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

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* Joint work with Benjamin Carton, Geoffroy Dolphin, Andrew Hodge, Amit Kara and Sebastian Wende (IMF). The views expressed in this presentation are those of the authors and should not be misconstrued for those of the IMF or its Executive Board.

Roadmap

- Motivation, policy questions and key findings
- Modeling approach:
  - GMMET model: key features
  - Baseline emission projection
  - EU climate policy scenarios
- Results
- Public vs private investment
- Conclusions

Motivation: EU's ambitious climate targets and policy agenda…

- EU emissions **declined by 37 percent** between 1990 and 2023
- EU has a binding emission reduction target of **55 percent by 2030 (Fit for 55)** and a provisionally agreed one of **90 percent by 2040**, with an interim **2035 target range 66.25-72.5** percent (relative to 1990)
- Policy package designed to achieve these targets has **three main pillars:**

ETS 1	ETS 2	Regulation & Subsidies
• Covers 40% of total emissions • Energy, industrial, aviation & maritime sectors • 62% reduction by 2030 (relative to 2005)	• Will cover 35% of total emissions • Buildings, transport & small industries • Will target 42% cut by 2030 (relative to 2005), entry into force Jan 2028	• ESR sets binding targets for sectors not covered by ETS • Other measures that are complementary to ETS: e.g. ICE car target, subsidies for heat pumps at national level etc

…entail highly uncertain implications for investment, and thereby for the macroeconomics and political economy of the transition

- **Wide divergence** in existing estimates of investment implications of meeting EU climate targets:
  - Additional annual investment needs of 2-3 pp of GDP in some key studies (e.g. I4CE; Pisani-Ferry & Mahfouz for FRA; Draghi report), but negligible in others (e.g. OECD; EC's Varga, Roeger and Velt)
- Reflects in part comparability issues (baseline, investment concept, time period...), but also fundamental difference in modeling frameworks—**'bottom-up' vs 'top-down' approaches**
- Getting investment effects right is key to the EU energy transition's:
  - **Macro effects**—output and inflation dynamics
  - **Fiscal impacts**—due to public investment needs—and case for EU rules to accommodate them
  - **Political (in)feasibility**
- Investment and broader implications will also depend on **how carbon pricing revenues are recycled** ➔ revenues vs public investment needs, use of revenues (e.g. green subsidies, transfers to households)

It is hard to compare different studies …

Comparability issues:

- **Investment concept:** green vs “net” (green minus brown) vs aggregate, treatment of EVs
- **Sectoral coverage:** wider sectoral coverage ➔ larger investment needs (in pp of GDP), all else equal
- **“Base” period:** more recent reference period (e.g. 2025 rather than 2016-20) ➔ smaller additional investment needs
- **Magnitude of emission cuts wrt to baseline:** larger projected fall in emissions under a current-policies baseline ➔ smaller additional investment needs. “Standardized” investment costs address this
- **Climate policy mix:** greater reliance on green subsidies vis-à-vis carbon pricing ➔ larger investment response?
- **Carbon pricing revenue recycling:** revenue uses that directly (e.g. green subsidies) or indirectly (e.g. corporate or labor income tax cuts) stimulate investment ➔ larger investment response?

…. but different methodologies drive different results

Fundamental divide between **bottom-up (BU) vs top-down (TD) approaches**:

➢ Investment needs typically much larger in BU (1.5+% of GDP) compared to TD (~ 0 for aggregate invst)

"Bottom Up": Sectoral Calculations and Energy system model

- Strength: detailed technological and sectoral analysis
- Limitations: no GE, some margins of adjustment not well captured (e.g. substitution across inputs, goods)

"Top Down": Computable General Equilibrium models and Dynamic General Equilibrium models

- Strength: GE linkages between agents/sectors, broad coverage of adjustment margins
  Limitations: less detailed descriptions of energy use (e.g. buildings) and generation (e.g. technical options)

Investment costs in existing studies

Table provides an overview of (selected) studies on Europe's energy transition ("Bottom-up" frameworks are shown on the left, "top-down" on the right)

"Bottom-up" **"Top-down"** **This study**

	"Bottom-up" frameworks					"Top-down" frameworks				
	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)**
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: ~ €350 bn (**~ 2% GDP**, authors' calc.) above level in '23	Avg. '25-'50, % of GDP in '21 **~ 1% GDP**, green-only (PES to DES)	In '30, % of bsl. GDP: **~ 2.3% GDP** total inv. **~ 3.5% GDP** green-only	Avg. '21-'30, % of bsl. GDP: **~ 0.6% GDP** energy systems inv. (from reference) ~ 2 rel. to avg. '11-'20	Avg. '26-'30, USD 2023, MER ~ 100 bn (**~0.5% GDP**, staff calc.) (~ 150 bn for APS rel. to avg. '21-'25, staff calc.)	In '30, total inv.: ~ 0.8% of bsl. Inv. (**~ 0.2% of bsl. GDP**, staff calc.)	**Negligible**	In '30, % of bsl. GDP: **~ - 0.4% GDP** total inv. **~ 0% GDP** green-only (capital services)	In '30, % of bsl. GDP: **~ 0.2% GDP** total inv. **~ 0.3% GDP** electricity-intensive-only (~0.1 and ~1.1 in '50) **~ 0.7% GDP** broad green aggregate	In '30, % of bsl. GDP: **~ 1.3% GDP** total inv. **~ 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.)
	Authors' Calculations									
Effort in 2030 (in MMT)	~ 220 extrapolating hist.'19 – '23 ~ 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 **~ 650 green-only** assuming constant '23	**~550 green-only** on avg. '25-'50	~500 total inv. **~800 green-only** year '30	**~ 500 green only** inv. on avg. '21-'30	**~ 500 green-only**	**~ 100 total inv.** year '30	**Negligible**	Negative total inv. **~ 20 green-only** year '30	~100 total inv. ~200 electricity-intensive-only **~ 500 broad green aggregate** year '30	~400 total inv. **~450 green-only** year '30

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- Investment costs in % of GDP: higher in "bottom-up" compared to "top-down"

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~ 1.3% on average

~ 0% on average

Investment costs in existing studies

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- Investment costs in % of GDP: higher in "bottom-up" compared to "top-down"
- "Standardized" investment costs: *much* higher in "bottom-up" compared to "top down"
- Our "top down" study: standardized investment costs closer to those in "bottom-up"

	"Bottom-up" frameworks					**"Top-down" frameworks**				
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~ avg. green €600 green inv. / tCO2e

~ avg. green: €150 / tCO2e

~ avg. total: €50 / tCO2e

What this paper does

- Use detailed insights from BU studies to inform granular sectoral modelling in TD GE framework ➔ **combine each approach’s strength**:
  - Expand IMF’s GMMET NK model with detailed modeling of key emitting sectors (building heating and insulation, energy-efficiency investments in EIIs, on top of electricity, transportation)
- (Re)Assess **3 key policy questions**:
  - How large are the investment implications of achieving the EU’s climate goals?
  - What are the broader macro implications of the EU’s energy transition? (output, inflation, energy prices, fiscal balances)
  - How are these impacts shaped by the climate policy mix and recycling of carbon pricing revenues?
- Limitations:
  - Focus on ETS1 and ETS 2 ➔ Excluded from scope of analysis: agriculture and waste; some specific investments in energy sector (e.g. interconnectors); a handful of EU regulations (e.g. on cars)

What we find

- **The EU's energy transition will not have large macro impacts if done the right way:**
  - Moderate impacts on investment (in between BU and TD), growth, energy prices, and fiscal balances…
  - …if ETS1 and ETS2 are ramped up as needed, and (only) partially used to finance well-designed green subsidies—**carbon pricing and green subsidies are complementary**
- Meeting the EU's targets implies about **1.3% percent of GDP higher green investment, but only 1% higher aggregate investment**, over the next decade in our central scenario ➔ in between BU and TD
- The policy mix matters, albeit not dramatically: **relying more on green subsidies would imply a larger investment increase, but still moderate**—about a quarter larger, compared to our central scenario
- **The EU can afford its energy transition fiscally if decarbonization relies sufficiently on carbon pricing:**
  - **Carbon pricing revenues could eventually reach about 1 percent of GDP annually while the public investment cost of the transition is less than 0.5** percent of GDP annually.
  - Use net fiscal space to address green market failures, cut other distortions and boost support for transition

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- Motivation, policy questions and key findings
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  - GMMET model: key features
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Global Macroeconomic Model for the Energy Transition (GMMET)

- Multi-region, multi-sector, non-linear, dynamic, structural model with forward-looking households, firms and monetary and fiscal policy, and a large set of nominal and real rigidities

- Macroeconomic core is built on our workhorse GIMF model

- To speak to the energy transition, it features sectors related to the generation and use of energy, and tracks associated emissions

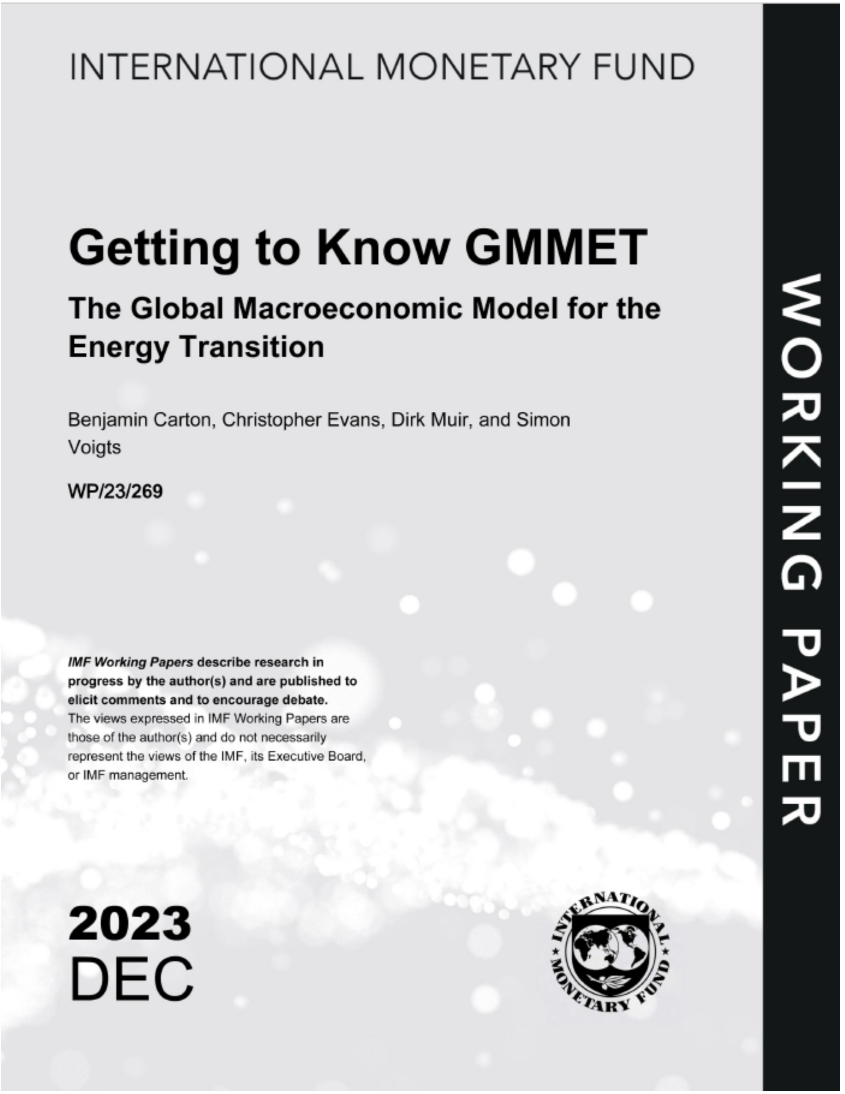
Selected applications

- October 2022 WEO, Chapter 3: Near-Term Macroeconomic Impact of Decarbonization Policies

- October 2023 World Economic Outlook, Chapter 3: Fragmentation and Commodity Markets: Vulnerabilities and Risks

- February 2024: Assessment of US Inflation Reduction Act Climate Measures and Complementary Policies

- October 2025 World Economic Outlook, Chapter 3: Industrial Policy: Managing Trade-Offs to Promote Growth and Resilience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Getting to Know GMMET

The Global Macroeconomic Model for the Energy Transition

Benjamin Carton, Christopher Evans, Dirk Muir, and Simon Voigts

WP/23/269

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2023
DEC

WORKING PAPER

Energy-related GMMET features

Energy supply	• Mining sectors for coal, gas and oil (specific capital stocks) • Trade in these fossil fuels • Electricity generation from coal, gas, renewables, nuclear and hydropower (specific capital stocks) > intermittency of renewables explicitly accounted for
Energy use	• Intermediate consumption of fossil fuel and electricity in energy-intensive (EIT) sector, regular tradables sector, and non-tradables sector (only elec.) • Transportation sector featuring both internal combustion engine (ICE) vehicles and EVs. (specific fleets) > Network externalities between charging station deployment and EV adoption are explicitly modelled • Heating sector provides heating services to commercial and residential buildings. Heat is generated from gas furnaces or heat pumps (specific capital stocks)
Energy savings	• Energy-efficiency capital can be substituted for energy by EIT and regular tradable sector (specific capital stocks) • Building insulation capital can be substituted for heating services

Baseline for Simulations

Baseline "freezes" current mitigation ambition

Separate baselines for ETS1 and ETS2 are combined with sectoral targets to calibrate the effort distribution across sectors

- ETS1 sectors: Assume flat emissions from "freezing" the current cap.

  Implied effort to reach targets:
  >> **~35% below sectoral baseline in 2030 and ~45% in 2035**

- ETS2 sectors: Forecast with linear projection to extrapolate non-policy mitigation. (Exception: no-policy EV uptake from 2025 WEO).

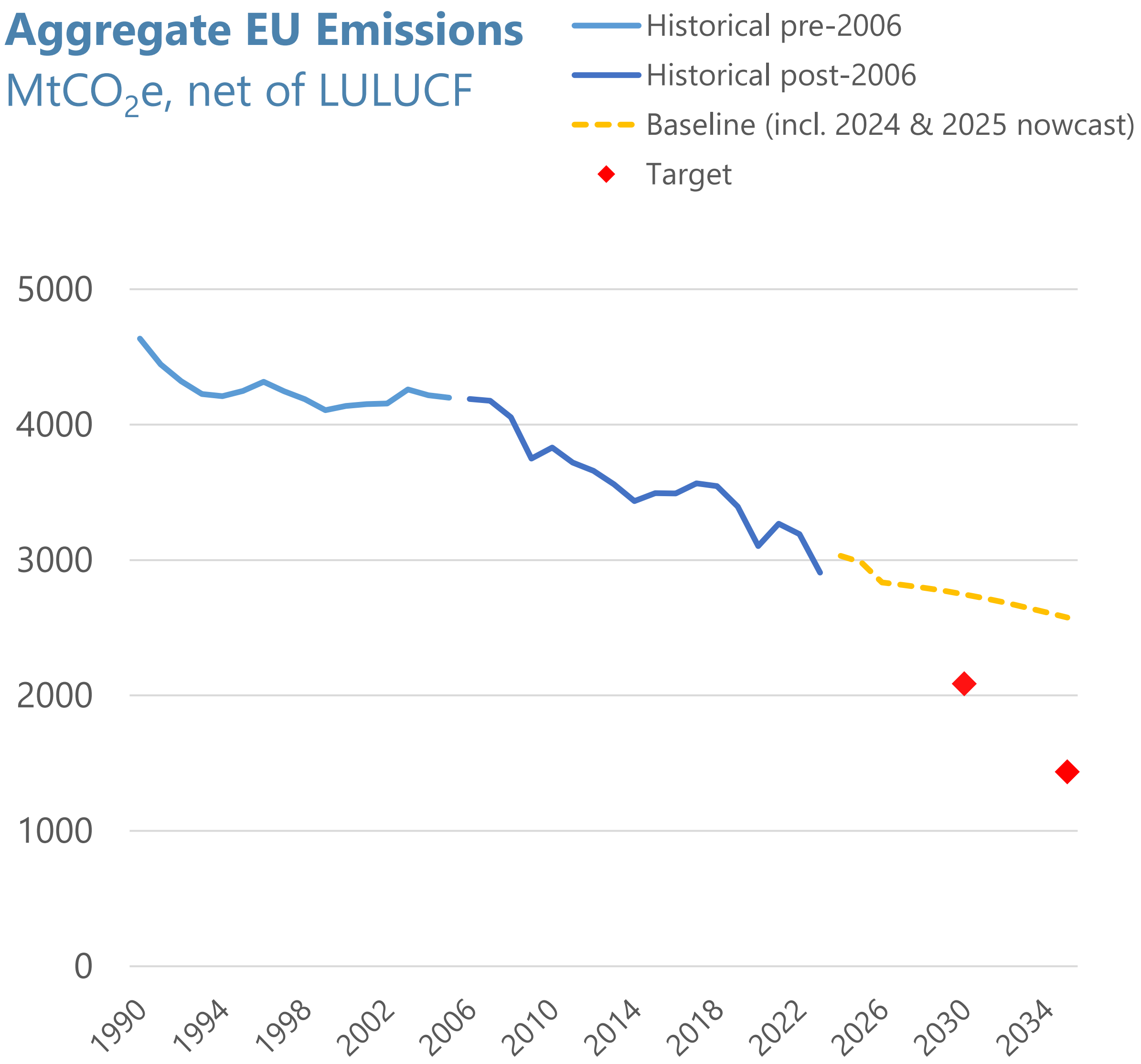
  Implied effort to reach targets:
  >> **~20% below sectoral baseline in 2030 and ~40% in 2035**

- 2035 target interpreted as 69% reduction (of 1990). There is no sectoral breakdown, so we assume 2/3 of the effort from ETS2.

> Simulation only covers ETS1 and ETS2.

Aggregate EU Emissions

$MtCO_2e$, net of LULUCF



Source: European Environment Agency (EEA) and authors' calculations.

Policy Scenarios

- All scenarios achieve ETS1 and ETS2 mitigation targets.
- In both trading systems, carbon prices rise linearly until 2035 (with ETS2 starting in 2028)

Differences in the recycling of revenues:

Central scenario

- 1/3 recycled as labor tax cuts
- 2/3 recycled as “green subsidies”, of which

  > 2/3 spent on renewables

  > 1/3 spent evenly on EVs, insulation and electricity-based heating
- CBAM: modeled as charge on imports of EII goods

Alternative 1: Full labor tax cut

- Full recycling as labor tax cut
- Slightly higher carbon price needed than in central scenario

Alternative 2: Transfers

- Full recycling as lump-sum transfers
- Slightly higher carbon price needed than in central scenario

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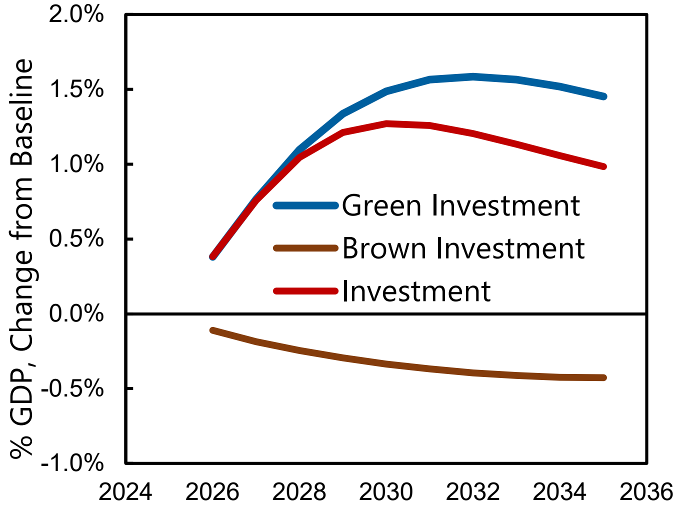
Central Scenario: Sectoral effects

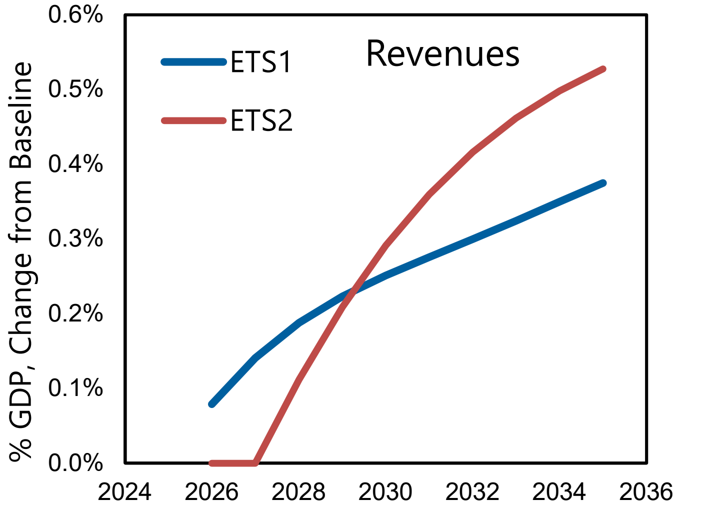
Shift in relative prices and new subsidies reshuffle investment flows:

- **“Green” investment rises significantly In 2030:**
  - Renewables +450%
  - Home insulation +100%
  - Energy-efficiency in industry +50%
  - Spending on EVs +130%
- **“Brown” investment declines**, driven by gas heating and remaining oil and gas extraction.
- **“Other” investment broadly constant** (not shown), reflecting minor impact on electricity price.

Material but more moderate rise in aggregate investment



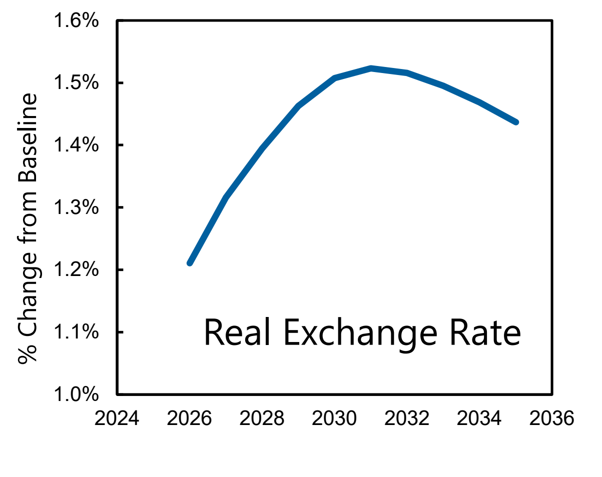
Gradual but ultimately sharp rise in ETS1 and ETS2 revenues



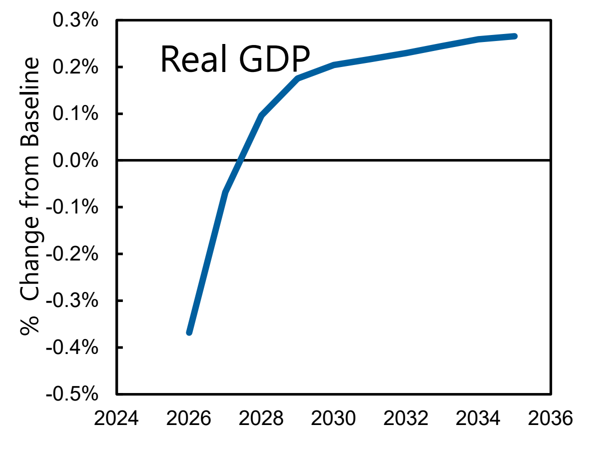
Categorization of “green” and “brown”:
Green: Renewables, energy-efficiency capital in EIT and T, insulation, electric heating
Brown: coal, gas and oil extraction, gas heating, coal and gas electricity

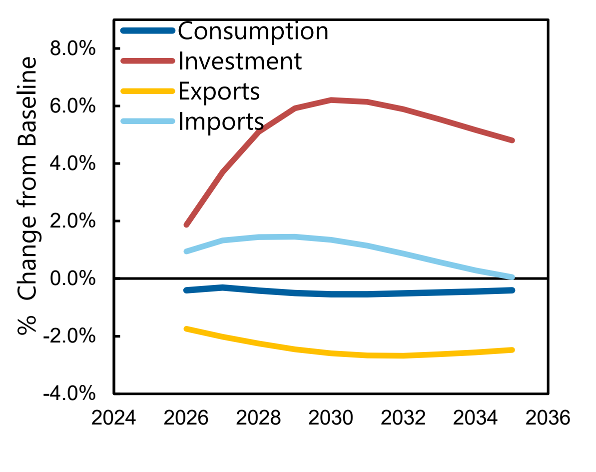
Central Scenario: Macroeconomic effects

Real exchange rate appreciation in anticipation of lower future fossil fuel imports

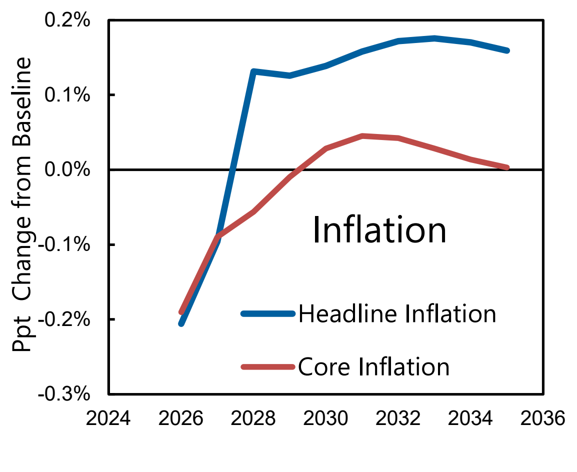


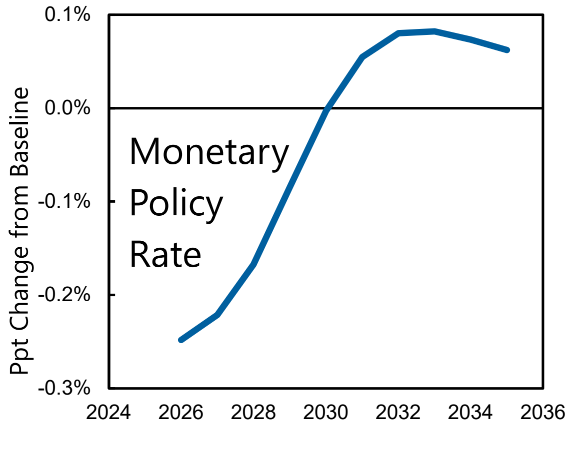
GDP decline in short run but rise in medium term (lower exports initially, investment rise subsequently)





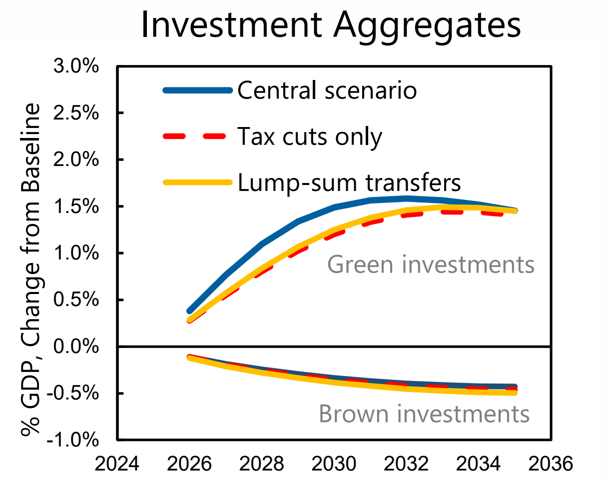
Higher inflation after initial drop, CB looks through direct impact of policy



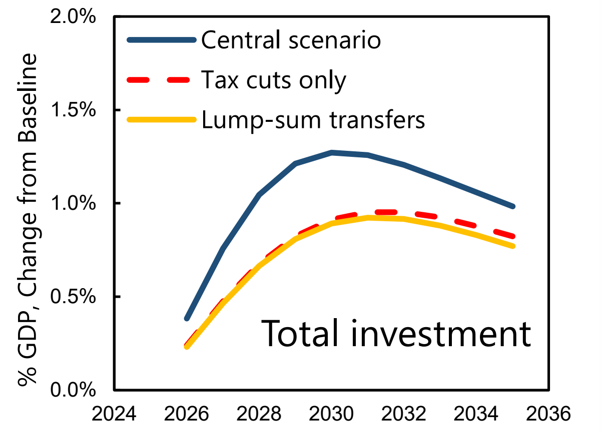


Alternative Scenario: Absent green subsidies…

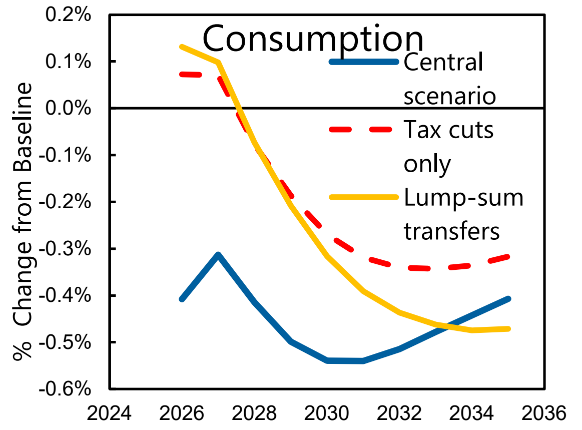
Green investment rises less



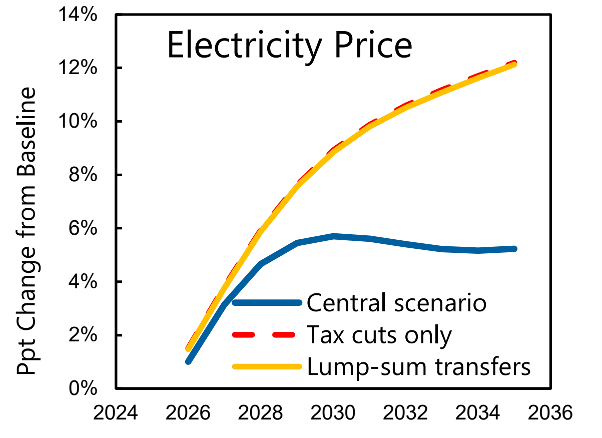
Total investment rises less (weaker green investment, higher electricity price)



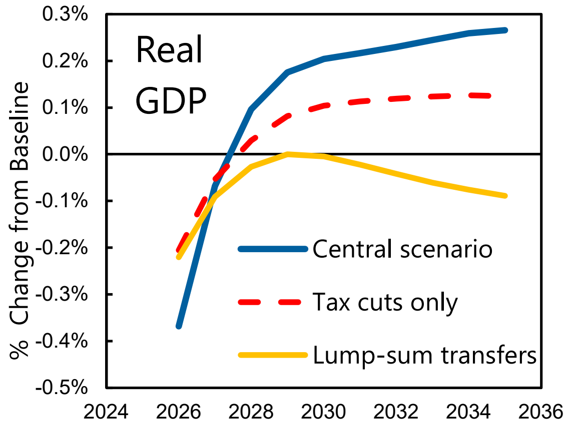
Consumption is higher as households receive support



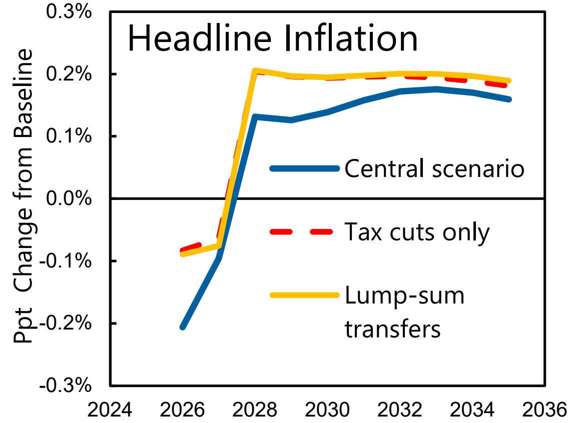
Electricity price rises more



Output rises less (labor tax cuts) or even declines (lump-sum transfers)



Headline inflation rises more (higher elec. and carbon prices)



Roadmap

- Motivation, policy questions and key findings
- Modeling approach:
  - GMMET model: key features
  - Baseline emission projection
  - EU climate policy scenarios
- Results
- Public vs private investment
- Conclusions

Public vs private investment

- GMMET features fiscal gains and costs of climate policy tools, does *not* distinguish between public and private investment

- Public financing of investment is required for **2 broad purposes**:

  - Public support to mostly private investment to address **externalities** (innovation, learning-by-doing, network externalities) associated with green R&D and deployment of existing green technologies

  ➔ That fiscal cost is partly a policy choice. It is captured in our simulations

  - Public investment to facilitate green **transition in public sector itself** (e.g. public buildings, public rail networks, cross-border electricity interconnectors) ➔ less scope for choice, and not captured

- What is the required *total* amount of public finance?

  - Existing studies: public finance ~ 30% to 60% of total investment needs

  - Even with 60% share, this is **less than 0.5% of GDP annually vs 1% of GDP ETS revenues by 2035**

Roadmap

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Concluding remarks

- **Moderate aggregate investment cost** of meeting EU's emission goals—in between those found in earlier (BU and TD) studies, which we help reconcile:
  - ~ 1 percent of GDP annually over next decade, varying a bit depending on climate policy mix
- **Modest macro implications** (GDP, consumption, electricity prices and inflation) provided policy mix be centered around scaled-up carbon pricing, with partial revenue recycling into green investment incentives
- **EU energy transition also affordable fiscally** unless ETS1 and ETS2 not ramped up as planned to meet emission objectives and/or there are too many competing demands on their revenues
- Other actions to smooth EU energy transition:
  - **Policy predictability**—2035 aggregate and ETS targets, CBAM, regulatory standards (e.g. cars)
  - **EU-level public goods** e.g. inter-connectors (European Grids Package, Energy Highways initiative)
  - **Easing frictions to K and L (re)allocation** (SIU, ALMPs, renewable permitting procedures etc)

Thank you!

BACKGROUND SLIDES

	"Bottom-up" frameworks					**"Top-down" frameworks**				
	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: ~ €350 bn (**~ 2% GDP**, authors' calc.) above level in '23	Avg. '25-'50, % of GDP in '21 **~ 1% GDP**, green-only (PES to DES)	In '30, % of bsl. GDP: **~ 2.3% GDP** total inv. **~ 3.5% GDP** green-only	Avg. '21-'30, % of bsl. GDP: **~ 0.6% GDP** energy systems inv. (from reference) ~ 2 rel. to avg. '11-'20	Avg. '26-'30, USD 2023, MER ~ 100 bn (**~0.5% GDP**, staff calc.) (~ 150 bn for APS rel. to avg. '21-'25, staff calc.)	In '30, total inv.: ~ 0.8% of bsl. Inv. (**~ 0.2% of bsl. GDP**, staff calc.)	**Negligible**	In '30, % of bsl. GDP: **~ - 0.4% GDP** total inv. **~ 0% GDP** green-only (capital services)	In '30, % of bsl. GDP: **~ 0.2% GDP** total inv. **~ 0.3% GDP** electricity-intensive-only (~0.1 and ~1.1 in '50) **~ 0.7% GDP** broad green aggregate	In '30, % of bsl. GDP: **~ 1.3% GDP** total inv. **~ 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 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 ~ 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$_2$Eq (euros/tCO2e standardized for comparison)	~ 1500 green-only extrapolating hist.'19 – '23 **~ 650 green-only** assuming constant '23	**~550 green-only** on avg. '25-'50	~500 total inv. **~800 green-only** year '30	**~ 500 green only** inv. on avg. '21-'30	**~ 500 green-only**	**~ 100 total inv.** year '30	**Negligible**	**Negative total inv.** ~ 20 green-only year '30	~100 total inv. ~200 electricity-intensive-only **~ 500 broad green aggregate** year '30	~400 total inv. **~450 green-only** year '30

NOTES TO COMPARISON TABLE

* 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.

Traditional GMMET features

Features in basic GMMET model that allow it to speak to the energy transition:

- Mining sectors for coal, gas and oil that replicate supply elasticities
- Trade in these fossil fuels, either bilateral or on world markets
- Electricity generation from coal, gas, renewables, nuclear and hydropower. (intermittency of renewables explicitly accounted for by utilities deploying the cost-efficient capacity of a variable gas backup)
- Fossil fuel and electricity intermediate consumption by energy-intensive (EIT) and regular tradable production
- Transportation sector features both internal combustion engine (ICE) vehicles and electric vehicles (EVs). Network externalities between charging station network and EV adoption are explicitly modelled.

Heating Sector in GMMET

Two margins are captured:

- Building insulation: A specific capital (akin to energy-efficiency capital) can be substituted for heating.

- Heating electrification: Bundle of electricity-plus-specific-capital can be substituted for a bundle of gas-plus-specific-capital.

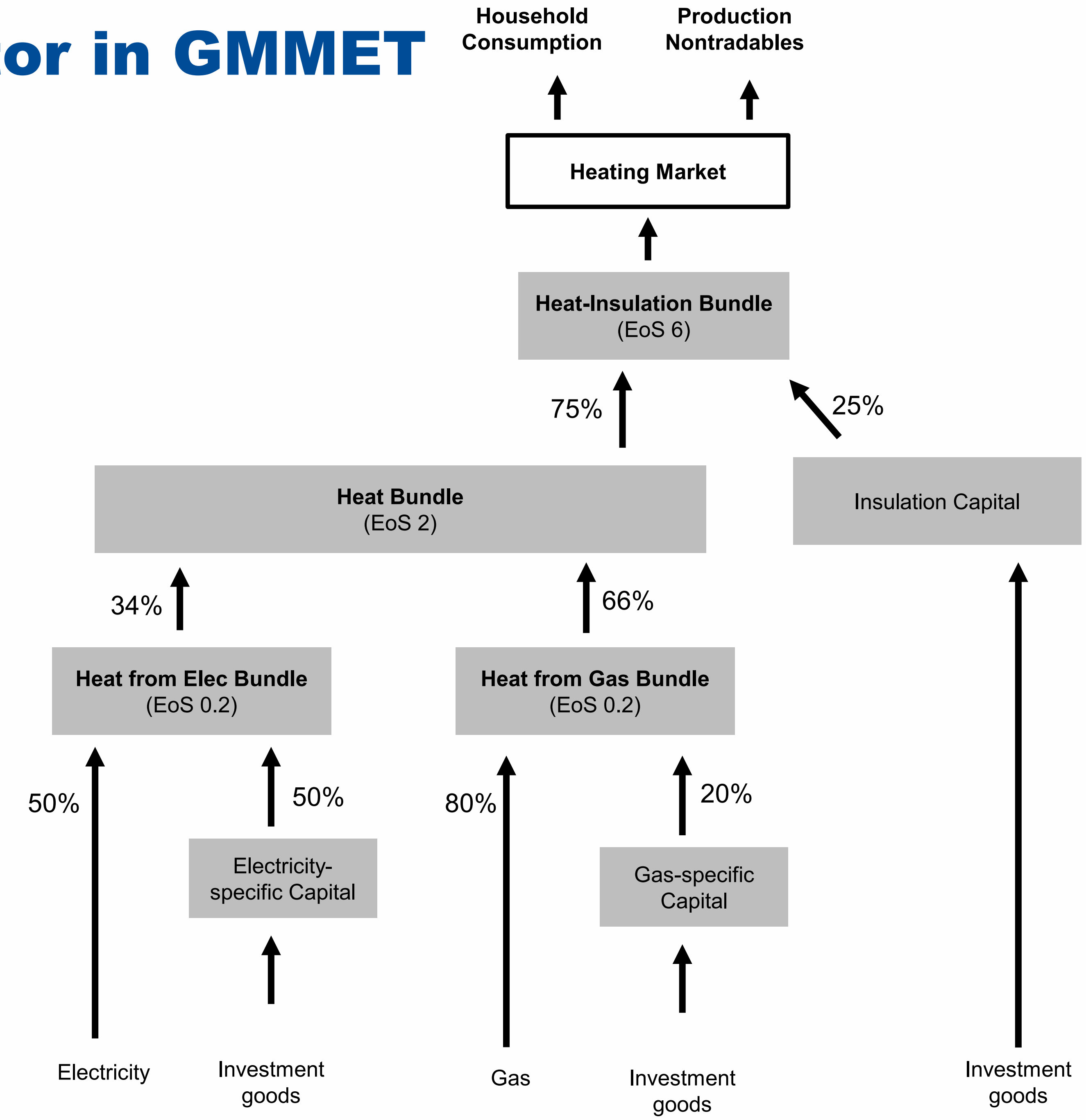
Heating Sector in GMMET

Heating from Elec and Gas substitutes (but weaker than heat-insulation)

Fuel (electricity or gas) and fuel-specific capital are complements

The capital share is higher for electricity-capital bundle than for gas-capital.

Heating and Insulation are close substitutes

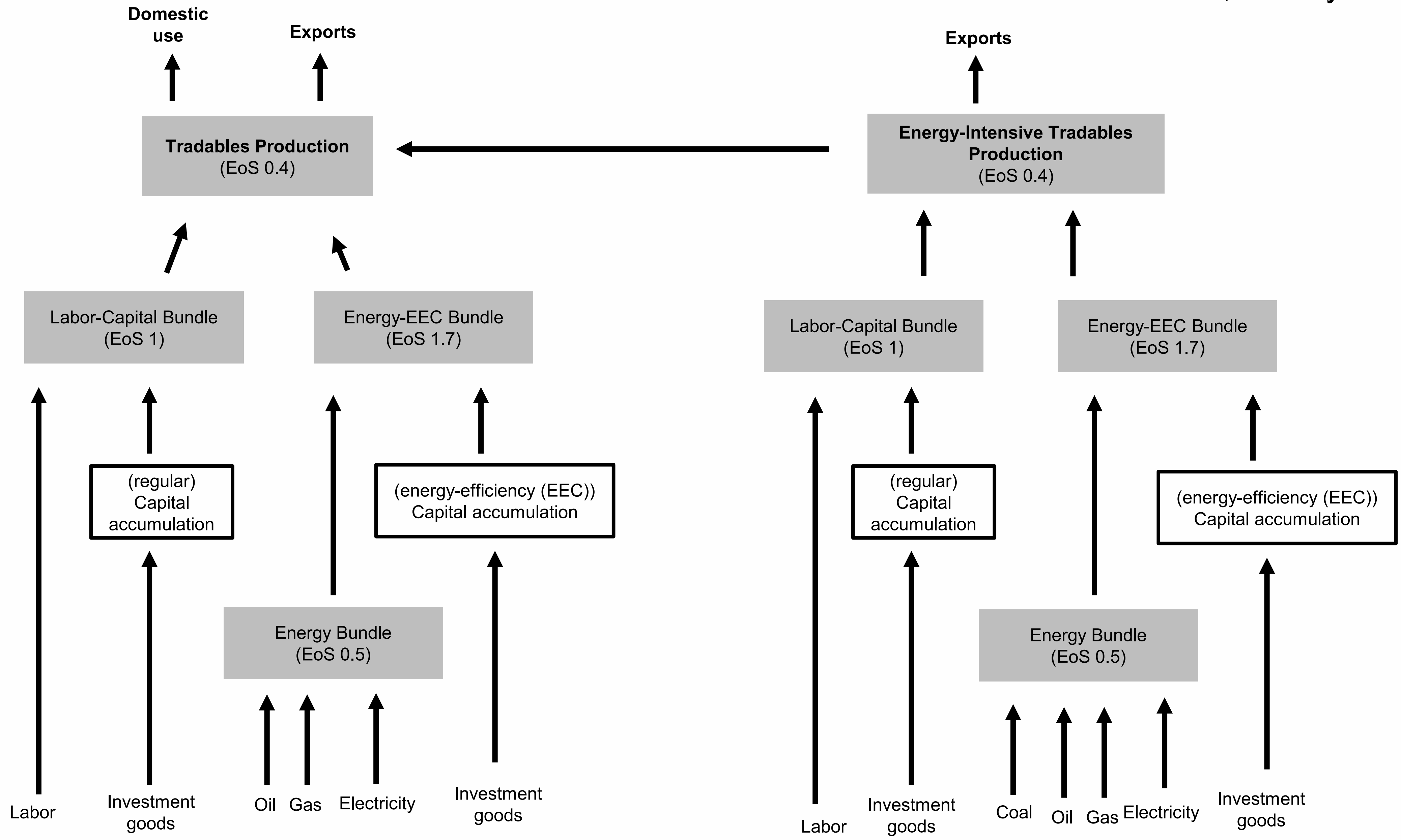


GMMET Model

- Annual multi-region, dynamic general equilibrium model
- 4 regions: European Union, United States, China, Rest of the world
- 3 sectors: Nontradables, tradables and energy-intensive tradables
- Calibration of economic data using global input-output data from GLORIA for 2023; emissions and energy from IEA
- New features (introduced for this exercise) include:
  - Energy-intensive tradables (helps to model CBAM later on)
  - Energy-efficiency capital (as in Pehl, Schreyer and Luderer, 2024 for energy-intensive sectors)
    - Reduces the cost of emissions reduction
    - Increases investment in response to higher energy prices
  - Abatement-specific capital for non-fossil fuel emissions [developed, but not yet integrated in the model]
    - Allows for abatement directly increase investment

Energy-Efficiency Capital Modelling

(Approach follows
Pehl, Schreyer and Luderer, 2024)



Energy-Efficiency Capital Modelling

- Elasticity of Substitution between the energy bundle and EEC capital is provided by Pehl, Schreyer and Luderer (2024): 1.7

- Initial share of EEC in total capital is not provided (and difficult to pin down!)

We use the following assumption as starting point:

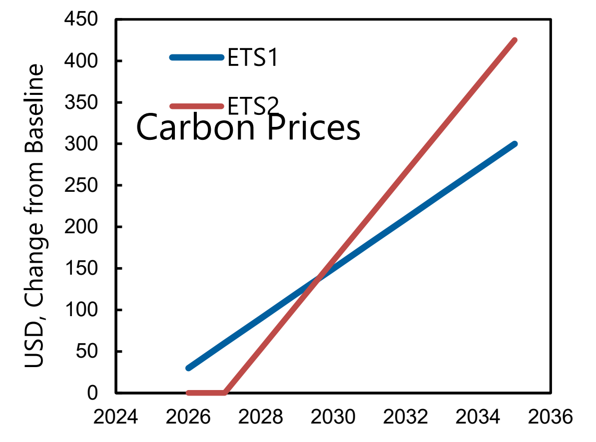
$$\frac{EEC\ capital}{total\ capital} = \frac{energy\ expenditure}{domestic\ supply}$$

Results:

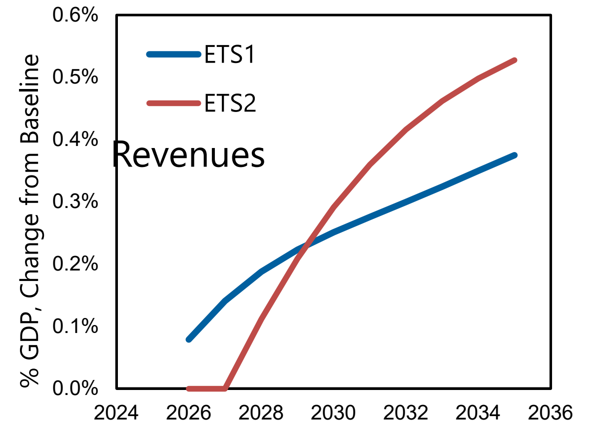
Energy costs as share of domestic supply	CHN	EUR	RC1	USA
Energy-intensive tradables	26%	27%	26%	25%
(Regular) tradables	20%	13%	20%	17%

Central Scenario Sectoral effects

Carbon prices rise to meet targets



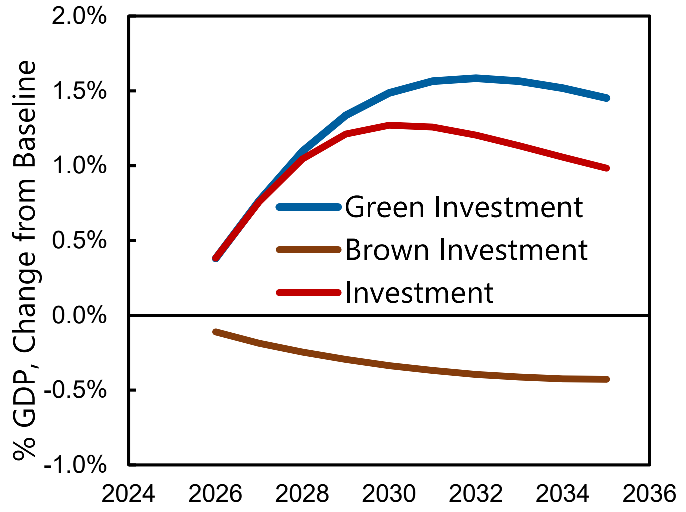
Revenues rise gradually as prices rise and free ETS1 allowances are phased out



Shift in relative prices and new subsidies reshuffle investment flows:

- **"Green" investment rises significantly. In 2030:**
  - Renewables +450%
  - Home insulation +100%
  - Energy-efficiency in industry +50%
  - Spending on EVs +130%
- **"Brown" investment declines**, driven by gas heating and remaining oil and gas extraction.
- **"Other" investment virtually constant** (not shown), reflecting a minor impact on the electricity price.

Material but more moderate rise in aggregate investment



Categorization of "green" and "brown":
Green: Renewables, energy-efficiency capital in EIT and T, insulation, electric heating
Brown: coal, gas and oil extraction, gas heating, coal and gas electricity