a hybrid modeling approach used to explore the economic impacts of resilient and low-emissions development pathways in the World Bank Group (WBG) Country Climate and Development Reports. The approach combines granular insights from sector-level analyses with the consistency and general equilibrium dimensions of macroeconomic models. In practice, the analysis starts from low-emission pathways for selected sectors—for example, power, transportation, industry, buildings—that describe the changes in supply and demand, productive capital, and technologies, as well as required investments and associated economic costs and benefits. These investments, costs, and benefits are then fed into macroeconomic models to explore the feasibility of the scenarios as well as implications for growth and other macroeconomic variables. Ministries of Finance would be able to benefit from the advantages of each of these two types of models to answer questions related to, for example, available technology options (using technology-explicit bottom-up analyses from the sectoral models) and the economic impact of various climate policy options (leveraging the ability of the sectoral models to represent nonprice policies in the macroeconomic framework).

The hybrid modeling approach

There are multiple challenges associated with modeling the macroeconomic implications of resilient and low-emission development pathways, including those related to the nonmarginal nature of the required transformation, the role of technologies, and the replacement of fossil fuel-based assets with greener ones. To address some of these challenges, the WBG Country Climate and Development Reports (CCDRs) have adopted a hybrid modeling approach that combines a set of sectoral analyses with macroeconomic models (Figure 1). Specifically, sectoral techno-economic models are employed to construct resilient and low-emission development trajectories in key sectors. The macroeconomic implications of these sectoral transitions are then assessed by linking the sectoral models with one or several macroeconomic models. Not all CCDRs have followed the same methodological approach: the tools and methodologies have been tailored to the country context and differences in data availability. However, the approach across CCDRs is similar in nature, in that it aims to combine granular insight from sector-level analysis (e.g., the power sector or hydrological modeling) with the consistency and general equilibrium dimensions of macroeconomic modeling.

The hybrid approach combines the advantages of multiple tools and captures the various dimensions of the transition, including the granularity needed to capture the sectoral transitions and the macroeconomic consistency needed to assess feasibility and costs. This approach allows the WBG to tackle multiple market failures, beyond the emissions externality; to analyze price and nonprice policies and their interactions; to highlight economic trade-offs from mitigation policies; to represent explicitly the replacement of assets and infrastructure; to identify positive and negative spillovers across sectors; and to assess the macroeconomic feasibility of the sectoral transitions and the required investments.

Figure 1. Integration of sector-level and macroeconomic analyses



Source: Hallegatte et al. (2024), based on Türkiye CCDD Background Note 6

Conceptually, the hybrid modeling approach is based on four ideas:

- **Capturing the complexity of the transition without losing transparency and interpretability.** Constructing a single integrated model that combines all the required dimensions and mechanisms leads to increasing complexity that makes results less transparent and more difficult to interpret. To improve transparency and tractability, the hybrid approach uses a set of connected tools, with outputs of sectoral models used as inputs into macroeconomic models. Such an approach benefits from the advantages of each of these two types of models. Specifically, sectoral models have a granular representation of technologies and the capital stock (e.g., the building stock or the fleet of vehicles), while macroeconomic models impose macroeconomic consistency and represent the behaviors of economic agents.
- **Focusing on the costs and benefits of plausible scenarios without being overly prescriptive about what an optimal pathway looks like.** To avoid applying a value judgment on what constitutes an optimal development pathway, the hybrid approach explores the implications of plausible but illustrative resilient and low-emissions pathways in key sectors, consistent with each country's own climate objectives. This is a move away from the usual intertemporal cost-benefit analysis of balancing transition and physical risks through a well-coordinated price mechanism, for which the discount rate (see, for example, Pindyck, 2013) and the calibration of the damage function play a key role. While the long-term costs of climate change are expected to be significant, their estimation is the subject of active academic debate. Consequently, analyses based on their estimates are subject to high uncertainty. The approach adopted by CCDDs instead relies on illustrative, but plausible, pathways to explore their feasibility, costs, and benefits consistent with each country's own climate and development targets. More analysis would be needed to settle on the best possible path, best distribution of action across sectors, and preferred policies and investments.
- **Capturing the complexity and diversity of climate policies, not just the impact of carbon pricing.** Instead of representing climate policies as an equivalent carbon price—the policy that is easiest to include in macroeconomic models—a hybrid approach is better able to consider nonprice interventions such as direct investments, norms and regulations, and

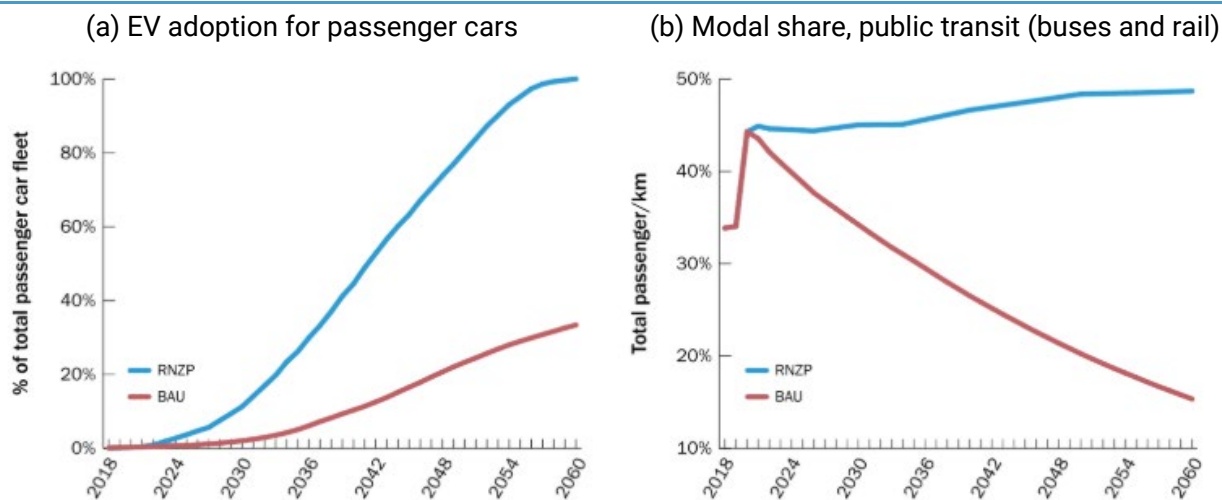
subsidies. A transportation model is, for example, well suited to represent nonprice policies such as the impact of performance standards or infrastructure investments.

- **Capturing all market and governance failures, including—but not limited to—the climate externality.** A hybrid approach is well suited to consider the many market failures that act as barriers to an efficient and smooth decarbonization process but also create opportunities for short-term synergies between climate and development policies. While macroeconomic models can easily represent the effect of distortive tax systems, it is more challenging to capture the effects of inadequate regulations or monopolistic behaviors that prevent some high-productivity lower-emissions technologies from entering the market. Sectoral models, on the other hand, are better placed to account for a broader range of market imperfections, for example, by using a baseline in power system modeling that does not minimize electricity production cost.

Case study: Türkiye

Hallegatte et al. (2024) illustrate the hybrid approach in an application to Türkiye. A resilient and net zero pathway was designed to achieve net zero emissions by 2053, in line with the country’s net zero commitment. The pathway was constructed using a variety of individual sectoral technoeconomic models for key emitting sectors (power, transportation, buildings, and forest landscapes) and more simplified roadmaps for industry and agriculture. As an example, the resilient and net zero pathway in the transportation sector differs from the baseline with a combination of modal shift, energy efficiency, and electrification, all of which also affect the total energy consumption in the country, the energy mix used in transportation, and the energy costs for households and firms as well as imports (Figure 2).

Figure 2. Illustrative technological roadmaps for the transportation sector, Türkiye



Note: RNZP = resilient and net zero pathway; BAU = business as usual.

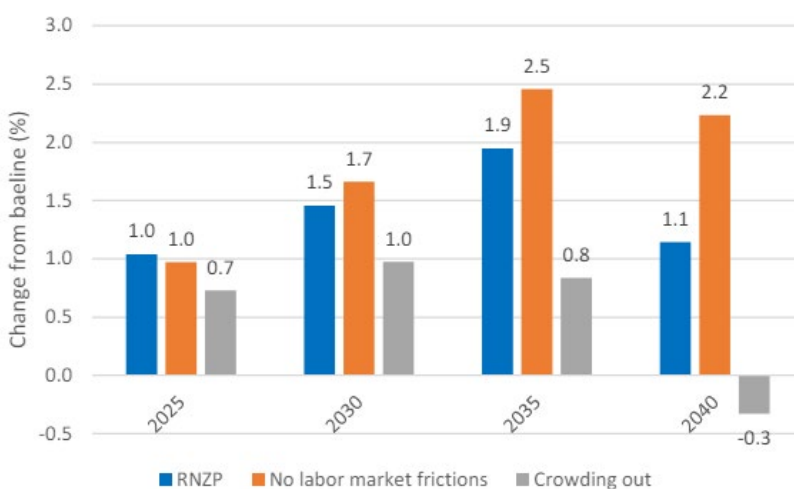
Source: World Bank Group (2022)

The sectoral pathways are linked to two macroeconomic models, in this case the World Bank’s single-country computable general equilibrium model, MANAGE, and the World Bank’s aggregate macrofiscal model, MFMod. To incorporate the sectoral scenarios in the MANAGE model, technology parameters are recalibrated to force the model to be consistent with the sectoral roadmaps while maintaining its internal consistency. To capture the cost of the transition, additional investment needs and economic costs and benefits identified in the sectoral scenarios are introduced in both macroeconomic models. The MANAGE model is then used to determine the equilibrium along the decarbonization path that will lead to slightly different results at the sectoral level, after

macroeconomic effects such as cross-sectoral effects are considered, and MFMod is used to account for aggregate price and wage rigidities when determining the fiscal and economic consequences of the transition.¹

Macroeconomic modeling shows that the resilient and low-emissions pathway would contribute positively to Türkiye’s economic growth, despite the large redirection of investment needed, especially if co-benefits are considered and if labor market frictions can be reduced. Different scenarios were explored to (i) assess the influence of macroeconomic assumptions and policy (labor market frictions and renewable energy subsidies) in unlocking the economic potential of the resilient and net zero pathway and (ii) identify transition trade-offs (carbon taxes and crowding out) or co-benefits (linked to reduced air pollution). Figure 3 shows that the growth benefits depend critically on how the investments needed for the transition are financed. If the investments needed to implement climate measures divert funds from other investments (i.e., they crowd out investments in the rest of the economy), the benefits are significantly reduced in the short to medium term and can become negative in the long term. For MoFs, this finding underscores the importance of deploying scarce resources strategically through suitable financial instruments that address sectoral barriers and can help leverage additional financing from other sources, such as the private sector.

Figure 3. GDP impact in selected scenarios (relative to the baseline), Türkiye



Note: RNZP = resilient and net zero pathway.

Source: Hallegatte et al. (2024)

A hybrid modeling approach is well placed to inform MoFs on the climate transition and help bring together perspectives across ministries and agencies into a consistent and integrated strategy. One benefit of the hybrid approach is that line ministries (in energy, transportation, agriculture, etc.) can develop their own detailed strategies, policies, and pathways using the technical models for their own sector. The sectoral models can capture and represent the nonprice policies that are typically implemented by the agencies in charge of various sectors. From an MoF perspective, however, these pathways are difficult to appraise and finance, as their consistency is not ensured. The hybrid approach can help by combining the different sectoral policies and pathways into a consistent macroeconomic framework, making it possible for MoFs to play their role in managing trade-offs across sectors and optimizing the sequencing of interventions, and developing consistent economywide strategies that account for economic and financial feasibility constraints.

¹ See also separate Compendium contributions from the World Bank: i) World Bank: World Bank Group climate aware macroeconomic models available for use by Ministries of Finance; ii) MFMod-CC: country-specific macrostructural models; iii) MANAGE-WB: a recursive-dynamic CGE model.

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