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# The EU's Energy Transition: Investment Impact and Role of Carbon Pricing Revenue Recycling

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**Prepared by Benjamin Carton, Geoffroy Dolphin, Romain Duval, Andrew Hodge, Amit Kara, Simon Voigts, Sebastian Wende**

Authorized for distribution by Kristina Kostial and Rafael Portillo
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**ABSTRACT:** The EU has ambitious goals for climate and energy security. Its targets and policies may have large macroeconomic implications, but investment impacts are particularly uncertain. Detailed "bottom-up" approaches based on sectoral calculations point to investment increases of 2 to 3 percent of GDP annually, while "top down" general equilibrium models often yield negligible aggregate investment effects. Further, the investment and broader macroeconomic impacts of the EU's energy transition will depend on how carbon pricing revenues are recycled. This paper addresses these issues using a modeling technique that bridges bottom-up and top-down approaches. A New Keynesian general equilibrium model (GMMET) is extended to feature a detailed representation of energy use in key emitting sectors, including buildings, transport and energy-intensive manufacturing. Simulations suggest that achieving the EU's 2035 climate goals implies an increase in aggregate annual investment of just around 1 percent of GDP. More broadly, the EU's energy transition only has modest macroeconomic impacts if it combines carbon pricing and green subsidies, partly because these are complementary—green subsidies lower energy prices and inflation and raise output, carbon pricing has opposite effects, and therefore combining both yields small effects on all accounts. The fiscal cost of the transition is modest provided decarbonization relies sufficiently on carbon pricing; while revenues from ETS1 and ETS2 could eventually reach about 1 percent of GDP, the public investment cost of the transition is less than 0.5 percent of GDP annually, leaving net fiscal space that could be used for other policy objectives.


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WORKING PAPERS

# The EU's Energy Transition: Investment Impact and Role of Carbon Pricing Revenue Recycling

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# I. Introduction

**The European Union's (EU) ambitious climate and energy security goals will have material macroeconomic implications, including for investment, energy prices and competitiveness.** The EU has multiple climate-related targets and policy instruments, anchored around a 'Fit for 55' agenda that aims to reduce EU emissions by 55 percent below 1990 levels by 2030 (Annex 1). An amplification of this agenda between 2030 and 2040 is planned; the European Parliament and member states have recently provisionally approved a binding 90 percent cut—still vis-à-vis 1990 levels—by 2040, while the European Council has also endorsed an interim 2035 target range of 66.25–72.5 percent. There is broad consensus that meeting the 2030 and future 2040 objectives will require sizeable new investment to decarbonize key emitting sectors such as electricity, transport, buildings and energy-intensive manufacturing industries (see e.g. Andersson and others, 2025; European Commission, 2023; IEA, 2024).

**However, existing estimates of these macroeconomic implications vary considerably between so-called "bottom-up" and "top-down" approaches**. While the former put the effect of the EU's energy transition on aggregate investment at over 2 and even 3 percent of GDP annually over the next ten to fifteen years (Calipel and others, 2025; IRENA, 2025; and for France, Pisani-Ferry and Mahfouz, 2023), the latter find it to be negligible or even negative (e.g. Coenen and others, 2024). While some technical issues are sometimes at play—for example, most bottom-up studies focus on "gross" green investment while top-down ones focus on green investment "net" of the decline in brown and other investment—there are also fundamental reasons behind this gap. "Bottom-up" approaches use detailed information on sectors and technologies to compute, and then aggregate up, the investments needed to achieve specific decarbonization objectives. They may range from advanced accounting approaches to more sophisticated engineering-economic assessments, but all of them share a partial equilibrium framework. They thereby fail to adequately capture some general equilibrium forces through which climate action may *reduce* other investment, such as lower aggregate demand due to higher prices, reduced use of—and thereby of investment in—fossil fuels (or even of broader energy), or shifts in demand away from carbon-intensive goods and services and the resulting contraction of these sectors. By contrast, "top-down" approaches harness general equilibrium (GE) models that capture aggregate resource constraints, but this typically comes at the cost of the representations of energy use and key technologies for emission mitigation being less detailed than in bottom-up approaches. These "top-down" approaches tend to yield far more benign investment implications of the energy transition, partly for good reasons such as the practical relevance of broader economic adjustment to climate action beyond decarbonization investments, but also for bad reasons including insufficient detail on the investments needed to abate emissions in key sectors such as building heating and insulation. Lack of detail can cast doubt on the broader insights from "top-down" models regarding the macroeconomic impacts of emission cuts, insofar as "bottom-up" studies provide a more plausible representation of green investment needs.

**The magnitude of EU climate and energy security policies' impacts on investment will critically shape the macroeconomic, fiscal and political economy implications of the EU's energy transition.** Should the investment effects of the EU's energy transition be large, they would significantly impact output, consumption, interest rates, exchange rates and current accounts. They would also entail major fiscal implications, given that a material share of total investment needs likely involves public investment (Eble and others, 2025; European Investment Bank, 2021; Mahfouz and Pisani-Ferry, 2023). Gauging this fiscal cost of the transition is critical given limited fiscal space in many EU countries. Finally, they could have first-order, albeit complex, political economy implications for the EU's climate and energy security policies. While large potential—particularly public—investment needs could motivate some member countries to call for a more gradual climate policy approach, they have also been put forward as an argument in favor of urgent action alongside new institutional initiatives such as greater EU-level funding and EU fiscal framework adjustments (Pisani-Ferry and Tagliapietra, 2024). Likewise, the smaller the energy price and broader competitiveness effects of the EU's energy transition are, the more likely it may be that EU policymakers will opt for larger emission cuts.

**The investment and broader implications of the EU's energy transition will also depend critically on how future revenues from carbon pricing are recycled.** The planned gradual tightening of the EU ETS1 emissions cap, phasing out of free ETS1 allowances, and introduction of ETS2 will build fiscal space whose magnitude should be quantified, and then compared to the public investment costs of the transition to assess its overall fiscal impact. Using any net fiscal gains to cut distortive taxes, such as those on labor, could enhance the output—and thereby investment—effects of the EU's climate and energy security policies. If a sizeable portion of revenues were instead to be recycled into green subsidies, decarbonization investments may rise further, and the impact on aggregate investment would depend on how the broader economy is affected.

**The goal of this paper is to provide greater confidence about the (private and public) investment impact of the EU's energy transition, shed new light on its broader macroeconomic implications, and analyze how these may vary depending on the EU's chosen mix of climate policy instruments.** To this end, the paper reconciles "bottom-up" and "top-down" studies by taking the best of them—namely, by bringing the detailed insights on sectoral abatement from the former (notably as regards electricity, buildings, transport and energy-intensive manufacturing industries (EIIs)) into the general equilibrium (GE) framework of the latter. We expand GMMET, a global New Keynesian macro-economic model featuring several regions (including the euro area) and sectors including detailed ones related to the generation and use of energy (Carton and others, 2023; IMF, 2022). This allows us not only to reassess the investment impacts of the EU's climate and energy security policies but also their broader macro effects on output, consumption, interest rates, exchange rates and current account dynamics. Finally, this framework also enables us to simulate alternative climate policy mixes (e.g. degrees of reliance on carbon pricing vs green subsidies), demonstrating their critical influence on the macroeconomic, fiscal and energy price impacts of the EU's energy transition.

**The analysis finds that a policy mix combining expanded carbon pricing and partial recycling of revenues into green subsidies would lead the EU to meet its climate and energy security objectives at little to no net fiscal cost, and with moderate implications for aggregate investment and the broader economy**. Specifically:

- **The EU's energy transition is projected to have a sizeable impact on *green* investment but a smaller one on aggregate investment**. The set of policies that deliver on both the current 2030 emission target and an illustrative but plausible 2035 target—result in an increase in green investment of around 1.6 percentage points of GDP annually at its peak and averaging 1.3 percentage points of GDP during 2026-2035 (2.2 trillion euros in cumulative terms). However, because higher green investment partly substitutes for lower other—particularly brown—aggregate investment rises by just 1.2 percentage points of GDP at its peak (1 percentage point of GDP on average). This figure falls roughly in the middle of those of existing "bottom-up" and "top-down" estimates—below the former because we capture the broader adjustment of the economy to policy action including substitution effects, but above the latter because our granular modeling of key sectors yields sizeable green investment costs.

- **The policy mix shapes these investment responses and their effects on energy prices.** The greater the reliance on green subsidies, the larger the increases in both green and aggregate investment are, all else equal. For example, compared to a hypothetical scenario in which the EU's emission goals are fully met by expanding the scope and allowance price levels of its emission trading schemes and the associated revenues are fully rebated to households, the peak response in aggregate investment increases by about a quarter (0.3 percentage points) if about two-thirds of carbon pricing revenues are instead recycled—two-thirds of which into subsidies to renewables and the other third split equally between subsidies to electric vehicles (EVs), building insulation and electricity-based heating (heat pumps). Likewise, in the latter scenario, electricity prices are found to rise only modestly—by some 5 percent by 2035, or about 0.5 percent per year.[1]

- **The EU's energy transition is found to have modest macroeconomic implications for demand, prices, interest rates and exchange rates, for a policy mix that combines carbon pricing, green subsidies and labor tax reductions.** Higher carbon pricing raises inflation and reduces output in the short term, as well as real incomes, consumption and—because the exchange rate appreciates in expectation of a reduced long-run fossil fuel imports bill—exports, with higher investment more than offsetting these effects after two years—from 2028. Even if the central bank looks through the direct impact of higher carbon prices on headline inflation, this creates some short-term output-inflation trade-off, leading the central bank to ease monetary policy only slightly in the specific simulations run in this paper. When added to the policy mix, well-designed green subsidies mitigate the output-inflation trade-off by containing the rise in energy prices and inflation while supporting investment and growth.

- **The net fiscal cost of the energy transition also appears to be modest provided a fraction of future carbon pricing revenues is used to fund public investment needs.** For example, assuming an illustrative 40 percent public share in aggregate investment needs—broadly in line with recent data and EU policy debates, the EU's energy transition would imply an increase in average annual public investment of up to 0.4 percentage points of GDP (0.5 percentage points of GDP at the peak), depending again on the policy mix—with larger fiscal costs the heavier the reliance on subsidies vis-à-vis carbon pricing. Such public funding needs would be just about half of the projected increase in carbon pricing revenues—which could reach about 1 percent of GDP.

- **Large future carbon pricing revenues offer an opportunity to address market failures (e.g. in innovation and deployment) and reduce existing distortions (e.g. to labor and capital).** At the same time, alternative revenue uses entail trade-offs between growth, energy price, energy security, fiscal and income distribution goals. For example, among recycling alternatives, well-designed green subsidies and labor tax cuts both reduce the fiscal gains and improve the growth impact of the energy transition—the former mitigate the required increase in carbon prices and foster capital accumulation, while the latter increase employment, respectively. However, green subsidies put downward pressure on electricity prices and thus entail larger energy security benefits, while lower labor taxes directly support workers' incomes and can be designed to benefit predominantly lower-income households as needed.

[1] Electricity prices are reduced by the accelerated deployment of renewables, but this decline is offset by higher costs of residual fossil-fuel-based (e.g. coal) electricity, the need for gas-fired power plants subject to carbon pricing as backup—at least for now, and green subsidies (e.g. to electric vehicles) that speed up electrification. The larger the rise in renewables subsidies, the larger is the drop in electricity prices, all else equal.

**The paper makes three main contributions to the literature.** First, it bridges the gap between "bottom-up" and "top-down" studies. GMMET includes a granular description of key sectors, whose investment needs for given emission abatement are calibrated consistently with results of bottom-up models. The model has a rich characterization of Europe's energy sector, with features such as the costs of electrification, heating and insulation of buildings, and abatement in energy-intensive manufacturing. At the same time, we capture these rich sectoral details in a general equilibrium setting, which avoids the pitfalls of partial equilibrium analysis. Second, we estimate jointly green investment by sector and the broader macro-fiscal impact. This is one of very few papers studying the medium-term implications of climate policy in a New Keynesian general equilibrium setting. Third, thanks to granular modeling of policies, it characterizes how results depend on the policy mix. We analyze a range of options for revenue recycling and show that these can significantly shape macroeconomic outcomes.

**Our approach has some limitations.** Some emission reduction measures in the sectors covered by EU emission trading schemes (ETS1 and ETS2) are not modeled (e.g. car emission regulations), while climate policy in sectors beyond the scope of ETS1 and ETS2 is not considered—including mitigation efforts in agriculture and those relating to non-CO2 gases. Some investment needs in the energy sector, such as for interconnectors, are not explicitly modeled, although any impact on the aggregate investment needs of the EU's fit-for-55 agenda would likely be very small as discussed further below. Furthermore, we do not consider some potential benefits of lower electricity prices, such as to support R&D and technological change.

**The paper is organized as follows.** Section II reviews the main investment needs of the EU's energy transition, discusses existing studies and highlights key sources of variation across available estimates. Section III briefly describes the extended GMMET model and its baseline calibration, presents our simulation results, and discusses the split between private and public investment needs. Section IV concludes.

# II. Previous Estimates of Investment Costs and Sources of Heterogeneity

**Existing estimates of green and aggregate investment needs from the EU's Fit-for-55 agenda differ dramatically across studies, ranging from negligible amounts to 3 percent of GDP per year.**[2] The dispersion in estimates reflects a variety of factors. This paper seeks to address a fundamental source of heterogeneity, namely the difference between "top-down" and "bottom-up" studies, but it should first be acknowledged that existing studies also differ on other grounds including:

- **Investment concept.** Required green investment will partially replace investment in other types of capital, dampening the overall increase in aggregate investment. As noted above, top-down studies typically account for these effects and thus estimate "net" aggregate investment needs. Others, such as Calipel and others (2025), focus on "gross" green investment needs, while yet others like International

[2] Additional investment associated with a given reduction in annual emissions is conceptually related to (cumulated) aggregate marginal abatement costs (MACs), but there are key differences. For example, investment costs for reaching a long-term mitigation target naturally consider that "green" capital yields long-lasting emission benefits, which is not typically the case for static MAC measures. There are also differences in the scope of both concepts, with MACs capturing costs beyond capital expenditure for green equipment, such as for example a potential loss in production efficiency when moving to less carbon-intensive processes. Another difference is the fact that, in contrast to typical MAC estimates, investment costs are influenced by general-equilibrium feedback effects from mitigation policy.

Energy Agency (2024) report the increase in green investment after netting out the decline in brown investment but not the change in other (neither green nor brown) investment. Some bottom-up studies may include EV purchases in their investment estimates, while EVs are recorded as consumption in national accounts—and thereby in some top-down models that rely on national account concepts.

- **Measurement of investment costs.** Studies differ in how they account for costs. For example, some studies such as Calipel and others (2025) include the full cost of an electric car, while others such as International Energy Agency (2024) only consider the cost of the battery.

- **Sectoral and geographical coverage.** Differences in which sectors are included in the analysis contribute to the wide range of investment cost estimates. Further, the Pisani-Ferry and Mahfouz (2023) study is specific to France, whereas the other studies listed in Table 1 relate to the EU.

- **Magnitude of emission cuts.** Estimates of investment needs depend on the magnitude of targeted emission reductions with respect to baseline, which differs across studies. All else equal, larger emission reductions imply larger investments.

- **Policy mix.** In studies that run mitigation scenarios, different combinations of mitigation instruments—such as carbon pricing vs subsidies vs regulation—can significantly affect the total level and allocation of investment across technologies and sectors. For example, Varga and others (2022) find that a mitigation policy centered around regulation has a larger negative impact on GDP and investment compared to one that relies on carbon pricing with revenue recycling into investment subsidies.

- **Recycling of carbon pricing revenues.** The previous point also illustrates the potential relevance of how carbon pricing revenues are used. Recycling them in ways that directly (e.g. investment subsidies) or indirectly (e.g. distortive tax cuts) stimulate investment may result in larger increases in aggregate investment, all else equal.

**Categorizing frameworks into bottom-up and top-down approaches provides a powerful lens to understand differences between estimated investment needs**. Bottom-up approaches harness detailed technological analysis of specific technologies and their potential for emission reductions, which are then aggregated without taking into account interactions with the broader economy. Bottom-up studies can use *sectoral calculations*, where the costs of lowering emissions are methodically tallied up, or alternatively can be based on detailed *energy system-type* models. Top-down approaches, in contrast, are typically general equilibrium models where sectors that play a key role for emission mitigation are represented in a highly stylized fashion and with sectoral decarbonization investment substantially below those in bottom-up studies. Some of these studies have a more disaggregated sectoral presentation and focus on the long term *(Computable General Equilibrium (CGE) studies)* while others have more of an economy-wide macroeconomic focus and concentrate on short- and medium-term dynamics *(Dynamic General Equilibrium (DGE) studies)*.

**Before turning to methodological differences between bottom-up and top-down approaches, we establish that decarbonization investment estimates from bottom-up approaches tend to be substantially larger than those from most top-down models.** This can be seen in Table [1], which provides a standardized comparison of the following studies that either explicitly estimate the investment required to meet the EU's Fit-for-55 climate targets, or present a related exercise.

- **Bottom-up approaches** (left of the table). One of the most well-known studies using *sectoral calculations* is that of Pisani-Ferry and Mahfouz (2023), which finds that additional investments of over 2 percentage points of GDP every year during the next decade are required to meet France's 2030 targets and be on track for net zero by 2050. Calipel and others (2025) finds that additional investment of a similar magnitude is required during 2025-30 relative to 2023 levels for the EU to achieve its 2030 targets. IRENA (2025) finds additional "green" investment needs of approximately 1 percent of GDP annually over 2025-2050 to achieve its 'Decarbonized Energy Scenario', relative to what is required under the 'Planned Energy Scenario'. A further benchmark is offered by the Draghi report (Draghi, 2024, not shown in the table) which, based on European Commission studies, puts investment requirements in the region at around 2.5 percent of GDP (about EUR 450 billion) annually during 2025-30. Among *energy system-type* studies, the IEA's 2024 World Energy Outlook finds a smaller investment need, of around 0.5 percent of GDP per year during 2025-30, to realize its "announced pledges" Scenario, relative to the "stated policy scenario". Another example is the European Commission's 2021 assessment report, which finds additional investment of around 0.6 percent of GDP per year until 2030 is required for the EU to achieve its Fit-for-55 targets.

- **Top-down approaches** (right of the table) generally yield much smaller—or even negative—aggregate investment cost estimates. Among *CGE studies,* OECD (2023) finds a negligible change in investment, in a scenario achieving the Fit-for-55 targets, where one-third of carbon tax revenues are recycled into investment in the grid and two-thirds to fund home renovation and the purchase of electric vehicles. Also in a Fit-for-55 scenario, Weitzel and others (2023) find a small total investment cost of 0.2 percent of baseline GDP. Turning to *DGE studies*, an analysis by Varga and others (2022) at the European Commission finds only a 0.2 percentage point increase in total investment, assuming that carbon tax revenues are recycled as subsidies for purchasing clean capital goods. Coenen and others (2024), using an extended version of the ECB's New Area-Wide (DSGE) Model, estimate that, under a smaller emission decline, total investment would fall by 0.4 percent relative to the baseline after five years, in a scenario where carbon tax revenues are both rebated to households as lump-sum transfers and used as subsidies for green energy.

**Normalized investment costs point to qualitatively similar, albeit quantitatively smaller, differences across existing studies.** One key insight from Table 1 is that the bottom-up studies yield investment needs of the EU's energy transition that are substantially larger than in most top-down analyses, which tend to suggest a very small investment impact on average. To control for variation in the magnitude of the assumed mitigation effort across studies (which may result from different baselines for the same absolute emission targets), the last row of Table 1 reports annual investment per tCO2e of abated emissions for all studies for which such ratio could be computed. In many cases, computing this metric requires making additional assumptions, which creates some uncertainty around the resulting figures that should be borne in mind when interpreting them. Bearing this caveat in mind, most bottom-up studies find total investment costs of around EUR 500 per tCO2e abated, including Pisani-Ferry and Mahfouz (2023) for total investment and IRENA (2025), the European Commission's 2021 assessment and IEA (2024) for green investment. Calipel and others (2025) finds larger green investment costs, of EUR 650 per tCO2e abated, relative to a constant emissions baseline. For the top-down studies, the standardized investment costs are mostly much smaller. They are around EUR 100 of total investment per tCO2e abated in Weitzel and others (2023) and Varga and others (2022), and are negligible in OECD (2023) and Coenen and others (2024). In addition to delivering small aggregate investment responses to mitigation policy action, existing top-down studies also tend to deliver modest green investment responses—in other words, the small aggregate investment response is typically not just the general equilibrium outcome of large but offsetting green and brown/other investment responses. Varga and others (2022) stand out among the surveyed studies by reporting larger green investment needs that are more closely in line with those found in bottom-up studies.

## Table 1. Existing Estimates of Investment Needs Implied by the EU's "Fit for 55" Targets

| | **Sectoral Calculations** | | | **Energy system model** | | **Computable General Equilibrium** | | **Dynamic General Equilibrium** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **I4CE: Calipel and others (2025)** | **IRENA (2025)** | **Pisani-Ferry and Mahfouz (2023)** | **EC assessment report (2021)** | **IEA World Energy Outlook (2024)** | **Weitzel and others (2023)** | **OECD (2023)** | **Coenen and others (2024)** | **Varga and others (2022)** | **Carton and others (2026) (this study)** |
| Period | 2025-2030 | 2021-2050 | 2021-2030 | 2021-2030 | 2023-2050 | 2030 | 2020-2035 | 2022-2037 | 2020-2050 | 2026-2036 |
| Baseline | n/a | Planned energy scenario (PES) | No transition | EC reference** | Stated policy scenario (STEPS) | -48%* in '30 | EC reference** | Constant (steady state) | EC reference** | No additional policy from '24 (-30%* in '30) |
| Mitigation target in '30 | Sectoral targets consistent with -55%* | Decarb. scenario (DES) | -55%* | -55%* | Announced pledges scenario (APS) | -55%* | -55%* | -7% of steady state | -52%* (-94%* in '50) | -55%* (only simulated for ETS1 and ETS2 sectors) |
| Additional annual investment | `Avg. '25-'30, euros in 2023:<br>~ €350 bn<br>(**~ 2% GDP**, authors' calc.) above level in '23 | Avg. '25-'50, % of GDP in '21<br>**~ 1% GDP**, green-only (PES to DES) | In '30, % of bsl. GDP:<br>**~ 2.3% GDP** total inv.<br>**~ 3.5% GDP** green-only | Avg. '21-'30, % of bsl. GDP:<br>**~ 0.6% GDP** energy systems inv. (from reference)<br><br>~ 2 rel. to avg. '11-'20 | Avg. '26-'30, USD 2023, MER<br>~ 100 bn (**~0.5% GDP**, staff calc.)<br>(~ 150 bn for APS rel. to avg. '21-'25, staff calc.) | In '30, total inv.:<br>~ 0.8% of bsl. Inv.<br>( **~ 0.2% of bsl. GDP**, staff calc.) | **Negligible** | In '30, % of bsl. GDP:<br>**~ -0.4% GDP** total inv.<br>**~ 0% GDP** green-only (capital services) | In '30, % of bsl. GDP:<br>**~ 0.2% GDP** total inv.<br>**~ 0.3% GDP** electricity-intensive-only<br>(~0.1 and ~1.1 in '50)<br>**~ 0.7% GDP** broad green aggregate | In '30, % of bsl. GDP:<br>**~ 1.3% GDP** total inv.<br>**~ 1.5% GDP** green-only |
| Framework | n/a | Remap, Plexos and Flextool energy system models | n/a | PRIMES and PRIMES-TREMOVE | Global Energy and Climate model | JRC-GEM-E3 (with inputs from PRIMES and POLES-JRC) | OECD ENV-Linkages | ECB's New Area-Wide Model with disaggregated energy production and use | E-QUEST, model with aggregated clean and dirty sectors | GMMET (see model description below) |
| Gross or Net investment | Gross | Net | Net | Net | Net | Net | Net | Net (total inv.) | Net (total inv.) | Net (total inv.) |
| Notes | Sectoral coverage: energy, buildings, transport and clean technologies manufacturing | | This study relates to France only | Scenario: MIX-CP (carbon price driven policy mix). ROW: fragmented action | | Carbon price (CPRICE) scenario (labor tax recycling, switch to auctioning) | Rev. recycling: subsidies. 1/3 grid investment, 2/3 home renovation and EV. | Rev. recycling: Transfers to households and subsidies for clean energy. ROW carbon tax increased by same amount (65 percent) | ROW: ambition unchanged<br><br>Rev. recycling: Subsidies for 'clean capital' | Rev. recycling: Subsidies for green investment & labor tax cuts |
| | | | | | **Authors' Calculations** | | | | | |
| Effort in 2030 (in MMT) | ~ 220 extrapolating hist.'19 – '23<br>~ 500 assuming constant '23 | ~ 150 | ~ 150 (France only) | ~ 450 | ~ 200 avg. '26-'30 | ~ 300 | ~ 300 avg.'23-'30 | ~ 220 | ~300 | ~700 |
| **Additional annual investment per mitigated $tCO_2Eq$** (euros/tCO2e standardized for comparison) | ~ 1500 green-only extrapolating hist.'19 – '23<br><br>~ 650 green-only assuming constant '23 | ~550 green-only on avg. '25-'50 | ~500 total inv.<br>~800 green-only year '30 | ~ 500 green only inv. on avg. '21-'30 | ~ 500 green-only | ~ 100 total inv. year '30 | Negligible | Neg. total inv.<br>~ 20 green-only year '30 | ~100 total inv.<br>~200 electricity-intensive-only<br>~ 500 broad green aggregate year '30 | ~400 total inv.<br>~450 green-only year '30 |

* Emission reduction expressed as a share of 1990 emissions.
** The EC reference scenario fixes 2020 policies but considers macroeconomic, demographic and technological trends. In this scenario, emissions in 2030 are about 43% below their 1990 level.
Notes for authors' calculations: Most studies provide emissions in both a baseline and a policy scenario, making the 2030 mitigation effort readily available. For studies that instead compare investment to achieve a given target with historical investment, the calculation requires assuming a baseline for 2030 emissions. The calculation of the "standardized" statistic of investment per mitigated emissions also requires nominal investment spending, which in some cases requires making additional assumptions. As a result, the values provided in this table are inherently uncertain. The following assumptions were made: **Calipel and others (2025)** compare additional investment to its 2023 value. Calculations are reported for two assumptions about how emissions evolve if investment remained at its 2023 level: (i) constant, and (ii) declining according to a linear extrapolation of the 2019-2023 trajectory. **IRENA (2025)** readily provides investment and emission for two scenarios. **Pisani-Ferry and Mahfouz (2023)** report the emission decline associated with the estimated additional spending. **EC assessment report (2021)** provides the additional average investment (from 2021 to 2030) needed to reach the target (in the MIX-CP scenario) starting from the reference baseline scenario. To compute the associated average emission reduction, we assume that over the same period, emissions in the policy scenario decline linearly below the reference scenario so that the target is achieved in 2030. **IEA World Energy Outlook (2024)** reports investment and emissions under two long-term scenarios up to 2050. As a crude approximation, we read the 2026-2030 averages from the provided charts and compare them. **Weitzel and others (2023)** show investment response in 2030 in the policy scenario, which is converted into an output share with additional data provide by the authors. **OECD (2023)** readily provides investment costs. Table 4 of OECD (2023) reports emissions in 2030 vs 1990 levels in the Fit-for-55 and reference scenarios. We compute emissions effort as the average difference between the reference and Fit-for-55 emissions paths during 2023-30, each of which is calculated as a linear interpolation from 2023 (when Fit-for-55 was formally adopted) and 2030. **Coenen and others (2024)** do not report additional investment as a share of output, requiring additional assumptions. Relatively low investment costs are in line with their focus on the energy sector. **Varga and others (2022)**: simulate a long-term 2050 NZE scenario. 10-year effects were kindly provided by the authors. "Electricity-intensive" investment goods exclude sectors, such as building insulation, that count towards "green" investment in GMMET. To compare aggregates that are more closely related, the statistic is also computed for additional investment aggregates from Varga and others (2022) and from GMMET simulations. For Varga and others (2022), a broad measure of "green" investment including electricity-intensive investment goods and consumer durables, as well as in power generation and clean-technology producing sectors yields about 500 euro per mitigated tCO2e in 2030. For GMMET, an investment aggregate that counts EV purchases as "green" investment leads to a value of around 700.

**Differences in the size of decarbonization and aggregate investment costs between bottom-up and top-down studies can be explained by the equilibrium concept and by the degree of detail in sectors that play a key role for emission mitigation**. Bottom-up approaches typically feature a high degree of sectoral technological detail but do not capture general equilibrium effects. Top-down approaches, on the other hand, capture general equilibrium but typically feature a highly simplified representation of "green" sectors, which tends to imply substantially lower sectoral decarbonization investment needs.

- **"Bottom-up" approaches focus on detailed technological and sectoral analysis, assessing specific technologies and their potential for emission reductions.** This includes studies based on sectoral calculations, such as Pisani-Ferry and Mahfouz (2023), as well as more formal models of the energy sector, such as the European Commission's 2021 assessment. These linear programming models hail from the engineering literature and identify the cheapest way to generate a desired amount of energy, given a detailed model of the available technology.[3] These models can be used to evaluate the investment costs of particular mitigation measures which, once aggregated across all key sectors, yield an estimate of the overall investment impact of a given set of (sectoral and aggregate) emission targets. As such, bottom-up studies can provide highly reliable insights on the green investment needs of the energy transition. However, these approaches typically fail to capture all available margins of adjustment in response to mitigation policy, such as the possibility for firms to optimize input choices across a broad portfolio of more or less emission-intensive ("brown" vs "green") options, and the possibility for households to substitute greener goods and services for browner ones. As a result, they are likely to be less suited for the quantification of the aggregate investment impacts of the energy transition. More broadly, bottom-up approaches do not capture all economy-wide interactions and general equilibrium effects—such as those on aggregate output, saving, investment and interest rates. The combination of greater technological detail and partial equilibrium nature of bottom-up approaches tends to deliver sizeable investment impacts of mitigation policies.

- **"Top-down" models instead prioritize breadth of coverage and the general equilibrium linkages between different sectors of the entire economy, making them particularly useful for assessing the macroeconomic effects of mitigation policy.** For example, they typically capture the negative consequences of a mitigation-policy-induced green investment push for other investment through at least the following channels: i) lower fossil fuel investments in the energy sector; ii) lower demand for, and thereby investment in, brown goods and services as the demand for green ones rises; iii) the feedback effects from changes in aggregate output and interest rates on investment—including any contractionary short-term impact of mitigation policy on aggregate investment, for example. However, these advantages of top-down models come at the cost of a simplified representation of energy production and use across the economy, including green and brown technological options and the costs of substituting across them. Of potential concern is the much smaller green investment numbers they tend to deliver compared to bottom-up studies, given the latter's comparative advantage on this front. For example, either the buildings sector is not singled out or, when it is, abatement is typically modeled in simplified form as a (constant-elasticity) substitution between green(er) and brown(er) fuels, while in practice dedicated investments in heat pumps and building insulation are required to decarbonize this sector. Taken together, the general equilibrium structure of, and simplified representation of energy in top-down models tend to yield modest—and sometimes even negative—aggregate investment effects of

[3] Prominent examples of "bottom-up" models include IIASA's MESSAGE and European Commission's energy systems optimization model (PRIMES), and The International Energy Agency's (IEA) GEC model that combines detailed bottom-up energy sector models for 27 regions.

emission reduction policies.[4]

**Investment per abated ton of CO2eq emissions in GMMET falls closer to bottom-up studies—yielding a combination of the "best of both worlds", namely a general equilibrium framework as in top-down studies, whose detailed representation of key "green" sectors is broadly consistent with bottom-up ones.** The version of GMMET in this paper introduces additional detail to the modelling of "green" sectors—including building heating and insulation and energy-efficiency investments in energy-intensive manufacturing industries—where the sectoral investment response associated with a given decarbonization is closer to magnitudes found in bottom-up studies (see the standardized comparison in the final row of Table 1). At the same time, falling into the top-down category, GMMET captures general equilibrium effects that limit the amount of additional *aggregate* decarbonization investment implied by the improved modelling detail in the key sectors, due to offsetting effects such as crowding-out of investment in emission-intensive sectors. Hence, the combination of greater detail in key "green" sectors with general equilibrium effects implies a smaller response of aggregate investment to mitigation policies compared to bottom-up studies (where the crowding-out of "brown" investment is typically not covered, for example), but a larger response compared to most existing top-down studies (where low sectoral detail contributes to substantially lower sectoral decarbonization investments compared to bottom-up studies). Indeed, GMMET simulations below will imply additional aggregate investment of about EUR 400 per abated tCO2e, significantly above the small figures found in top-down analyses but below the EUR 500 per abated tCO2e figure implied by several bottom-up studies.

# III. Model-Based Analysis

## III.1. Modeling approach

**The model used for analysis in this paper blends the "top down" general equilibrium approach with a more detailed "bottom-up" characterization of the energy sector.** It is an extended version of the IMF's Global Macroeconomic Model for the Energy Transition (GMMET) (Carton and others, 2023).[5] This set-up fuses together a multi-country, structural model of the macroeconomy, with a detailed representation of energy generation and use, all fully endogenous and in general equilibrium. Instead of using aggregates of "green" and "brown" goods, the framework explicitly models key sectors including power, tradables (e.g., manufactured goods), as well as transport and heating of buildings, making it well-suited to study the impacts of abatement policies in key emitting sectors, including the EU ETS1 and ETS2 emissions trading schemes. The modeling approach of GMMET's novel sectors that play a key role in emission mitigation (as e.g. electricity generation, fossil fuel mining, transportation, or the building sector) is motivated by sector-specific bottom-up studies, which also inform the respective sector's calibration.

**The macroeconomic core of the model builds upon a standard New Keynesian framework with a neoclassical long run.** It is based on the Global Integrated Monetary and Fiscal Model (GIMF) (Kumhof and

[4] Examples of "top-down" models used in policy institutions include Computable General Equilibrium (CGE) models like IMF's IMF-ENV, OECD's ENV-Linkages and the World Bank's ENVISAGE, as well as Dynamic General Equilibrium (DGE) models more suitable for short-term analysis such as the European Commission's E-Quest, Eurosystem's C-EAGLE, ECB's NAWM-E, Deutsche Bundesbank's EMUSe, Bank for International Settlements' BIS-MS, Banco Central de Chile's SEEM, and the IMF's GMMET. CGE models may incorporate feedback effects from climate onto the economy, in which case they become Integrated Assessment Models (IAMs), prominent examples of which include DICE (Nordhaus, 2014), FUND (Anthoff and Tol, 2013), and REMIND (Aboumahboub and others, 2021).

[5] This model is also used in a forthcoming Network for Greening the Financial System (NGFS) report. Investment effects significantly differ between the two studies because the NGFS report considers a different (simple carbon price) policy scenario and assumes coordinated international action that reduces global demand in the short term.

others, 2010), a micro-founded, multi-country, multi-sector DSGE model used by the IMF for dynamic policy and scenario analysis. While the model has multiple regions with detailed trade linkages between them, the focus in this paper is on the euro area—which accounts for about 85 percent of the EU economy—factoring in the global general equilibrium effects of EU climate policy scenarios through trade and financial linkages. Fiscal policy in the model is non-Ricardian, and can stimulate economic activity in the short run, while crowding out public investment in the longer term. This reflects the presence of Overlapping Generations (OLG) households, which have a finite forward-planning horizon. Monetary policy targets stable inflation over time and follows an inflation-forecast-based interest rate rule. Monetary policy can have real effects in the short run, thanks to nominal rigidities that make prices and wages sticky. There are also real adjustment costs, including for investment and labor hiring, that slow the adjustment of the capital stock and employment to shocks and make key impulse responses of the model realistic and in line with existing empirical evidence.[6]

**The novelty of the set-up in the context of this paper is that it now also includes detailed modeling of almost all key emission-generating sectors, informed by bottom-up studies (see Annex II for more details).** The model includes an energy sector with various fossil-fuel based (oil, coal, gas) and clean sources of electricity generation (wind, solar, hydro), as well as nuclear energy. Fossil fuels (coal, oil and gas) are tradable and can be obtained from mining where reserves exist. The need for renewables to have a fossil-fuel backup, given intermittency of supply, is explicitly accounted for. Fossil fuels and electricity are inputs into intermediate goods production, while energy is also a final good consumed directly by households. The intermediate goods in the model include both energy-intensive and regular tradables (manufacturing) sectors. In these sectors, an energy-efficient capital good can substitute for energy, which is one way that investment can be part of the green transition. The model also contains a transportation sector and a heating sector. Energy is an input into the transportation sector, where Internal Combustion Engine (ICE) vehicles run on oil fuels while electric vehicles (EVs) run on electricity. The model also explicitly models network externalities between EV adoption and charging station deployment. The heating sector warms both commercial and residential buildings, generating heat from gas furnaces or heat pumps. Building insulation can substitute for heating services. Compared to Carton and others (2023), the key improvements of the model relate to the detailed modeling of the heating and energy-intensive non-manufacturing sectors, with calibration informed by bottom-up studies in each case. Agriculture is the only large emitting sector that is not modeled in detail in GMMET and ignored here.

**The model has a rich set of fiscal instruments that can be used to simulate different climate policy packages.** In terms of climate policy, the model allows for pricing (taxation) of all sources of carbon emissions. Revenues raised from carbon pricing can be "recycled" back into the economy, either by reducing other taxes (on consumption, labor or capital), providing subsidies, or rebating them to households in lump-sum fashion. Subsidies can be offered to incentivize the use of clean energy either directly in particular sectors, or indirectly by encouraging the uptake of electric vehicles and heat pumps.

**Depending on the policy mix, emissions are reduced in the model by substituting away from fossil fuels and fossil-fuel-intensive goods and services, as well as by making green investments and scaling down brown ones.** "Brown" capital investments in the model are made in the mining sector for fossil fuels (coal, oil and gas), fossil-fuel-based (coal and gas) electricity generation, gas furnaces in the heating sector, and the ICE vehicle fleet of the transportation sector—although technically vehicles are durable goods purchases and, as such, are not counted as investment in the simulation exercises. "Green" investments include those needed for generation of renewable energy—including in the energy grid, as well as those in building insulation, electric

[6] Featuring a broad set of frictions and forward-looking agents makes GMMET suitable for the analysis of short-term macroeconomic dynamics. This is a key difference with respect to computable general equilibrium (CGE) models, which are typically static or dynamic but solved in a recursive manner that prohibits forward-looking decision making.

heating (heat pumps), and energy-efficient capital in the energy-efficient and other tradables sectors. In the transport sector, the new purchases of EVs are tracked and add to the existing fleet of emission-free vehicles.

## III.2. "No additional policy" baseline assumptions and projections

**The simulations consider policy-induced emissions reduction relative to a "no additional policy" baseline.** This baseline captures what the trajectory of emissions would be like if mitigation policies were kept exactly as they are currently. In order to construct this baseline, a sectoral approach is adopted. For sectors covered by ETS1, it is assumed that the allowance cap remains frozen at current levels, so that emissions are unchanged at 2024 levels in the baseline over the ten years to 2035. For ETS2 sectors, a different approach is taken for the transport and buildings sectors respectively. Baseline emissions from heating of buildings are projected using a linear extrapolation of historical data (last 10 years), which implies a 23 percent reduction in emissions during 2026-35. In the transport sector, emissions from passenger vehicles are forecast taking into account the projected uptake of EVs in Europe under current policies (IMF, 2025). For non-passenger vehicles, we project baseline emissions through a linear extrapolation of past data. The net result is a 23 percent baseline emissions decline between 2025 and 2035 in the transport sector as a whole. In sectors not covered by ETS1 or ETS2, we again project baseline emissions using a linear extrapolation of past trends. In the simulations, however, we only consider policy action in ETS1 and ETS2 sectors which together account for about three-quarters of total GHG emissions. The implicit, but not explicitly modeled assumption is that complementary policy action in other sectors, including agriculture, will be taken to achieve the EU's aggregate targets.[7]

## III.3. Policy scenarios

**All the policy packages in the simulations are calibrated to meet the existing 2030 and preliminary 2035 targets for emission reduction.** In November 2025, the Council of the European Union (the Council) reached agreement on a new 2040 target of 90 percent reduction in net GHG emissions vis-à-vis 1990 levels—later provisionally approved by the European Parliament and member states—and also approved an updated Nationally Determined Contribution (NDC) of the EU and its member states. This updated NDC reiterated the EU's goal of cutting its GHG emissions by 55 percent by 2030 and introduced an indicative contribution of between 66.25 percent and 72.5 percent for 2035 (both compared to 1990 levels). Therefore, for the simulations in this paper, the 2035 target is assumed to be a 69 percent emissions reduction below 1990 levels, which is about the mid-point of the reported range for the 2035 NDC. The 69 percent absolute reduction in aggregate emissions relative to 1990 levels translates into a 44 percent reduction of emissions *relative* to the projected baseline emissions in 2035. For the corresponding 2035 sector-specific ETS1 and ETS2 targets, it is necessary to make assumptions. Although official targets exist for 2030 that we explicitly consider in our policy simulations, they have not yet been set under each ETS for 2035. We set them in the following illustrative way. First, the official targets are used for 2030; a 62 percent by 2030 relative to 2005 for ETS1 sectors and 42 percent by 2030 for ETS2 sectors—for clarity, we do not factor in the European Commission's plans to use the ETS 2 Market Stability Reserve to stabilize allowance prices around €45–55 per ton of $CO_2$ in the early years of the scheme, since this policy is not necessarily consistent with meeting the 2030 ETS2 target and its future beyond the first few years of ETS2 implementation is unknown. Between 2030 and 2035, we then assume that the targeted percentage reduction in emissions in ETS2 is twice that in ETS1, to reflect the greater potential to reduce

[7] Specifically, in the policy scenarios described below, these non-modeled residual emissions would need to fall by 45 percent vis-à-vis a simple baseline projection based on a linear extrapolation of past trends.

emissions in those sectors that have not previously been subject to a carbon price. Given this assumption, the 2035 target for ETS1 is a 47 percent reduction in emissions below the baseline, while for ETS2 it is 40 percent.[8]

**In all simulations, the ETS1 and ETS2 carbon prices are increased over time to meet their respective emission reduction targets.** This means carbon prices vary between ETS1 and ETS2 sectors to meet respective targets. Carbon prices increase by about $200 per ton (expressed in today's prices, i.e. in "real" terms) by 2030 and rise further afterwards to meet their respective targets (Figure 1). Further, the increase in ETS1 carbon prices begins immediately, while ETS2 is assumed to come into force only in 2028, which is fully anticipated by households—who also anticipate how revenues will be recycled. The allocation of free ETS1 emissions allowances is gradually phased out over 2026-2034, in line with current EU plans, while there are no free allowances in ETS2. The EU's CBAM is phased in as currently legislated. It is assumed to cover the direct (scope 1) emissions of all CBAM products as well as some indirect (scope 2 and 3) emissions of those products, as specified in the CBAM regulation. The CBAM is modeled in simplified fashion as a charge on the imports of energy-intensive tradable goods, which is computed based on the detailed data on carbon intensity at country-sector level used in Dolphin and Ferrucci (2025).

**A range of simulations assess the implications of achieving the EU's climate targets for the macroeconomy and illustrate how these depend on the policy mix.** The only dimension along which the simulations differ is the way in which revenues generated by these two trading schemes are used—in particular, the emission targets are identical across all three scenarios discussed below. We consider three main scenarios:

- **The central simulation assumes a policy package of carbon pricing, with revenues recycled into both subsidies for green investment and labor tax cuts.** In this simulation Two-thirds of carbon pricing revenues are assumed to be used for "green subsidies" and the other third for cuts in labor taxation. Two-thirds of the subsidies, in turn, are allocated to renewable energy capital, while the remaining third is split equally between EVs, insulation and electricity-based heating (heat pumps). While illustrative, these recycling assumptions are broadly consistent in spirit with the EU and its member states' current approach, which combines carbon pricing and direct support to clean energy and green production.

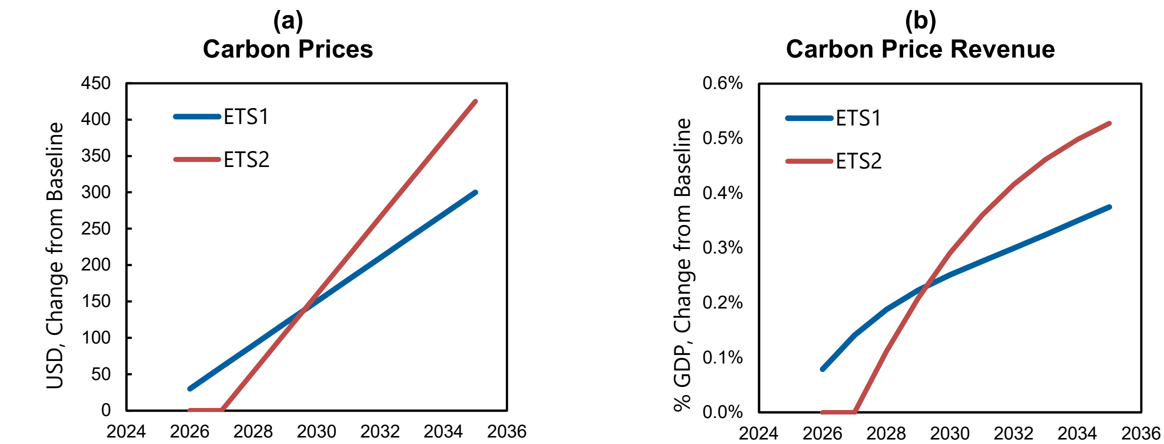
- **An alternative simulation uses all carbon pricing revenues to fund a cut in labor taxation.** This is similar to the central scenario, except that all revenues raised are offset by labor tax cuts, with none of the revenue spent on "green subsidies". This involves a re-balancing of the tax system from labor taxation to carbon pricing, which can illustrate the potential economic benefits of using carbon pricing revenues for labor-supply-friendly—and more broadly growth-friendly—tax cuts. In practice, they could also be designed in such a way as to be progressive and benefit those at the lower end of the income distribution the most, although this is not captured by the model. It should nonetheless be acknowledged that, given high debt, rising interest costs and large future spending pressures in many EU countries, including those related to population ageing, using carbon pricing revenue in full for offsetting tax cuts is unlikely to be feasible. Instead, at least some of the additional revenue raised by carbon pricing may be needed to shore up EU countries' fiscal positions. Furthermore, the decarbonization of the economy by 2050 will ultimately shrink the base for carbon taxation, making the recycling of carbon pricing revenue an unsuitable substitute for broad-based labor or income taxation.

[8] To identify the investment and broader macroeconomic impacts of the EU's own climate policy, all scenarios assume that climate policies in the rest of the world remain unchanged over the simulation horizon.

- **The third illustrative simulation assumes that the EU's targets are met through carbon pricing alone, with all revenue recycled into lump-sum transfers to households.** The primary aim of this simulation is to isolate the impact of carbon pricing, by recycling all revenues raised to households without any allocative effects. While this policy is not realistic, it is a valuable exercise since it abstracts from the impact of subsidies and labor tax cuts on economic incentives and resource allocation, which can and does meaningfully impact the results.

**The carbon price required to meet emission reduction targets depends on the policy mix.** That is, green investment subsidies generally lower emissions and thereby reduce the carbon price required to meet a particular emission target.

**Figure 1. Central Scenario: Carbon Prices and Revenues**




Source: authors' calculations.

## III.4. Results

### *Central Scenario*

**There is a significant peak increase in green investment of about 1.6 percentage points of GDP to achieve the EU's emission goals (Figure 2).** Green investment is incentivized by the increase in both ETS1 and ETS2 carbon prices, as well by the subsidies, which are funded out of the 1 percent of GDP of additional revenue raised from ETS1 and ETS2 by 2035—a quadrupling compared with current levels—and assumed to be provided at a constant rate.[9] Annual green investment over 2026-2035 is about 1.3 percentage points above its baseline level: it rises by almost 1.5 percentage points of GDP by 2030 and peaks at about 1.6 percentage points of GDP by 2032 before declining slightly afterwards. It is primarily propelled by additional investments in renewable energy generation and buildings insulation, which more quadruple and double, respectively. Both are incentivized by the sharp rise in ETS1 and ETS2 permit prices, respectively, with investment in renewables also stimulated by the large assumed subsidies and higher investment in buildings insulation also reflecting the sizeable investment need per ton of abated CO2 in this sector (see Annex II and, for example, Pisani-Ferry and

[9] ETS revenue was around ¼ percent of EU GDP in 2023.

Mahfouz, 2023).[10] Investment in energy-efficient capital in energy-intensive tradable sectors also rises by over 50 percent above baseline. Subsidies also support an increase in EV uptake, with the share of EVs rising by some 15 percentage points above baseline by 2030, and by over 30 percentage points by 2035—bearing in mind that technically EVs are durable goods purchases rather than green investments. As investment rises and green capital stocks are accumulated, the need for further increases in investment wanes despite continued increases in carbon prices; the overall green investment response to the simulated policy package peaks at about 1.6 percentage points of GDP above baseline in 2031 before falling to 1.4 percentage points of GDP by 2035.[11]

**Brown investment declines by over 0.4 percentage points of GDP, such that the aggregate investment response to the policy package peaks at just about 1.2 percentage points of GDP.** Almost one third of the additional green investment is offset by a steady reduction in brown investment, of 0.3 percentage points of GDP on average during 2026-2035 and over 0.4 percentage points by 2035. This includes a decline in gas heating investment of more than 80 percent, the discontinuation of remaining investment in oil and gas extraction, and a drop of over 8 percent in investment in energy-intensive tradable sectors. Accompanying these changes is a sharp decline in (already low) fossil fuel mining, e.g. in coal. Although brown investment declines on a net basis, investment in gas electricity generation increases by over 40 percent over 2026-2030, since this is an important backup source of energy generation, to support intermittently available renewable energy. Other investment—neither green nor brown, in non-tradables and non-energy intensive tradables—stays close to its baseline level.

**The higher green investment offsets weaker net exports and lifts economic output.** Output initially falls slightly below the baseline in the central scenario, as the anticipation of a reduced fossil fuel imports bill in the long term (once the economy is significantly decarbonized) leads to a real exchange rate appreciation that weighs on exports, which fall by 2.5 percent. This effect is quickly outweighed by higher total investment, which rises by almost one percentage point of GDP after five years (about 5 percent above baseline). Real GDP increases by almost 0.2 percent on a net basis, notwithstanding a small decline in consumption. This medium-term increase in GDP from an ambitious climate policy package featuring a steep rise in carbon prices reflects ultimately two forces: (i) a rise in net—green minus brown and other—investment, which translates into higher GDP—albeit not in higher consumption; (ii) higher labor supply and employment from the assumed recycling of one-third of carbon pricing revenues into labor tax cuts.

**Electricity prices rise only modestly, as the expansion of cheap renewables offsets the inflationary impact of ETS1 price increases.** Higher ETS1 carbon prices lift the cost of electricity by just 5 percent above baseline by 2035, or about half a percentage point per year. To put such increase in perspective, despite their decline since their sharp rise during 2021-22, average pre-tax household electricity prices in the EU and the euro area remained about 60 percent above their 2020 level by the first half of 2025. The 5 percent increase in electricity prices reflects a generation mix that still includes a small portion of coal initially, and the higher cost of the gas backup as carbon prices rise. Higher electricity demand from EV adoption and a general expenditure

10 Because of the large investment needs per ton of abated CO2 in buildings insulation, relying more (less) on ETS2 (i.e. setting more stringent targets) vis-a-vis ETS1 in achieving the assumed overall 2035 emissions target would imply larger (smaller) investment costs, all else equal.

11 While we model electricity transmission and distribution, it is an open question whether our analysis fully captures the additional grid capacity and inter-connectors required for the electricity sector to accommodate the simulated rise in renewables—a hotly debated topic in Europe in recent years, and one of the several motivations behind the European Grids package and Energy Highways initiative proposed by the EC in late 2025. At the same time, in our simulations, the rise in renewables is too limited in terms of percentage points of GDP for this issue to materially affect the results. For example, if one euro of extra investment in renewables required 0.6 euro of extra investment in grid capacity—a figure that would be roughly consistent with the IEA 2025 World Energy Investment Report's cost estimates for EU power generation and transmission and distribution costs, respectively—the rise in renewables investment in our central scenario would imply at most a 0.1 percentage point of GDP higher peak increase in electricity grid investment than simulated here.

switching towards electricity in the energy-intensive and other tradable sectors also put upward pressure on electricity prices. However, the overall price increase is contained by the vast subsidies-driven expansion of cheap renewables electricity, whose share in the overall electricity mix rises sharply. Electricity prices could even remain stable if one assumed even higher recycling of carbon pricing revenues into renewables subsidies than assumed in the illustrative central scenario.[12]

**Inflation and interest rate dynamics are largely benign, as the stronger exchange rate helps contain headline inflation.** Headline and core inflation initially fall in the central scenario, given the decline in aggregate demand and the appreciation of the real exchange rate, which lowers import prices. Under the monetary policy rule in the model--where the central bank is assumed to look through the direct impact of mitigation policies by targeting core inflation--monetary policy eases in the first few years. Over time, as investment rises, the economy recovers and so does inflation, which is also subject to upward pressure from higher ETS1 and ETS2 carbon prices—with inflationary pressures being modest in electricity, as noted above, but more significant for other goods and services such as energy-intensive tradables. As a result, monetary policy adjusts and becomes slightly restrictive during the second part of the simulation period.

***Alternative Scenario: Recycling all Carbon Pricing Revenues into Labor Tax Cuts***

**Excluding green subsidies from the climate policy package, and instead recycling revenues fully into labor tax cuts, would result in lower green and overall investment (Figure 3).** In a scenario that recycles ETS1 and ETS2 revenues entirely into labor tax cuts, the peak increase in green and aggregate investment vis-à-vis baseline is about 1.2 and 0.9 percentage points of GDP, respectively—about a quarter (0.3 percentage points of GDP) less than in the central scenario. In particular, without subsidies, investment in renewables rises significantly less (less than doubling rather than quadrupling), resulting in higher energy prices that also depress investment in other sectors due to the complementarity between energy and capital. This is partly offset by the greater stimulative impact for green investment of carbon prices, which now need to be higher—by about $50—than in the central scenario to achieve the emission targets.

**Without green subsidies, real GDP is also marginally weaker and inflation a bit higher, but households gain from the larger labor tax cut.** Compared to the central scenario, the smaller rise in green and aggregate investment translates into slightly lower GDP, while the larger increase in electricity and broader energy prices fosters slightly higher inflation. At the same time, the larger labor income tax cut benefits households, whose consumption rises materially compared to the central scenario. In practice, a recycling strategy based on labor tax cuts could focus on reducing effective marginal tax rates for lower incomes, with a meaningful impact on labor force participation, poverty and income inequality that is not captured in the model.

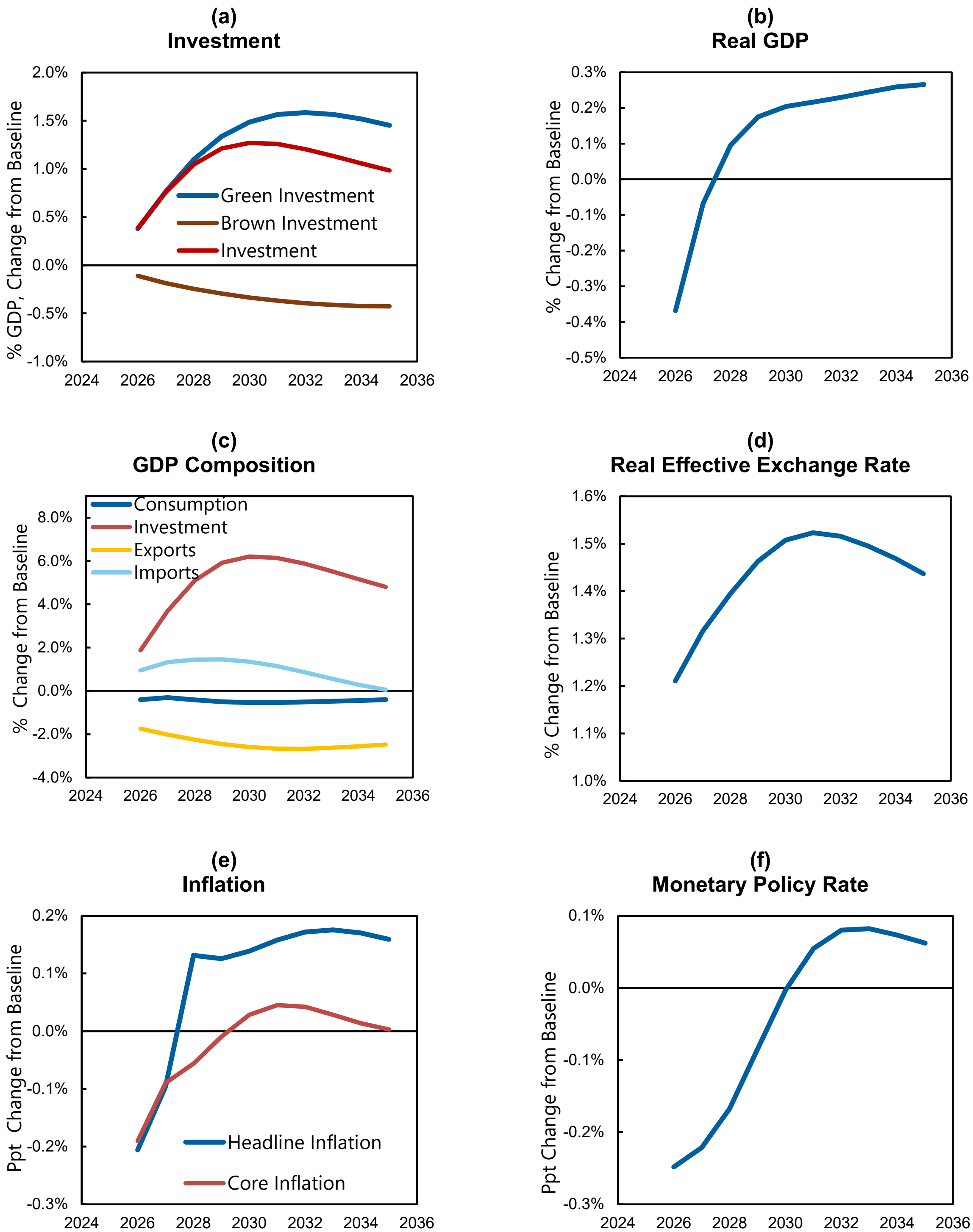
***Illustrative Scenario with Only Carbon Pricing and (Lump-Sum) Transfers to Households***

**More broadly, the simulations show that smart recycling of carbon pricing revenues is key to enhancing the macroeconomic impacts of the EU's energy transition.** Broadly speaking, revenue recycling into green subsidies keeps energy prices low and supports GDP, while revenue recycling into labor tax cuts not only supports GDP but also households' labor supply and consumption. As a result, an illustrative scenario under which revenues are rebated entirely as lump-sum transfers to households (with carbon prices again rising more than in the central scenario) performs more poorly than the central scenario on GDP and energy prices because

[12] Furthermore, our analysis does not factor in the potential impact of the central scenario's policy package on the pace of technological progress and cost reductions in renewable electricity storage, which could significantly lower electricity prices, all else equal.

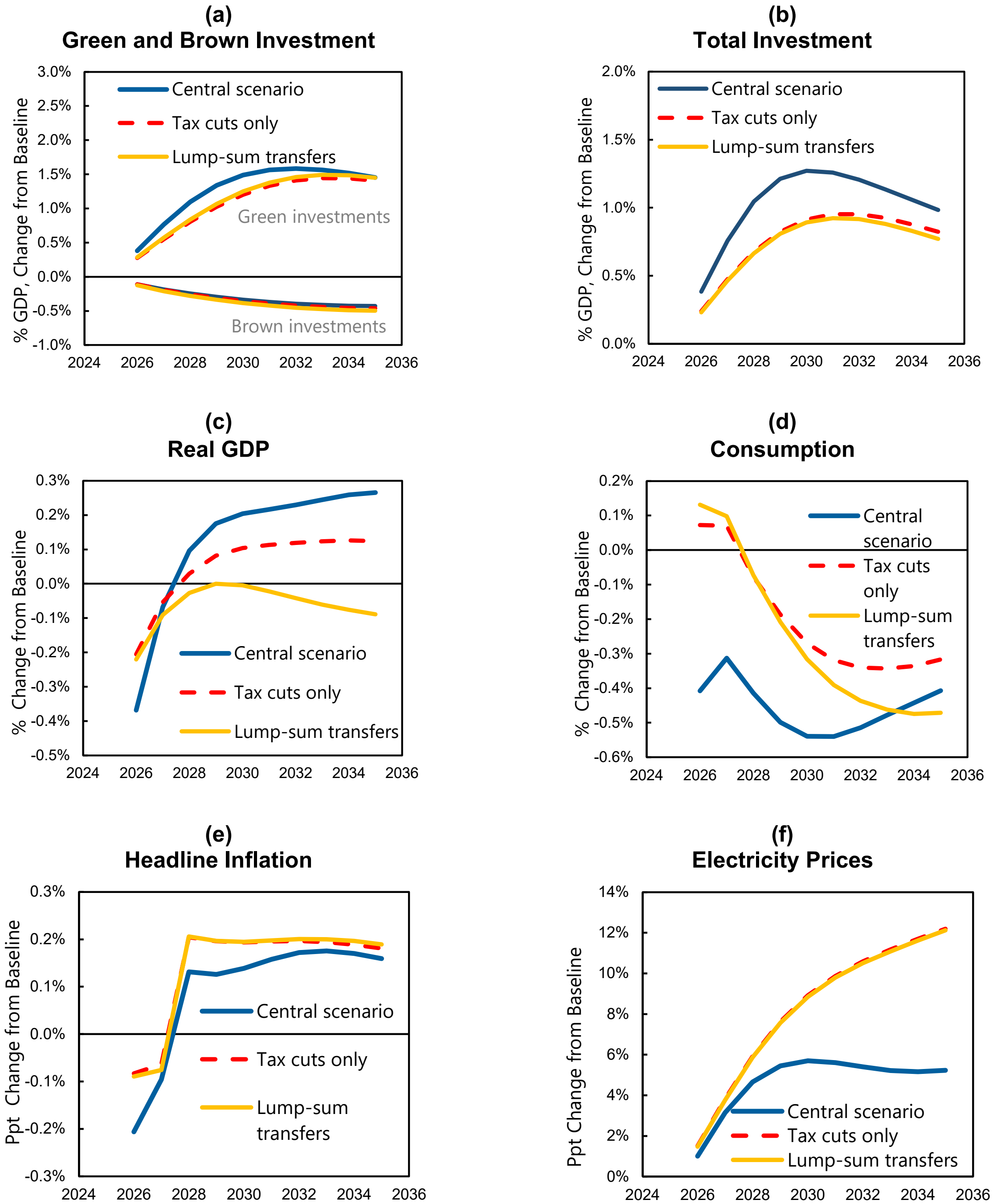
it does not boost renewables capacity as much, and more poorly than the alternative labor tax cut scenario on households' incomes and consumption because it fails to stimulate labor supply. Looking beyond these particular simulation results, the overarching conclusion is that large future carbon pricing revenues offer an opportunity to reduce existing distortions (e.g. to labor and capital) and address market failures (most of which are not captured by GMMET, such as innovation failures) that should not be squandered.

**Figure 2. Central Scenario: Macroeconomic Impacts**




Source: authors' calculations.

**Figure 3. Central versus Alternative Scenarios**




Source: authors' calculations.

### III.5. Public vs private investment implications

**Public financing of investment plays a critical role in addressing areas where private finance alone cannot deliver, but its role ultimately reflects a policy choice**. Public finance is required for two broad purposes:

- *Public support to (mostly private) investment to address market failures*—other than the GHG externality, which in theory can be addressed through carbon pricing alone—that may otherwise impede an efficient energy transition. These include the positive innovation (e.g. in next-generation nuclear), learning-by-doing (e.g. in onshore wind and solar electricity in the past and offshore wind today) and network externalities (e.g. in the installation of charging points and refueling stations) associated with R&D in new green technologies and the deployment of existing ones. In principle, an optimal level of public funding could be inferred from the magnitude of the various R&D and deployment externalities, but these are hard to quantify in practice. As a result, governments face a more practical choice between alternative private and public finance mixes to achieve a given emission reduction objective. To simplify, the more the EU decides to rely on subsidies and other forms of (costly) public support vis-à-vis carbon pricing to achieve its fit-for-55 goals, the greater the role of public finance will be. This choice was captured in the illustrative GMMET simulations of the previous section. In these simulations, public financing of investment need *not* imply investment by the public sector—indeed GMMET considers only aggregate investment and does not explicitly separate public from private components.

- *Public investment to facilitate the energy transition of the public sector itself*. This typically requires public investment, e.g. in renovating public buildings or upgrading public rail networks, electricity grids and inter-connectors. This type of public finance is not directly captured by our simulations.

**Estimates of EU investment that needs to be publicly financed vary from 30 percent to 60 percent across existing studies, depending on both methodology and policy assumptions.** To achieve the 2030 climate goals as set out in EU country-level National Energy and Climate Plans (NECP), Darvas and Wolff (2022) estimate that the public sector will have to contribute around 30 percent of the total investment required. A similar analysis conducted by the European Investment Bank, also based on member state NECP submissions, yields an unweighted public investment share at 45 percent (European Investment Bank, 2021) with a wide variation ranging from 37 percent in Western and Northern Europe to 60 percent in Central and Eastern Europe. In its main scenario, Baccianti (2022) puts the share at 50 percent at the EU level with the largest sectoral share in rail and public transport and buildings. Pisani-Ferry and Mahfouz (2023) offer a similar 50 percent figure for France. Andersson, Köhler-Ulbrich, and Nerlich (2025) estimate that the public sector will have to cover approximately 17 percent of the EU's additional climate-related investment needs from 2021 to 2030, amounting to about EUR 83 billion annually. Likewise, the IEA (2022) suggests that the public investment share may be closer to 20 percent for advanced economies, markedly below the estimates cited above. Factoring in the uncertainty, Pisani-Ferry and Tagliapietra (2024) argue that the public contribution to overall green investment needs may range from 25 to 50 percent; with aggregate investment needs of about 2 percent of GDP to meet the EU's 2030 climate targets, the additional public effort may thus range between 0.5 and 1 percent of GDP over 2025–2030. Against this backdrop, our illustrative assumption of a 40 percent public share lies towards the higher end of the distribution of published estimates.

**Public financing needs are greatest in rail, public transport and buildings, but again depend on policy design.** For example, in the central scenario of Baccianti (2022), which assumes a balanced mix of carbon pricing and subsidies, public spending would cover 45 percent of the annual investment gap in residential and non-residential buildings, and 90-95 percent of the gap for rail and public transport infrastructure. In an alternative low-public-cost scenario, which relies more heavily on carbon pricing and reduces the use of grants and subsidies, the public share drops to 35 percent for buildings and 80 percent for transport. In a high-public-cost scenario, with greater reliance on public funding, the shares rise to 65% for buildings and 100% for transport.

**The additional public financing required to achieve the EU's climate goals would be less than 0.5 percent of GDP in the central GMMET scenario—just half of projected carbon pricing revenues.** GMMET does not distinguish between public and private capital, but an illustrative calculation can be performed using a 40/60 percent split between public and private financing of overall investment needs, based on existing data from the Climate Policy Initiative's Global Landscape of Climate Finance[13] and also broadly in line with studies mentioned above. Under such assumption, the peak impact on aggregate investment of around 0.9 percent of GDP (0.7 percent of GDP on average over 2026-2035) in the model's scenario with full recycling into lump-sum transfers—which is appropriate for such back-of-the-envelope calculation since it does not already include some public financing of investment—would imply a peak increase in public investment of about 0.4 percent of GDP (0.3 percent of GDP on average).[14] Because public support to investment itself may lead to a larger peak impact in aggregate investment—as was the case in the central policy scenario above, a 40/60 split may imply slightly larger public financing needs in practice, of up to 0.5 percent of GDP at the peak (0.4 on average). Such public investment needs would amount to just about half of the projected fiscal revenues from ETS1 and ETS2, leaving space for other growth-friendly recycling (e.g. labor tax cuts) and fiscal consolidation goals.

**Both national and EU budgets will likely have to be mobilized to deliver such additional publicly-funded investment, given that the EU already provides significant public funding through various programs.** The EU provides public funds through the Multiannual Financial Framework, 2021-27 (MFF) and the Next Generation EU (NGEU) program. The Recovery and Resilience Facility (RRF), which is part of NGEU, is the largest program representing over 40 percent of total public funding (of both public and private investments) for the green transition. The Common Agricultural Policy (CAP) and Regional Policy, which are part of MMF, together account for another 36 percent (Andersson, Köhler-Ulbrich, and Nerlich, 2025). These funds primarily consist of grants, subsidies, and tax credits (notably, 43 percent of the climate-related RRF funds are subsidies and tax incentives aimed at firms to promote investments in energy infrastructure, electric vehicles, and energy efficiency). Guarantees and risk-sharing instruments are also used to mobilize private capital. The RRF is available until the end of 2026, after which new mechanisms such as the Social Climate Fund will become operational. The Social Climate Fund aims to mitigate the costs of ETS2's introduction for vulnerable households and micro enterprises.

# IV. Conclusion

**Granular general equilibrium modeling points to a moderate net investment cost of achieving the EU's climate targets—above the very low costs found in most "top-down" studies while below the large ones highlighted by "bottom-up" analyses.** Using a more detailed representation of the energy sector than in most other general equilibrium modeling approaches, and taking into account the need to decarbonize buildings and transport, our modeling implies an average aggregate investment cost of around 1 percent of GDP over the

[13] This estimated public / private split of climate spending in European countries is based on data from 2022 in Climate Policy Initiative (2025).

[14] The calculation implicitly assumes that public investment would account for 40 percent of both green and brown investment needs. To the extent that the public sector's contribution to the fall in brown investment in the central scenario would be less than 40 percent, the overall rise in public investment would be greater than computed here. At most, it would reach about 0.6 percentage points of GDP vis-à-vis baseline at the peak (and 0.5 percentage points of GDP on average over 2026-2035) in the absence of any decline in brown public investment.

coming decade (1.2 percent of GDP at its peak). This is partly because of significant degree of substitutability between "green" and "brown" technologies—lower brown investment is estimated to offset almost one-third of the required 1.2 percent of GDP rise in average green investment (1.6 at its peak). Meeting the EU's climate targets implies that resources shift toward investment in renewable energy generation and transmission, EVs, decarbonization of buildings and other capital that improves the energy efficiency of manufacturing, while moving away from fossil fuel extraction, fossil-fuel-based electricity generation and (gas) heating.

**The simulations also indicate that emission targets are achieved with modest implications for GDP, consumption, electricity prices and inflation when the climate policy mix combines scaled-up carbon pricing and revenue recycling into fiscal incentives for green investment and income tax cuts for households.** This finding is broadly in line with the findings in IMF (2022) regarding global mitigation policies[15]. It is currently planned that the EU ETS1 emission caps[16] will be lowered (alongside phasing in CBAM and phasing out free allowances) and EU ETS2 (covering buildings and transport sectors) will be implemented starting from 2028. Our simulations find that this approach is the cornerstone of a smooth energy transition. So is smart revenue recycling; recycling a material fraction of the large projected increase in the corresponding carbon pricing revenues into green subsidies is found to support investment and GDP, as well as speed up the expansion of renewables supply which is key to keep electricity prices in check. It is also helpful to offset the costs of some of the decarbonization investments for households, such as those of electric heat pumps. In practice, these subsidies could be implemented as a mix of feebates, direct subsidies or tax credits. Recycling a fraction of carbon pricing revenues into labor income tax cuts targeted to lower incomes could also support consumption and alleviate any adverse effects of higher carbon pricing on income inequality.

**Other measures that go beyond the scope of the analysis in this paper will also help minimize the costs and maximize the benefits of Europe's energy transition, such as reducing policy uncertainty and funding European energy-related public goods.** Predictable climate and energy security policies incentivize households and firms to invest early on, thereby alleviating the need for costlier adjustments later on (IMF 2022). The recent adoption of the EU's 2040 emissions target and NDC for 2035 is an important step in this direction, clarifying the scale of the task for climate policy and anchoring expectations about the trajectory of emissions. Clarifying swiftly the accompanying regulatory standards, including by concluding the ongoing review into emissions standards for cars and vans, could also help. So would a more detailed plan for the implementation of the EU's Green Deal Industrial Plan. Additional steps could include carbon price floors or corridors to dampen carbon price fluctuations, which are likely to remain elevated and hamper investment otherwise. There is also a case for accommodating spending on EU public goods related to the energy transition, such as public investments in inter-connectors that entail large economic gains (D'Arcangelo and others, 2026), in the EU's multiannual financial framework or through any alternatives involving joint spending by some or all members of the EU.

**Complementary structural and financial sector policies will also matter, not only for investment but also to ease the frictions to capital and labor reallocation that were ignored in this paper.** These include, among others, a simpler and stronger taxonomy of green investment products, streamlining permitting and planning processes for renewables, investing in skills to smooth the reallocation of workers away from

[15] The policy recommendations discussed in this working paper are consistent with those in official IMF papers.

[16] The EU ETS1 cap is reduced over time according to a linear reduction factor (LRF). The current ETS Directive was revised in 2023 to align the settings of EU ETS 1 with the Fit-for-55 objectives. The LRF was set at 4.3 percent for the period 2024-2027 and 4.4 percent from 2028 onward, and two one-off reductions in the annual cap ('rebasing') were agreed (2024 and 2026). The cap was also adjusted to account for the maritime transport industry being brought within the scope of ETS1. The aviation industry has a separate emissions cap.

contracting jobs towards expanding ones (IMF 2025), and amplifying ongoing efforts to deepen the capital markets union to facilitate access to finance for green investment and capital reallocation more broadly. Finally, as the analysis of green subsidies in this paper confirms, industrial policy can also play a role in supporting the energy transition; however, it should be coordinated among countries at the EU level to alleviate risks of a costly subsidy race (Hodge and others, 2024).

# Annex I. Current EU Policies to Reduce Emissions

**The EU's climate strategy is anchored in its commitment to achieve climate neutrality by 2050, with interim targets for 2030, 2035 and 2040.** These include a legally binding 2030 target of reducing net GHG emissions by at least 55 percent relative to 1990 levels, a new 2040 target of a 90 percent reduction provisionally agreed by the European Parliament and member countries, and another legally binding 2050 goal of full climate neutrality. In addition, in the Fall of 2025 ministers supported an interim 2035 target range of 66.25–72.5 percent, which is not binding for now but aims to anchor expectations. Flexibility mechanisms such as the use of international carbon credits (for up to 5% of the 2040 emission reduction target), emergency brakes, and review clauses have been introduced to accommodate economic shocks, technological and environmental uncertainty, and ensure a balanced implementation pathway

**Table AI. 1. EU Climate Targets Overview**

| Target Year | GHG emission reduction Objective | Legally Binding | Notes |
|---|---|---|---|
| 2030 | ≥55 percent reduction vs. 1990 | Yes | Enshrined in EU Climate Law; part of Fit-for-55 package |
| 2035 | 66.25–72.5 percent reduction vs. 1990 | No | Not legally binding |
| 2040 | 90 percent reduction vs. 1990 (including up to 5 percent through carbon credits) | Yes | The amended EU Climate Law has cleared the trilogue stage |
| 2050 | Climate neutrality | Yes | Legally binding under EU Climate Law; net-zero GHG emissions |

**These overarching goals are operationalized by a suite of sector-specific policies and targets.** The most prominent among these are the two EU ETS carbon pricing schemes ETS 1 and ETS 2. ETS 1, launched in 2005, uses a cap-and-trade design with a declining emissions cap and auctioning. It covers power generation, heavy industry, aviation, and maritime sectors, aiming for 62 percent emissions reduction by 2030 relative to the 2005 level. ETS 2, starting in 2028, will apply a similar cap-and-trade approach to buildings, road transport, and small-scale fuel use, targeting a 42% reduction by 2030. To stabilize prices early on, the European Commission plans to use the ETS 2 Market Stability Reserve, which adjusts the supply of allowances to keep prices near €45–55 per ton of $CO_2$. Additional policies include the Renewable Energy Directive (RED III) that is designed to drive structural change in the energy mix and energy demand across a wide range of sectors, the Effort Sharing Regulation (ESR) which sets binding targets for segments of the transport sector, buildings, agriculture and waste, and the LULUCF framework, which sets targets for carbon removals and emissions from land use. Furthermore, sector-specific standards for cars and vans—including a ban on selling new internal combustion engine (ICE) vehicles by 2035—and buildings ensure that the new capital stock aligns with the climate neutrality goal. A summary of the sector-specific policies and regulations is presented in the table below.

**Table AI.2. Sector-specific Policies and Regulations**

| Policy or Regulation | Target / Objective | Coverage / Sector |
|---|---|---|
| EU ETS 1 | 62 percent emissions reduction by 2030 relative to 2005 levels | Power generation, heavy industry, intra-EU aviation, maritime |
| EU ETS 2 | 42 percent emission reduction by 2030 relative to 2005 levels. Planned implementation starting from 2028. | Buildings, road transport, small-scale fuel use |
| Renewable Energy Directive (RED III) | 42.5 percent share of renewables in final energy consumption by 2030 with an aspirational goal of 45 percent | Electricity, heating/cooling, transport |
| Energy Efficiency Directive (EED) | 11.7 percent reduction in final energy consumption relative to 2020 EU reference scenario projection for 2030 | Cross-sectoral (buildings, transport, industry) |
| Effort Sharing Regulation (ESR) | 40 percent emissions reduction relative to 2005 levels by 2030 | Transport (non-ETS), buildings, agriculture, waste, small industry |
| LULUCF Regulation | 310 Mt $CO_2$-eq net removals across the EU by 2030 | Land use, forestry, carbon sinks |
| $CO_2$ Standards for Cars and Vans | 100 percent reduction in new car and van $CO_2$ emissions (zero-emission vehicles only) by 2035—a target the EC proposed to reduce to 90 percent in December 2025 | Road transport |
| Energy Performance of Buildings Directive (EPBD) | All new buildings zero-emission by 2030; public buildings by 2028 | Residential and non-residential buildings |
| ReFuelEU | Minimum Sustainable Aviation Fuel (SAF) of 2 percent by 2025 rising to 70 percent by 2050; Minimum Synthetic Fuel Share rising from 1.2 percent in 2030 to 35 percent in 2050. | Air transport |

**These policies are designed to complement each other.** In many cases, a policy or regulation applies to multiple sectors, while a given sector is covered by multiple policies and regulations. For example, the buildings sector is simultaneously subject to carbon pricing under ETS 2, the Energy Efficiency Directive, the Effort Sharing Regulation, and the Energy Performance of Buildings Directive. Likewise, road transport is covered by ETS2 and CO2 standards, including the 2035 ICE car ban. This multi-layered approach aims to ensure that market-based incentives and regulatory standards are mutually reinforcing to deliver adequate decarbonization incentives. For example, due the inherent uncertainty about its future coverage and level, especially beyond 2030, carbon pricing alone may not send a clear enough signal in sectors such as buildings and road transport, where investments have long horizons. In such sectors, well-designed regulations can complement carbon pricing and enhance the efficiency of overall mitigation policy.

# Annex II. An Extension of the GMMET Model and its Calibration

GMMET is a large-scale non-linear structural New-Keynesian dynamic general equilibrium model. These types of models are traditionally used for the quantitative short- and medium-term analysis of monetary and fiscal policy and a variety of macroeconomic shocks. GMMET builds on the IMF's workhorse Global Integrated Monetary and Fiscal model (GIMF, see Kumhof and others (2010)). In GMMET, households and firms are forward looking and choose consumption, wage setting, asset holdings, price setting, and investment optimally, considering their preferences and expectations about the future. Nominal and real frictions as well as the explicit modeling of expectations allow the analysis of cyclical fluctuations and stabilization policies.

GMMET significantly extends GIMF to capture various aspects of energy production, trade, and use by various sectors, and their implications for emissions. In the following, we summarize key aspects of the model and refer the reader to Carton et. al. (2023) for a detailed model description. We then turn to the new model features introduced in the present paper to better align the investment response with bottom-up studies, namely energy-efficiency capital and the heating sector.

Key energy-related aspects of GMMET are the following:

- Fossil fuels (oil, fossil gas and coal) mining requires three factors (labor, physical capital and endowment). Their initial shares match revenue shares and their short- and long-run adjustment to fossil fuel prices reproduce empirical estimated supply elasticities. Fossil fuels are internationally traded.

- Electricity is generated from five different technologies varying in their cost structure and emission intensity: Coal, fossil gas, nuclear power, hydroelectric power, and renewables.

- To capture how renewable generation intermittency (uncontrollable weather-related fluctuations) limits deployment of solar and wind generation in the real world, the model assumes this technology is paired with a flexible backup (gas generation). The required backup capacity and generation is derived from a cost-minimization problem that accounts for the variable and fixed costs of both technologies as well as the distribution of weather regimes.

- The model also features a dedicated transportation sector that distinguishes between internal combustion engine cars burning fossil fuel and electric vehicles running on electricity. The sector has stock-flow accounting of vehicle fleets and newly purchased vehicles. It also features an explicit role for charging and fueling stations, capturing network externalities between electric vehicle adoption and the deployment of charging stations.

- Greenhouse gas emissions unrelated to burning fossil fuels are tracked, and the possibility of abating them is accounted for by sector-specific emission abatement technologies—but not exploited in the present paper, which focuses on abatement in ETS1 and ETS2 sectors.

- In the extended version of the model used in this paper, energy-efficiency capital can be deployed to substitute for fossil fuels as input to the production process of energy-intensive tradable goods.

- Also in the extended version of the model, a heating sector provides heating services to households and to the non-tradable goods sector. Heating can be produced from fossil gas and electricity, each combined with fuel-specific capital. Insulation capital can be substituted for heating services, reducing energy demand.

The model features a rich fiscal sector with a variety of fiscal revenues and spending instruments, some of which are used in this paper. To conduct mitigation policy, the government can levy carbon prices and subsidize low-emission technologies, as e.g., renewables electricity capital, EVs, energy-efficiency capital or insulation. It can also impose regulatory measures, not considered here; these would typically be implemented as revenue-neutral tax-subsidy combinations where one or more inputs of a sector are taxed, and the revenues used to subsidize the remaining inputs.

Monetary policy is modelled through a standard policy rule under which the policy rate responds to deviation of inflation from target and the neutral rate to stabilize inflation. Both expected future inflation and past inflation enter the rule so as to achieve interest rate smoothing. In the model version at hand, the relevant inflation measure is core inflation. The latter excludes energy from the consumption basket and offsets fiscal measures that directly affect consumer prices, such as e.g. EV subsidies. As a result, monetary policy looks through the direct impact of mitigation policies on prices. The neutral rate is a smoothed version of the real interest rate, which is in contrast to New-Keynesian models that interpret the neutral rate as the interest rate absent nominal rigidities.

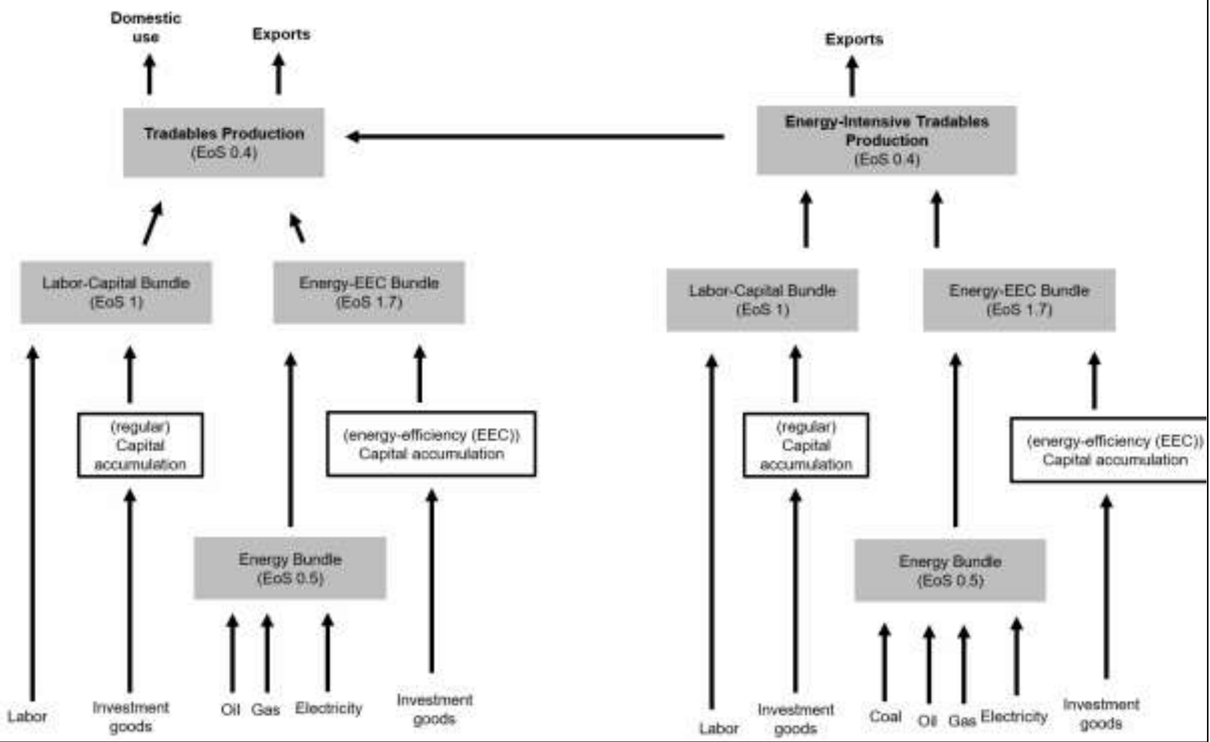
**Energy-efficiency Capital**

In this paper, to highlight the role played by a few large emitting sectors in decarbonization scenarios, the manufacturing sector is split in two: the energy-intensive tradable goods sector (cement, fertilizers, metals) on the one hand, and the tradable goods sector (other manufacturing) on the other hand. In both sectors, emissions reduction is achieved through energy substitution (to less carbon-intensive sources of energy) and energy saving (investing in energy-efficiency capital). In addition, the energy-intensive sector produces an intermediate good used in the tradable good sector. Figure AII.1 illustrates the modeling structure with nested CES aggregators. At the bottom stage, different types of energy are associated within a single energy bundle; at the second stage, the energy bundle is associated with an energy-saving capital stock. The resulting composite of energy and energy-efficiency capital is then used jointly with the capital–labor bundle in production. The approach is proposed by Pehl, Schreyer and Luderer (2023) in the context of the REMIND integrated assessment model for selected industries.

We follow the authors in using calibration value 1.7 for the elasticity of substitution between energy and energy-efficiency capital, while the remaining elasticities are taken from GMMET. The calibration of the initial share of energy-efficiency capital assumes that the share of energy-efficiency capital in the total sectoral capital stock equals the share of energy intermediate consumption in sectoral domestic supply.[1] This yields about a quarter of energy-efficiency capital for the energy-intensive tradable goods sector and half that share for the general tradable goods sector.

[1] This assumption is consistent with the notion that industries with higher shares of energy inputs have concomitantly higher shares of energy-efficiency capital in total capital, reflecting their greater incentive to save on energy costs. In the diagram, taking the energy-intensive tradables sector as an example, the share of “Energy Bundle” in “Energy-Intensive Tradables Production” equals the share of “(EEC) capital accumulation” in the sum of “(EEC) capital accumulation” and “(regular) Capital accumulation”.

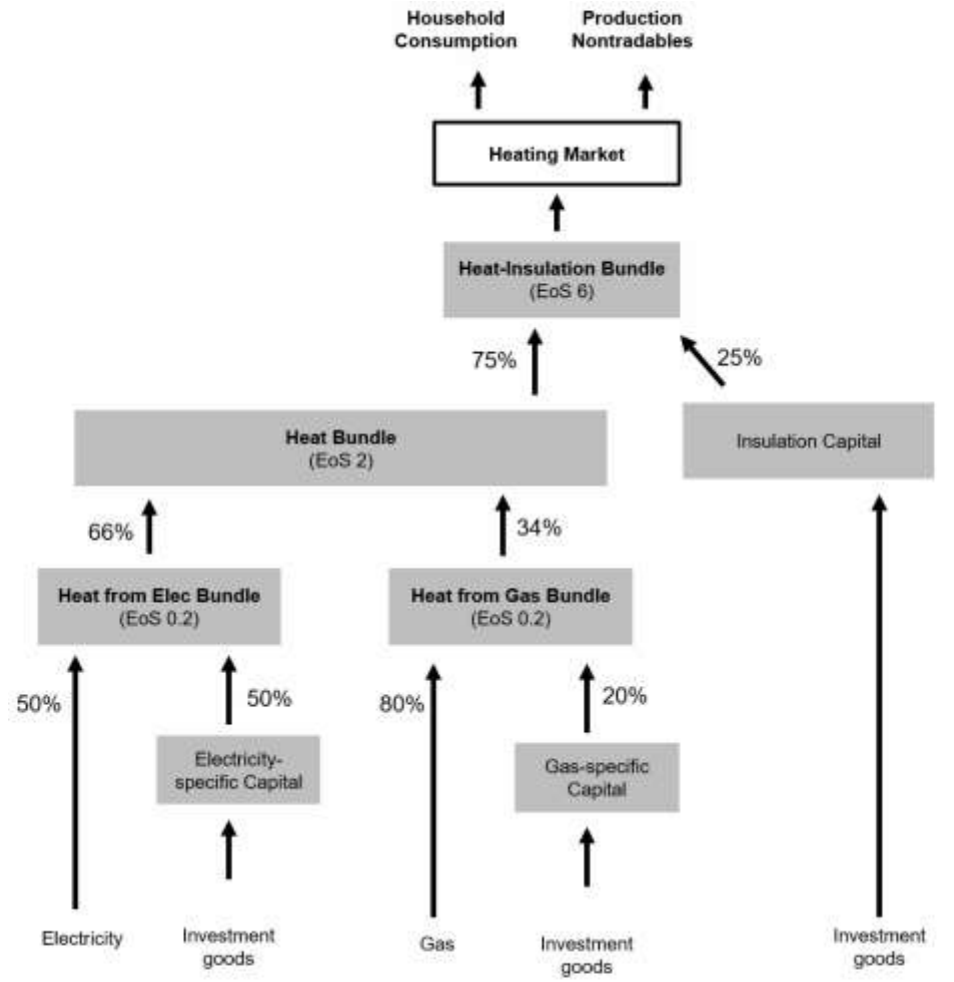
**Figure AII.1. Tradable Goods and Energy-Intensive Tradable Goods**




## Heating Sector

Final heating services are both demanded by households and also used as input in the production of non-tradable goods with Figure AII.2 providing a stylized overview of the sector. Final heating services are supplied through a CES bundle combining heat and insulation capital (in the diagram, "Heat Bundle" and "Insulation capital", respectively), where insulation capital functions analogously to energy-efficiency capital. The heat component itself is a bundle of electricity-based and gas-based generation, each of which combines the respective energy carrier (electricity or gas) with a dedicated capital stock. When the relative price of heat rises, it is substituted with additional insulation capital.

**Figure AII.2. Heating Sector**




Calibrating the sector is challenging because of uncertainty surrounding estimates for additional investment for a given sectoral emission reduction. European Commission (2019b) features an analysis estimating historical expenditures on buildings energy renovation and energy efficiency improvements between 2012 and 2016. The study reports that total annual energy renovation investment in the EU28 during that period was approximately €280–290 billion, corresponding to a cumulative investment of roughly €1.4 trillion. Over the same period, direct emissions from residential and commercial buildings declined by around 12 percent. Assuming that the energy renovation investment is behind the emission reduction, scaling it down linearly would suggest a cost of €117 billion per ppt of emissions reduction. More recently, the IEA (World Energy Investment 2025) reports that approximately $55–70 billion per year were invested in buildings energy efficiency in the EU (excluding the UK) between 2015 and 2024, implying a cumulative investment in the order of $600 billion. Over this period, residential and commercial direct emissions declined substantially (-21 percent) which, again assuming causality and scaling linearly, would imply a cost of about $29 billion per ppt of emissions reduction. Therefore, the EC and IEA figures seem to imply very different investment intensities per percentage point of emissions reduction. However, this largely reflects different methodologies. The EC estimates are based on bottom-up renovation cost data, which may overstate the true expenditure cost. Conversely, IEA figures are based on less granular energy efficiency investment categories and may understate the investment cost associated with buildings energy efficiency improvements. To account for this uncertainty, we consider half the figure implied by the EC study, which yields a calibration target of about €60 per ppt reduction in sectoral emissions, roughly in between the two estimates. This choice is supported by the adjustment dynamics of the sector obtained when using the CPAT model described in Black, Parry, Mylonas and Zhunussova (2023), which is broadly consistent with ours.

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