# Different Paths, Different Outcomes: Comparing EU ETS Revenue Recycling Scenarios in a Hybrid CGE Model

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**Abstract**

This paper assesses the macroeconomic, environmental and distributional impacts of different strategies for recycling EU ETS and ETS2 revenues in the Czech Republic, using a detailed hybrid general equilibrium model (MERCI-CZ) with an integrated bottom-up electricity module with technology-specific detail, and a discrete choice module capturing consumer preferences for vehicle technologies. The analysis confirms that carbon pricing can bring not only emission reductions, but also economic and social benefits if revenue recycling is set up appropriately. At the same time, it shows that the choice of revenue allocation method fundamentally affects the balance between short-term economic stability, long-term structural transformation and social equity.

In all scenarios, moving to carbon neutrality by 2050 implies a significant macroeconomic adjustment, with GDP falling by 4.5-6% in 2050 compared to the WEM reference scenario without the Fit for 55 package. The differences between the scenarios are mainly due to the way the revenues from auctioning emission allowances are used. The WAM NECP and WAM SCF scenarios - combining social support and targeted investment in green technologies - are able to mitigate the negative impacts on GDP in the initial phase and even generate modest short-term gains. Household consumption in these scenarios grows both through direct financial support and through long-term savings from increased energy efficiency and electrification.

In contrast, the WAM NoSocial and WAM Debt scenarios show the risks of no support for household demand. While these approaches reduce fiscal spending, they reduce consumption in the early years, deepen the decline in output and delay the social benefits of the transition. The Debt scenario - using revenues to reduce public debt - shows the worst results for GDP and consumption in the first half of the period, although it partially makes up the difference in the later stages due to lower operating costs.

From an environmental perspective, all scenarios with ETS2 achieve significant and sustained emission reductions, with NoSocial performing best due to the highest investment in energy efficiency and technology. However, these additional reductions are offset by weaker short-term economic performance and the absence of direct support to vulnerable groups. The NoETS2 scenario shows that while exempting transport and buildings from carbon pricing reduces economic costs, it slows decarbonisation in key sectors.

The results highlight that there is no clear best strategy for revenue recycling. The optimal approach should balance support to households with targeted investments in low-carbon technologies to mitigate disparities in impacts, maintain policy acceptability while achieving deep emission reductions. Strategies focused solely on fiscal consolidation or technology investment may undermine social acceptance or slow economic recovery. The analysis confirms that linking carbon pricing to fiscal, social and industrial policies is key to making the path to carbon neutrality economically feasible, socially equitable and environmentally ambitious.

**Keywords:** Hybrid CGE model, EU ETS, Revenue recycling, EUA

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# 1 Introduction

Climate change represents one of the most pressing challenges of the 21st century, and effective environmental policy has become central to sustainable development and economic planning. Within the European Union (EU), addressing the climate crisis is guided by a robust institutional framework, anchored in the European Green Deal and the "Fit for 55" legislative package. These frameworks commit the EU to achieving climate neutrality by 2050 and to reducing net greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels (European Commission 2021a).

At the core of the EU's climate strategy is the EU Emissions Trading System (EU ETS), a cap-and-trade mechanism that applies to key sectors such as energy, manufacturing, and aviation. Since its inception in 2005, the EU ETS has contributed to a 47% reduction in emissions from power plants and industrial sites across Europe (Gutzianas, Hartvig, and Petravičiūtė, n.d.). It does so by capping total emissions and allowing firms to trade allowances, with each allowance representing the right to emit one tonne of CO2 equivalent. Over time, the cap decreases, creating scarcity and incentivizing decarbonization.

In addition to functioning as a carbon pricing mechanism, the EU ETS also serves as a significant source of public revenue. Since 2013, it has generated over 175 billion EUR through the auctioning of emissions allowances (European Environment Agency 2024). These revenues are intended to support the green transition: the EU ETS Directive requires that Member States use at least half of their auctioning proceeds—and all revenues from aviation activities—for climate and energy purposes.

The introduction of ETS2, which will extend carbon pricing to emissions from solid fuels used in the building and transport sectors in 2027, along with the creation of the Social Climate Fund (SCF), raises the stakes for the strategic allocation of these revenues. The SCF aims to mitigate the social impacts of carbon pricing by funding targeted support to vulnerable households and communities (European Commission, 2021b). As such, the allocation of ETS and ETS2 revenues is increasingly becoming a matter not just of climate effectiveness but also of economic efficiency, equity, and political feasibility (Ergon et al. 2025; Wallenko and Bachner 2025). Recent evidence further suggests that, despite broad agreement on the role of carbon pricing itself, there is no clear expert consensus on how carbon pricing revenues should be recycled, particularly with respect to the balance between household compensation and investment-oriented uses (Nesje, Schmidt, and Drupp 2025). Our paper contributes to this debate by providing a quantitative, institutionally grounded assessment of alternative revenue recycling strategies within a realistic European policy setting. By embedding detailed representations of the EU ETS, ETS2, and the Social Climate Fund into a dynamic hybrid CGE model calibrated to the Czech Republic, the analysis moves beyond stated expert preferences and evaluates how different revenue-use choices translate into macroeconomic performance and emissions reductions over time.

Given the regressive potential of carbon pricing—where lower-income households tend to bear a proportionally higher burden due to higher energy expenditure shares (Baranzini, Goldemberg, and Speck 2000) —the way auction revenues are recycled can significantly alter distributional outcomes. Revenue use options include social support to households, subsidies for energy efficiency and renewable energy investments both for firms and households, compensation for energy-intensive industries, and public R&D

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funding. Each option carries different implications for macroeconomic performance, emissions reduction, and social welfare (Gavard, Voigt, and Genty 2022).

To evaluate these effects in the Czech context, this report employs the MERCI-CZ model, a recursive-dynamic hybrid Computable General Equilibrium (CGE) model implemented in GAMS and solved using the PATH solver, and based on the Austrian CGE model of Miess et al. (2022)

To increase the realism and policy relevance of the analysis, MERCI-CZ includes several extensions. First, it features a disaggregated electricity sector, modeled using a bottom-up approach consistent with engineering cost data, zero-profit conditions, and capacity constraints. Second, it integrates a discrete choice model for private vehicle purchasing decisions, based on mixed logit estimates using survey data, allowing it to endogenously reflect preferences for internal combustion engine vehicles (ICEVs), plug-in hybrids (PHEVs), and battery electric vehicles (BEVs). This component is further coupled with a stock-flow model that simulates the evolution of the vehicle fleet based on purchases, depreciation, and technology substitution. Third, we introduce a mechanism that endogenously captures productivity improvements in energy use, driven by ETS revenue-financed investments in energy efficiency.

The scenario design in this study is built around a common policy baseline reflecting the Czech Republic's updated National Energy and Climate Plan (NECP) and the core instruments of the European Green Deal—namely, the EU ETS, and the upcoming ETS2 for buildings and transport (starting in 2027). Against a baseline scenario reflecting a world without Fit-for-55, five revenue recycling configurations are simulated to evaluate how different allocations of ETS and ETS2 auction proceeds influence key outcomes under Czechia's NECP.

The scenarios vary both in the type of expenditures (e.g., social support, subsidies for renewable energy, investments in energy efficiency technologies) and in institutional setups (e.g., presence or absence of ETS2 or the SCF). The WAM NECP scenario reflects the use of revenues under the "With Additional Measures" projection in the NECP, which was designed to achieve both economic, environmental, and social objectives (and entails the largest social support in comparison with the other scenarios). The WAM SCF scenario explores the impacts of constraining the social support only from the Social Climate Fund, whereas other revenues are used solely for investment support. In contrast, the WAM noSocial and WAM noETS2 scenarios isolate the macroeconomic and distributional consequences of excluding these mechanisms, allowing us to assess the added value of social and sectoral extensions in the carbon pricing regime. Finally, the WAM Debt scenario examines the effects of financing climate-related investments through public borrowing instead of relying solely on ETS revenues, offering insight into the fiscal flexibility of green investment strategies.

This scenario framework enables a systematic comparison of revenue recycling choices under realistic institutional constraints and policy designs. It responds to increasing academic and policy interest in the dual role of carbon pricing—as both a market signal and a fiscal tool—and aims to inform future decisions on how best to use ETS-generated resources to support a cost-effective, equitable, and politically sustainable transition. By combining detailed sectoral modeling with macroeconomic closure and behavioral realism, the hybrid CGE approach adopted here offers a powerful framework to assess how different configurations of EU ETS revenue use can affect the Czech economy's transition to climate neutrality. The analysis aims to inform national policymakers, EU institutions, and stakeholders about the opportunities

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and trade-offs involved in aligning carbon pricing with broader socioeconomic objectives, including just transition and sustainable growth.

The remainder of the report is structured as follows. Chapter 2 describes the methodological approach used for the analysis of the scenarios presented in Chapter 3. The scenario results are provided in Chapter 4. Chapter 5 contains a comparison of Post-Keynesian versus Neoclassical modeling approach, and Chapter 6 concludes.

# 2 Methodology

## 2.1 The core CGE model

In this paper, we employ the recursive-dynamic hybrid CGE model, MERCI-CZ (Model for Electricity and Climate Change Policy Impacts), implemented in GAMS as a Mixed Complementarity Problem and solved using the PATH solver, based on the Austrian CGE model of Miess et al. (2022). On the production side, the model distinguishes 24 different cost-competitive sectors, all employing labor, capital, and materials as inputs in their production. The nesting structure of producing sectors is shown in Figure 1. The dynamics of the model follow the simple Ramsey model in a steady state, where savings are endogenous according to an intertemporal and optimal choice of household agents to trade off current consumption and future investments via their savings decision. Labor is assumed to remain constant over time and the labor market follows the standard full employment assumption. Capital and labor are assumed to be homogeneous across sectors, and the Czech economy is modeled as a small open economy, with the shares between imported and domestically produced goods assumed fixed, and exports growing exogenously according to the steady-state growth path. The closure rule for the public sector follows a zero deficit rule. The model is calibrated to 2018 values, and solves in 1-year time steps up to 2050.

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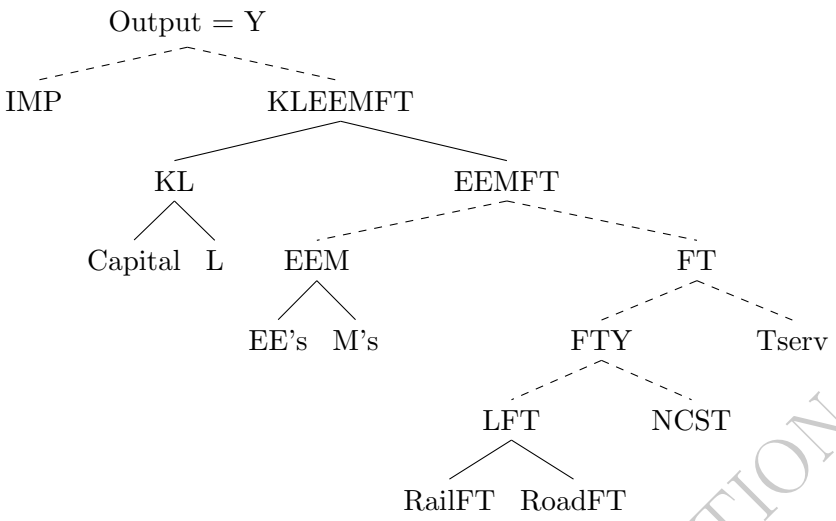


Figure 1: Nesting Structure of Producing Sectors

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### 2.2 Electricity sector

Böhringer and Rutherford (2008) show that the properties of casting an economic equilibrium as an MCP allow modelers to integrate bottom-up activity analysis directly within a top-down representation of the broader economy. The electricity sector in our model is characterized by the following equations:

- Technology-Specific Zero-Profit Conditions:

$$\Pi^E_{tec} = p_{\text{ELE}} - \sum_m a^Y_{tec,m} p_m - a^K_{tec} r_K - a^L_{tec} p_L - \sum_f a^F_{tec,f} p_f - \mu_{tec} \tag{1}$$

where

$a^Y_{tec,m}$ denotes the material input coefficient for technology $tec$,
$a^K_{tec}$ is the capital input coefficient,
$a^L_{tec}$ refers to the labor input coefficient,
$a^F_{tec,f}$ is the energy input coefficient (e.g. coal, oil, or gas inputs), and
$E_{tec}$ is the associated complementary variable.

Figure 2 illustrates the electricity sector's nesting structure. Leontief nests are characterized by dashed lines. Nests, where the substitution elasticity is non-zero, are represented by continuous lines. $\mu_{tec}$ represents technology $tec$'s shadow price on its available generating capacity. Each technology operates at different production costs, but there can only be a unique market price

for electricity. The electricity price is determined by the production cost of the most expensive technology that actively supplies electricity to the market.

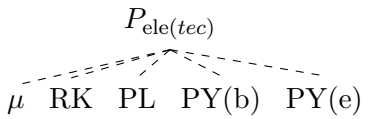


Figure 2: Cost Structure of an electricity-generating technology

The disaggregation of the electricity sector for the Czech Republic is done generally following the method proposed by Sue Wing (2008) to data for the Czech electric power sector to estimate the allocation of capital, labor, energy, and material inputs among two different activities (generation and distribution) and eight power generation technologies in a way that is consistent with engineering cost data, and the zero profit and market clearance conditions which characterize the power generation sector's production structure from a micro-consistent macroeconomic perspective.

- Capacity-Constrained Technologies: The model stipulates that the electricity production by each technology should not exceed its available capacity. Capacities are determined exogenously, based on external data, and adjusted with specific coefficients to match engineering data. Baseline capacities are in line with TIMES-CZ results for the WEM scenario from the NECP.
- General Electricity Market Clearing: On a macro-scale, the module mandates that the aggregated electricity supply from all technologies meets the total electricity demand. This ensures that the electricity market is always in equilibrium.

### 2.3 Discrete choice model for private individual transport

The CGE model is coupled with the endogenous demand for low-emission, energy-efficient technologies based on heterogeneous consumer preferences derived from a discrete choice model estimated using survey data specifically designed for this purpose.

Figure 3 shows the nesting structure of our representative household's consumption. At the top nest, the agent substitute between the consumption of mobility and non-transport goods. In the mobility nest, households substitute between an individual transport (IT) and public transport (PT) composite, ITPT, and other forms of transport, which mainly represents long distance travel by air. In the model split decision branch, the ITPT nest, the representative consumer substitutes between PT and IT. Expenditures on the individual transport composite comprise expenses of new vehicle purchases, and to operation costs of the existing vehicle stock (such as fuels, service and maintentance, taxes).

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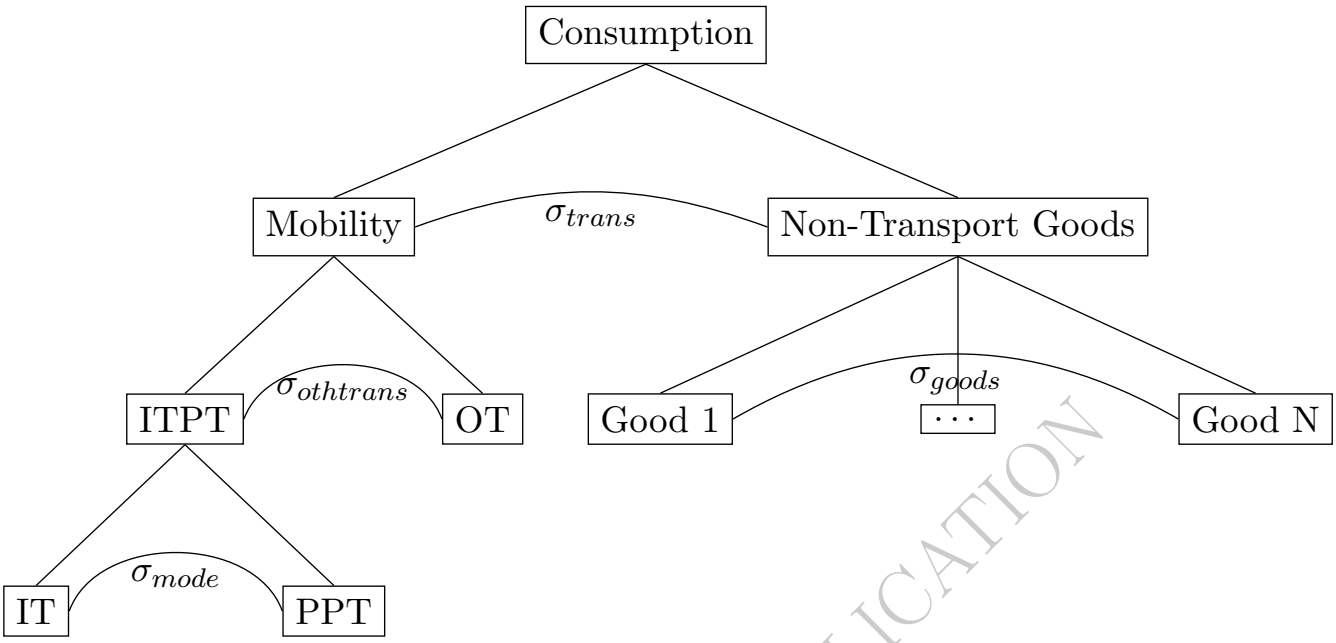


Figure 3: Nested structure of household consumption

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Vehicle purchases are determined by our representative household's preferences, and the purchase price of vehicle technologies and their technological characteristics. Given the lack of possibility to substitute between purchasing a vehicle, and using it, expenditures on the use of the vehicles are a linear function of the size of the vehicle stock. The cost share between vehicle purchase and use components is determined endogenously over time. Any rise in vehicle purchases that exceeds the number of decommissioned vehicles will lead to an increase in the vehicle stock. In order to depict these developments correctly, we incorporate a discrete choice model and a vehicle fleet accounting model into the core CGE model. A schematic illustration of the procedure is provided in Figure 4. A detailed description of the integration procedure of the discrete choice model in the CGE is provided in the Appendix.

The purpose of the discrete choice model is to determine the market share of vehicle technologies – petrol[1] and diesel[2] cars representing conventional (CV) vehicles, plug-in hybrids (PHEV) and battery electric vehicles (BEV) – when it comes to vehicle purchase decisions that then translate to new registrations.

The utility parameters of households are estimated using a mixed logit model based on specific characteristics of vehicles, such as the purchase price, fuel costs, and driving range for BEVs. Mixed logit estimation outputs a vector of specific utility parameters for each variable. When multiplied by the initial levels of the variables, we get an indirect benefit of acquiring a vehicle of a certain type (Truong and Hensher 2012). Based on indirect benefits, the probability of choice for all four vehicle types is derived,

1. Petrol cars category include CNG, LPG and hybrid petrol vehicles (HEV-B) as well.
2. Diesel cars category include hybrid diesel vehicles (HEV-D).

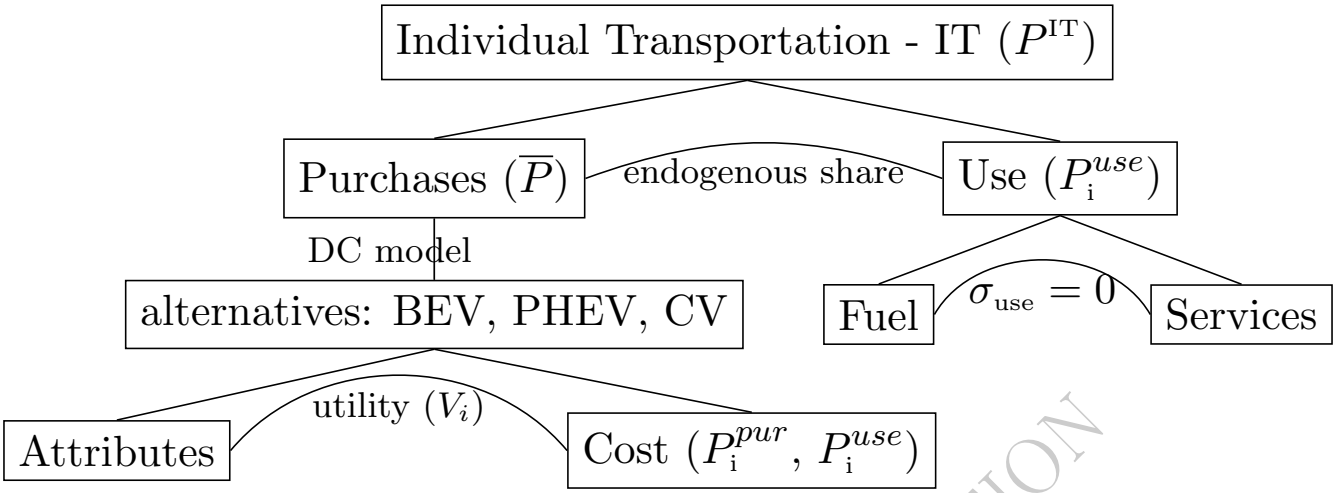


Figure 4: Individual transport consumption structure (DC model of the purchase decision)

representing the market shares in car purchases, which, when multiplied with the aggregate demand of households for individual transport, determine the demand for Petrol, Diesel, PHEV, and BEV. In addition to consumer preference, the market shares of vehicles also depend on the development of the purchase price, changes in taxation, or the price of fuel and electricity.

### 2.4 Vehicle Stock and Flow Model

Demand for Petrol, Diesel, PHEVs, and BEVs is reflected in the resulting number of car purchases entering the fleet. The demand for fuel, maintenance, and repair is evolving in line with the evolution of the vehicle fleet. While the number of newly registered cars corresponds to the purchasing decisions of households, the stock of each of the five types of cars develops according to the standard process of accumulation and depreciation. Therefore, the stock of vehicles at time $t$ is equal to the stock in the previous period *t-1* plus the number of newly registered vehicles minus the depreciation of worn-out cars.

### 2.5 Financing energy efficiency improvements

As in (Fragkos and Fragkiadakis 2022), the installation of low-emission and energy-efficient technologies is considered an intermediate input, rather than additional investment demand by the representative firms. Energy efficiency improvements can be modeled through specific investments that enable the substitution of fuel consumption with capital and other inputs. In our modeling excercise, the EU ETS revenue allocated to energy efficiency improvements is used to boost the intermediate consumption by firms (or households) of the output of the economic industry in charge of producing energy efficiency technologies:

$$EE_{t,a} = \psi_t^{EE} \cdot PY_{t,\mathrm{ENG}} \cdot \theta_a^{\mathrm{ENG}} \cdot ID_{t,\mathrm{ENG},a}$$

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where $EE^{exp}_{t,a}$ represents the revenue going directly into energy efficiency expenditures by agent $a$ at time $t$, $\theta_{j,a}$ is the value share of energy input $j$ on production costs for agent $a$, $ID_{t,j,a}$ is the intermediate demand of input ENG by agent $a$ at time $t$, $\psi^{EE}_t$ is the subsidy in energy efficiency finaced from the EU ETS revenue, and $PY_{t,\text{ENG}}$ is the price of the ENG sector.

Cumulative expenditures on energy efficiency, $CEET_{t,a} = \sum_{k}^{t} EE_{k,a}$, are subsequently linked to energy-related input-specific $j$ productivity increases:

$$EEFP_{t,j,a} = \left(\frac{CEET_{t,j,a}}{CEET_{t-1,j,a}}\right)^{\nu^{ee}_j}.$$

where $\nu^{ee}_j$ is the energy efficiency improvement rate of agent $j$. As in (Du et al. 2020), we simulate the influence of improvements in energy efficiency by introducing an input-specific productivity shock, $EEFP_{t,j,a}$, into the functions of the energy-materials composite used in the nested production structure of the CGE model. The productivity shock in year $t$ is defined by the relative change in cummulative expenditures between year $t$ and $t-1$, and the energy efficiency improvement rate. Droping the $t$ and $a$ indeces for exposition purposes, the functions of the energy-materials composite used in the model's nested production structure are presented below:

$$QEM_j = \cdot \left[\delta^{em}_j \cdot QM_j \rho^{ke}_j + \left(1-\delta^{ke}_j\right) \cdot (EEFP_j \cdot QEN_j)^{\rho^{ke}_j}\right]^{\frac{1}{\rho^{ke}_j}},$$

$$QEN_j = QEM_j \cdot \left[\frac{(EEFP_j)^{\rho^{ke}_j} \cdot \left(1-\delta^{ke}_j\right) \cdot PEM_j}{PEN_j}\right]^{\frac{1}{1-\rho^{ke}_j}},$$

$$QM_j = QEM_j \cdot \left[\frac{\delta^{ke}_j \cdot PEM_j}{PM_j}\right]^{\frac{1}{1-\rho^{ke}_j}},$$

where $QEM_j, QEN_j$, and $QM_j$ represent the quantity of the energy-material composite, energy composite, and materials composite, respectively; $PEMj, PEN_j$, and $PM_j$ represent the price of the energy-materials composite, energy composite, and materials composite; $\delta^{ke}_j$ is the share parameter of the material composite demand, $\rho^{ke}_j$ is the elasticity substitution parameter between and energy and material composites, and $EEFP_j$ represents energy efficiency improvement rate of industry $j$.

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# 3 Scenarios

This report analyzes projections of key economic indicators for the Czech Republic from 2025 to 2050 under five alternative policy scenarios and evaluates their results as deviations from the baseline "Business-As-Usual" case WEM ("With Existing Measures"), which serves as a reference point.

**WEM:** WEM describes the "World without Fit for 55". Emission allowance prices (EUA) correspond to the DG Climate Action's recommended harmonized trajectories (HCT) for WEM (European Commission 2022). Only the EU ETS1 system is implemented. The use of emissions trading revenues corresponds to the implementation in practice as of 2023, i.e. approximately 40% of revenues from the ETS1 system are not explicitly used to support decarbonization, i.e. only the Modernization Fund is implemented. A reduction emission target for greenhouse gases is not enforced, nor is the carbon border adjustment mechanism (CBAM) in place[3]. Regarding nuclear energy, the lifetime of the existing Dukovany (EDU) nuclear power plant (NPP) with an installed capacity of 2040 MW is assumed in both WEM and WAMs scenarios described below until the end of 2045 (EDU1 510 MWe), until 2046 (EDU2 510 MWe and EDU3 510 MWe) and until 2047 (EDU4 510 MWe), termination of operation of the Temelín (ETE) NPP is assumed until 2060 (ETE1 1,100 MWe) and 2062 (ETE2 1,100 MWe). Commercial Operation Date (COD) of the new capacity of EDU5 (1100 MW) is assumed to occur in 2040.

**WAM_NECP:** The With Additional Measures (WAM) scenario incorporates the goals and interventions outlined in the latest EU frameworks—such as the European Climate Law (European Commission 2021b), Fit for 55, and REPowerEU (European Commission and Directorate-General for Communication 2022). It projects that the EU may attain emissions neutrality—or at least the most ambitious feasible outcome by 2050—according to its modeling. This scenario represents the analytical basis for drafting both the National Energy and Climate Plan (NECP,2024).

For the Czech Republic, the greenhouse gas emissions target is set at 9.7 Mt $CO_2$ in 2050. Emissions allowances (EUAs) follow the recommended Harmonized Cost trajectories for WAM by the European Commission (2022). A second EU emissions trading system (ETS 2)—covering buildings, road transport, and other sources—will begin operating fully in 2027. During 2027–2030, it includes a price cap of €45 (in 2020 euros), with prices thereafter gradually aligning with those of the original ETS system.

A major change in electricity generation is the planned phase-out of coal power plants by 2033, which will require a significant increase in alternative energy sources. The plan includes a faster transition away from fossil fuels and a major development of wind farms and the continued development of photovoltaic (PV) power[4]. A major role for nuclear energy is planned including the addition of new (large) nuclear sources and the potential for small modular reactors (SMRs). COD of new capacities is assumed as follows: EDU5 COD is 2036, ETE3 COD is 2039 and ETE4 COD is 2041.

From 2035 onward, the registration of new passenger vehicles powered by conventional combustion engines is disallowed.

Revenues from both ETS streams are assumed to be reinvested in comprehensive decarbonization efforts and moderated via social support measures—such as lowering labor taxes or providing lump-sum transfers to households—as envisaged under the Fit for 55 revenue-recycling frameworks. The complete assumptions for revenue recyling rules in all scenarios are summarized in Table 1.

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3. The CBAM is currently not a part of this CGE model.

4. The WEM scenario, while still showing a significant shift away from coal and toward lower emission sources, does not fully incorporate the same level of ambition. It also envisages a greater dependence on imports of electricity to meet demand

**WAM_SCF:** The WAM_SCF scenario is a variation of WAM_NECP with a difference in allocations of lump sum money transfers from the state budget to households that are used now for subsidizing BEVs and increased support of sectoral energy efficiency measures.

**WAM_noETS2:** This scenario excludes ETS 2 and focuses only on industrial sectors, otherwise aligns with WAM_NECP.

**WAM_noSocial:** Revenues are directed exclusively toward green projects and there are no lump sum revenues dedicated to households.

**WAM_debt:** Revenues are directed toward reducing public debt, so no state budget allocation is used for recycling.

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Table 1: Scenarios description

| | | | ETS1 | | ETS2 | |
|---|---|---|---|---|---|---|
| | IF | MF | SB 2021–2025 | SB 2026–2050 | SCF | SB |
| **WAM_NECP** | | | | | | |
| EE all sectors | - | 35% | - | 37% | - | 50% |
| Heat pump subsidy | - | 5% | - | 5% | 10% | - |
| EE households | - | 10% | - | - | 32.5% | 25% |
| PV + Wind subsidy | - | 40% | - | - | - | - |
| BEV subsidy | - | 10% | - | - | 20% | 25% |
| Lump sum | - | - | - | 40% | 37.5% | - |
| Other government | - | - | - | - | - | - |
| R&D | 100% | - | - | - | - | - |
| revenues forgone | - | - | 100% | 18% | - | - |
| **WAM_SCF** | | | | | | |
| EE all sectors | - | 35% | - | 57% | - | 50% |
| Heat pump subsidy | - | 5% | - | 5% | 10% | - |
| EE households | - | 10% | - | - | 32.5% | 25% |
| PV + Wind subsidy | - | 40% | - | - | - | - |
| BEV subsidy | - | 10% | - | 20% | 20% | 25% |
| Lump sum | - | - | - | - | 37.5% | - |
| Other government | - | - | - | - | - | - |
| R&D | 100% | - | - | - | - | - |
| revenues forgone | - | - | 100% | 18% | - | - |
| **WAM_noSocial** | | | | | | |
| EE all sectors | - | 35% | - | 57% | - | 50% |

| | | | | | | |
|---|---|---|---|---|---|---|
| Heat pump subsidy | - | 5% | - | 5% | 10% | - |
| EE households | - | 10% | - | - | 50% | 25% |
| PV + Wind subsidy | - | 40% | - | - | - | - |
| BEV subsidy | - | 10% | - | 20% | 40% | 25% |
| Lump sum | - | - | - | - | - | - |
| Other government | - | - | - | - | - | - |
| R&D | 100% | - | - | - | - | - |
| revenues forgone | - | - | 100% | 18% | - | - |
| **WAM_noETS2** | | | | | | |
| EE all sectors | - | 35% | - | 37% | - | - |
| Heat pump subsidy | - | 5% | - | 5% | - | - |
| EE households | - | 10% | - | - | - | - |
| PV + Wind subsidy | - | 40% | - | - | - | - |
| BEV subsidy | - | 10% | - | - | - | - |
| Lump sum | - | - | - | 40% | - | - |
| Other government | - | - | - | - | - | - |
| R&D | 100% | - | - | - | - | - |
| revenues forgone | - | - | 100% | 18% | - | - |
| **WAM_Debt** | | | | | | |
| EE all sectors | - | 35% | - | - | - | - |
| Heat pump subsidy | - | 5% | - | - | 10% | - |
| EE households | - | 10% | - | - | 32.5% | - |
| PV + Wind subsidy | - | 40% | - | - | - | - |
| BEV subsidy | - | 10% | - | - | 20% | - |
| Lump sum | - | - | - | - | 37.5% | - |
| Other government | - | - | - | - | - | - |
| R&D | 100% | - | - | - | - | - |
| revenues forgone | - | - | 100% | 100% | - | 100% |

*Notes: IF = Innnovation fund, MF = Modernisation fund, SB = State budget, SCF = Social Climate fund.*

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# 4 Results

## 4.1 Macroeconomic Impacts

All scenario values are expressed relative to the baseline WEM scenario. The macroeconomic variables analyzed include GDP, investment, consumption of both households and government, production, and employment.

### Gross Domestic Product

All modeled scenarios are characterized by a similar trend over the long term. Overall, the environmental regulations exert negative preassures on the Czech economy. By 2050, the Czech Republic experiences a reduction in GDP relative to the baseline in the order of 5 to 6%. Over the entire 2025-2050 period, the negative GDP impacts are strongest under the WAM_Debt scenario, followed progressively closer over time by the WAM_noSocial scenario. Both scenarios are characterized by a lack of lump-sum transfers, removing a key demand stimulus in the initial years of the green transition. Particularly, in the case of the Debt scenario, a large share of the EU ETS funds is used to finance State Debt, forgoing the opportunity to directly sustain the economy by means of increased government spending, transfers to households, or additional spending in the promotion of energy-saving technologies. With no surprises, the Debt scenario performs the poorest in terms of GDP impacts, with a continuous reduction in GDP relative to baseline over the entire modeling period, whereas all other scenarios experience moderately positive GDP impacts in the first years of our modeling exercise, as can clearly be seen in Figure 5.

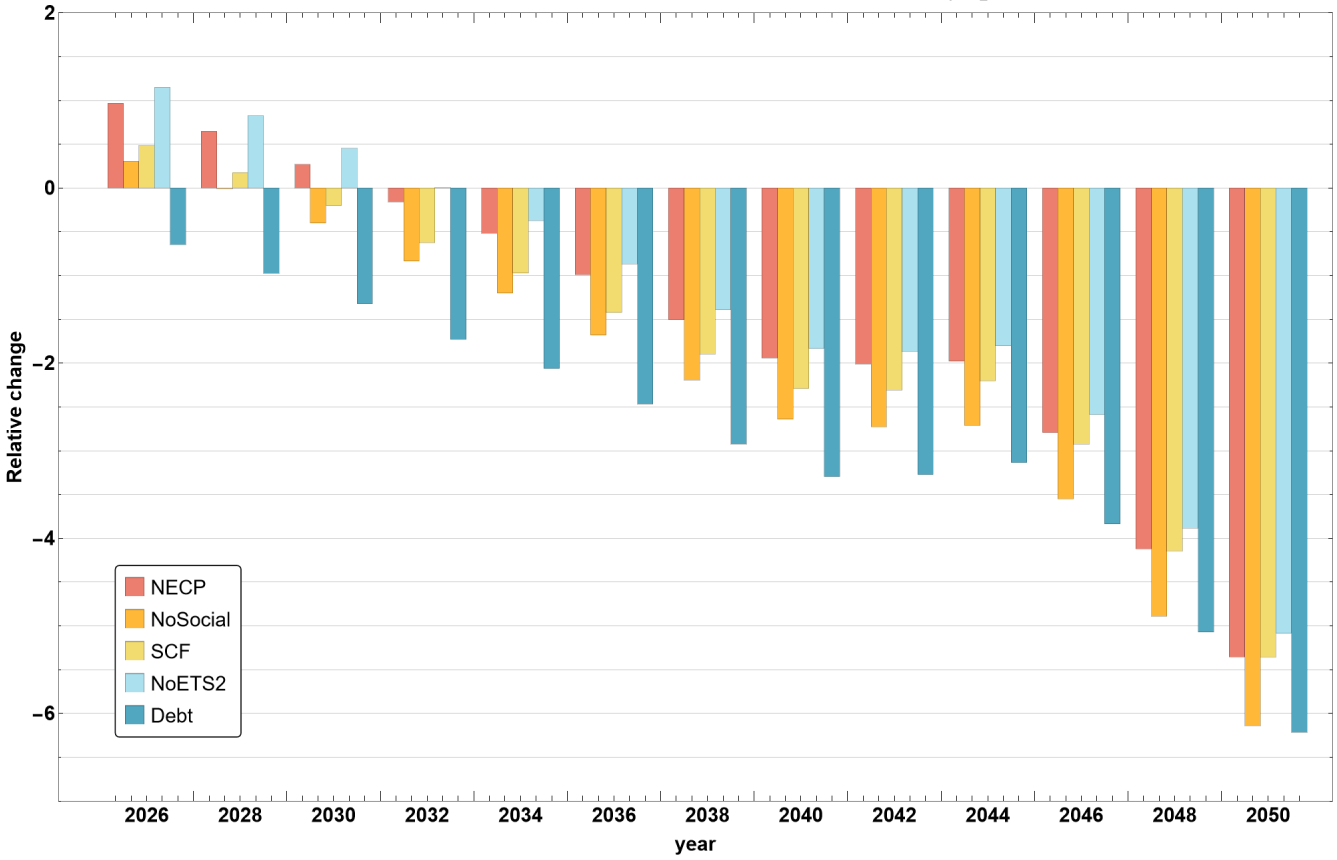


Figure 5: Relative deviation (in %) from baseline - GDP

Compared to the Debt scenario, both NECP and SCF scenarios are distinguished by a stronger

emphasis on the use of EU ETS revenue to sustain government spending and households' final consumption through lump-sum transfers, and on the promotion of spending in energy efficiency by both households and industry. Coupled with the fact that the price of ETS1 allowances does not increase drastically until 2035, and hence does not create significant distortionary negative effects in the economy, the green transition delivers small positive effects -typically under +1% - on the economic activity of the country in the first 5 to 7 years of the modeling period. As the price of ETS1 and ETS2 increases, the economic activity of the country progressively deteriorates when compared to the WEM. Lastly, it can be noted that the NoETS2 scenario shows the least negative effects, declining by about 4.5% by 2050. This result confirms that ultimately, in the Czech context, carbon pricing's distortionary effects are generally sufficiently strong to exert pressure at the economy-wide level, even when the revenue collected is recycled back into the economy through complementary instruments.

**Production**

Across all scenarios, aggregate output in the Czech Republic declines relative to the WEM baseline, with deviations ranging between approximately –1% and –2.5% over the 2025–2050 horizon. While the magnitude varies slightly by scenario, the overall trajectory is broadly similar: a gradual decline in the first decade, a steeper drop during the mid-transition years, and partial stabilization toward 2050.

***Early Transition Phase 2025–2035:*** In the first decade, the reduction in output remains moderate (–0.9% to –1.7%). This reflects the initial stages of the power system transformation, with substantial new wind and photovoltaic capacity—especially after 2030—coming online in both WEM and WAM-type scenarios. In WAM variants, earlier commissioning of nuclear units further reshapes the generation mix. These investments create transitional disruptions but also sustain some industrial activity linked to infrastructure build-out.

***Intensified Transition and Structural Shifts 2035–2045:*** The decline deepens (–1.47% to –2.4%) as the coal phase-out by 2033 and the ban on new internal-combustion passenger vehicles from 2035 take effect. Output in directly affected sectors contracts, while demand shifts toward low-carbon alternatives. Expanded energy-efficiency subsidies reduce energy intensity across industries, cutting demand for fossil-fuel inputs but also dampening production in energy-supply sectors. This period captures the most significant reallocation of resources in the economy, with transitional losses in traditional industries outweighing gains in emerging ones.

***Stabilization and New Growth Drivers after 2045:*** Following the large-scale uptake of battery electric vehicles (BEVs), domestic vehicle production rises, cushioning the negative effect of persistently high emission allowance prices. Relative output impacts stabilize between –1.37% and –2.36%, with scenario differences driven mainly by the design of revenue-recycling policies and the scale of efficiency improvements.

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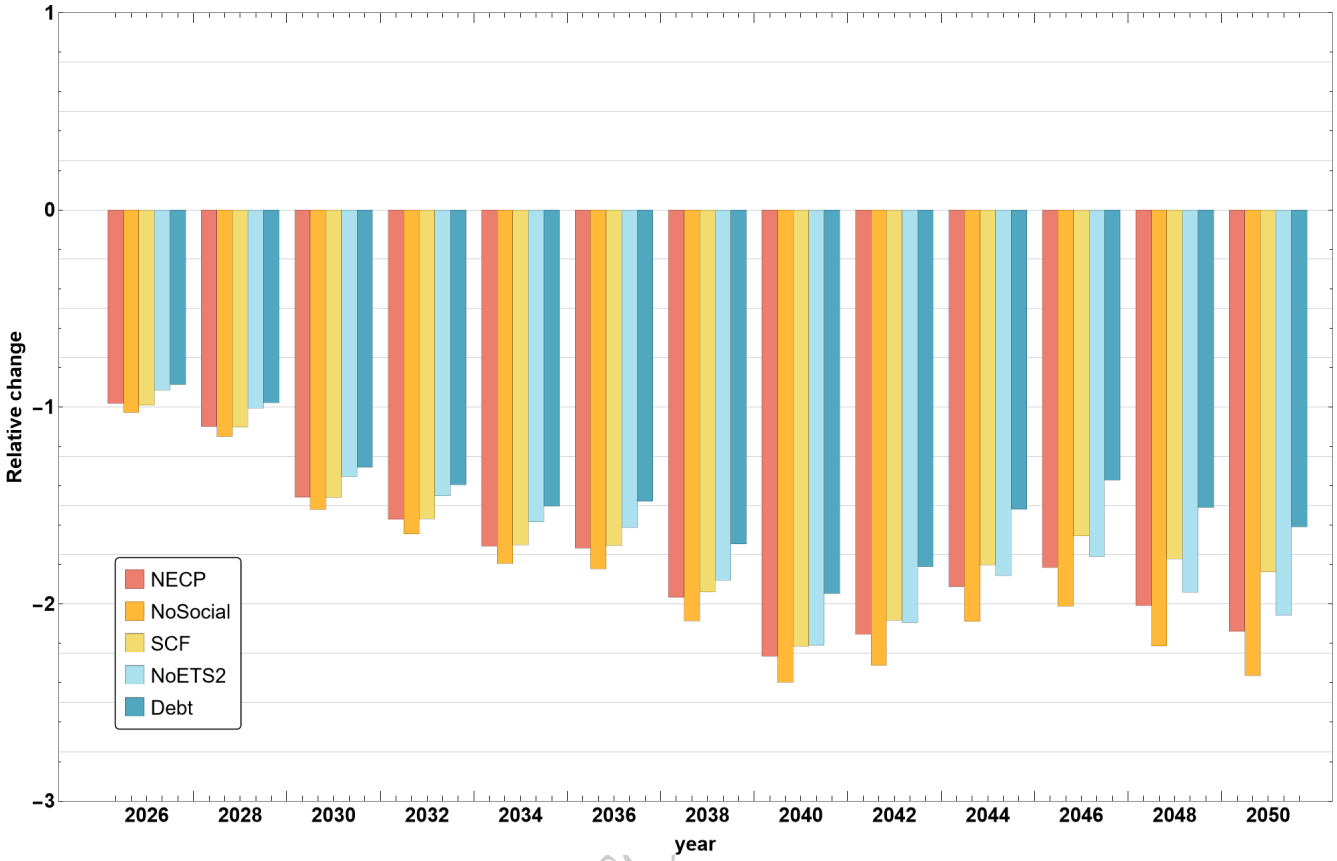


Figure 6: Relative deviation (in %) from baseline - Aggregate Output

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When comparing the scenarios, the SCF scenario shows a smaller output loss than NECP, despite NECP's lump-sum household transfers that boost final demand. In SCF, reallocating part of these transfers to BEV subsidies and sector-specific energy-efficiency programs changes the composition of intermediate demand and reduces relative prices for sectors with the highest efficiency gains. Two opposing forces are at work:

- Efficiency-induced cost reductions → Encourage higher household and government consumption, and raise intermediate demand for goods from efficient sectors, supporting output.
- Lower demand for energy goods → Depresses production in fossil-fuel and related sectors. In this case, the positive cost-reduction effect dominates, making SCF's aggregate output decline smaller.

In NoETS2 scenario, excluding ETS2 lowers carbon costs for transport and buildings, slightly reducing the negative impact on aggregate output compared with full ETS coverage. However, it also weakens decarbonization incentives in those sectors.

NoSocial scenario's redirecting of all revenues to green projects without household transfers removes a key source of final demand stimulus, resulting in deeper output losses than NECP.

The Debt scenario shows the smallest decline in output. With revenues used to reduce public debt rather than invested in energy efficiency, there is less structural change and a smaller reduction in demand for fossil-fuel inputs. While this cushions output, it also delivers the lowest emissions reductions among WAM scenarios.

### Investment

Aggregate investment in Figure 7 shows a broadly similar cyclical pattern across all WAM-type scenarios, with an initial decline, a sharper contraction during the core years of the transition, and partial recovery or stabilization toward 2050. The magnitude and timing of the changes vary depending on the policy mix, particularly in how revenues are recycled and the extent to which energy-efficiency measures are prioritized.

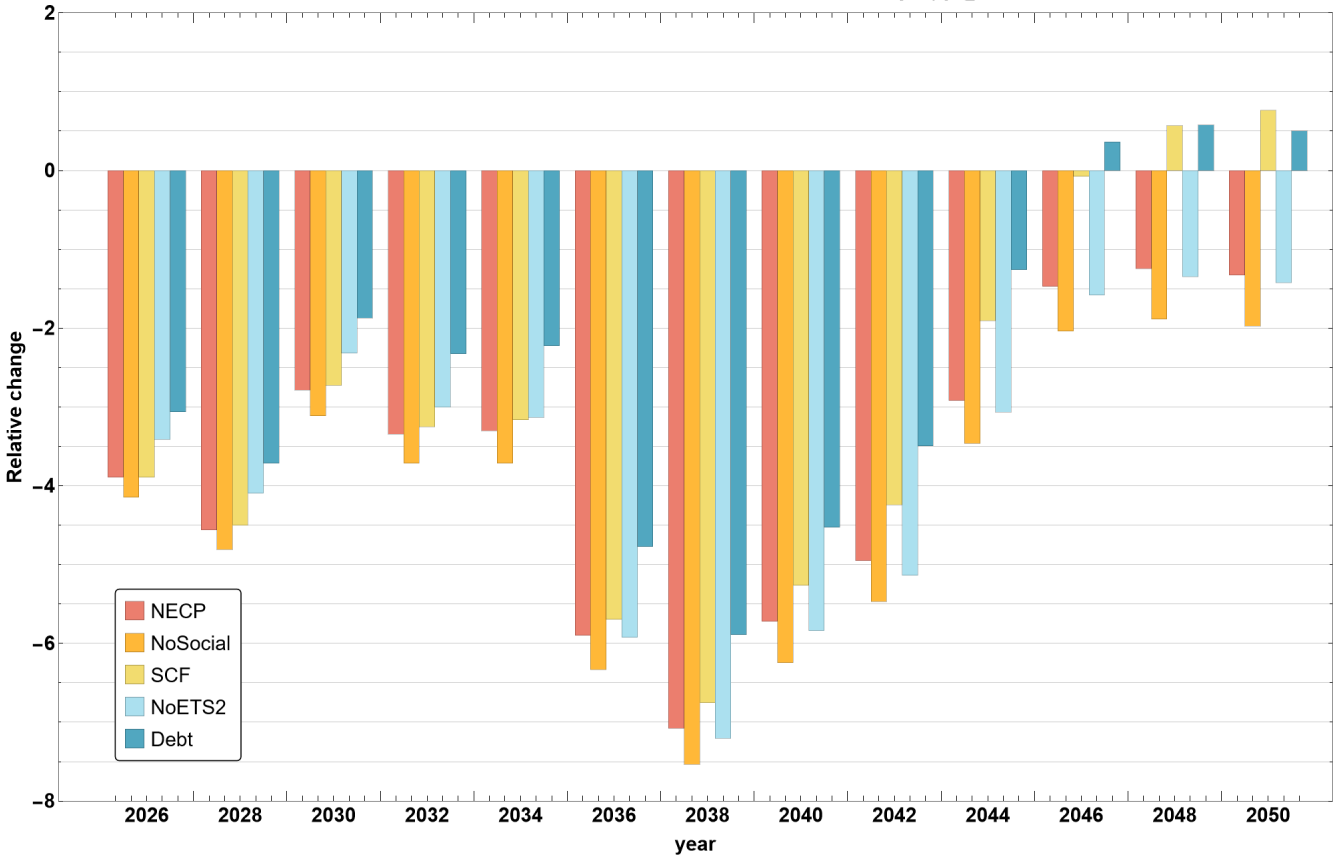


Figure 7: Relative deviation (in %) from baseline - Aggregate Investment

In the first decade, 2025–2035, the contraction in investment is relatively modest (–1.9% to –4.8%) compared to later years. While higher carbon prices and early efficiency measures put pressure on certain capital-intensive industries, these effects are partly offset by substantial capital spending in the power sector. In both WEM and WAM-type scenarios, accelerated deployment of wind farms and large-scale photovoltaic installations—especially after 2030—drives investment in construction and manufacturing. In WAM variants, the earlier commissioning of nuclear units (EDU5, ETE3, ETE4) further supports infrastructure investment despite broader economic headwinds.

The most pronounced declines occur in the period 2035–2045, with reductions in aggregate investment reaching –7.5% in the most affected scenarios. This coincides with the coal phase-out by 2033 and the ban on new internal-combustion passenger vehicles from 2035, which contract investment in fossil-fuel-based power generation, conventional automotive manufacturing, and related supply chains. Large-scale adoption of energy-efficiency technologies reduces demand for fossil fuels and non-green capital goods, causing intermediate and final demand shifts that dampen overall capital formation.

From the mid-2040s onwards, a surge in BEV adoption stimulates related manufacturing and infrastructure investment, partly countering the drag from persistently high carbon prices. As a result, relative investment impacts narrow, ranging from around –2% to +0.75% by 2050 depending on the scenario.

The noSocial scneario experiences the largest and most persistent drop in investment across the projection horizon. Without household lump-sum transfers, there is no offsetting boost to final demand to counter high energy costs. The focus on energy-efficient technologies accelerates contraction in fossil-fuel and non-green capital investments.

Both NECP and NoETS2 show similar magnitudes after 2035, but NoETS2 exhibits slightly more negative investment impacts in the later years. This partly reflects the interplay between ETS2 price trajectories and factor substitution: with smaller wage declines and stronger labor demand in NoETS2, capital is substituted with labor in production, reducing capital investment needs.

SCF has a slightly better investment outcomes than NECP, as targeted subsidies for BEVs and sector-specific efficiency programs stimulate capital spending in sectors undergoing green transformation.

While avoiding the sharpest early drops, the Debt scenario maintains relatively weak investment growth in later years because revenues are diverted to debt reduction rather than to capital-intensive decarbonization projects.

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**Employment**

Figure 8 shows impacts on the labor market relative to the WEM scenario. All scenarios show largely modest effects on employment. Throughout 2025–2050, the overall magnitude of employment impacts is modest, with year-on-year deviations never exceeding –2%. As discussed in the previous sections, aggregate output reductions across scenarios are translated into lower utilization of inputs used in production processes. This is particularly the case for primary inputs, labor, and capital. Given the lower demand for primary inputs, lower price levels are required for these markets to clear. A reduction in aggregate output, coupled with lower input use throughout the economy, implies changes in the relative prices. In

particular, relative changes between wages and the rental price of capital induce substitution between labor and capital use, thus provoking stronger negative effects in the use of one of the inputs, relative to the other. We find that regardless of the scenario, investment and employment generally follow opposite trends, albeit, at different magnitudes.

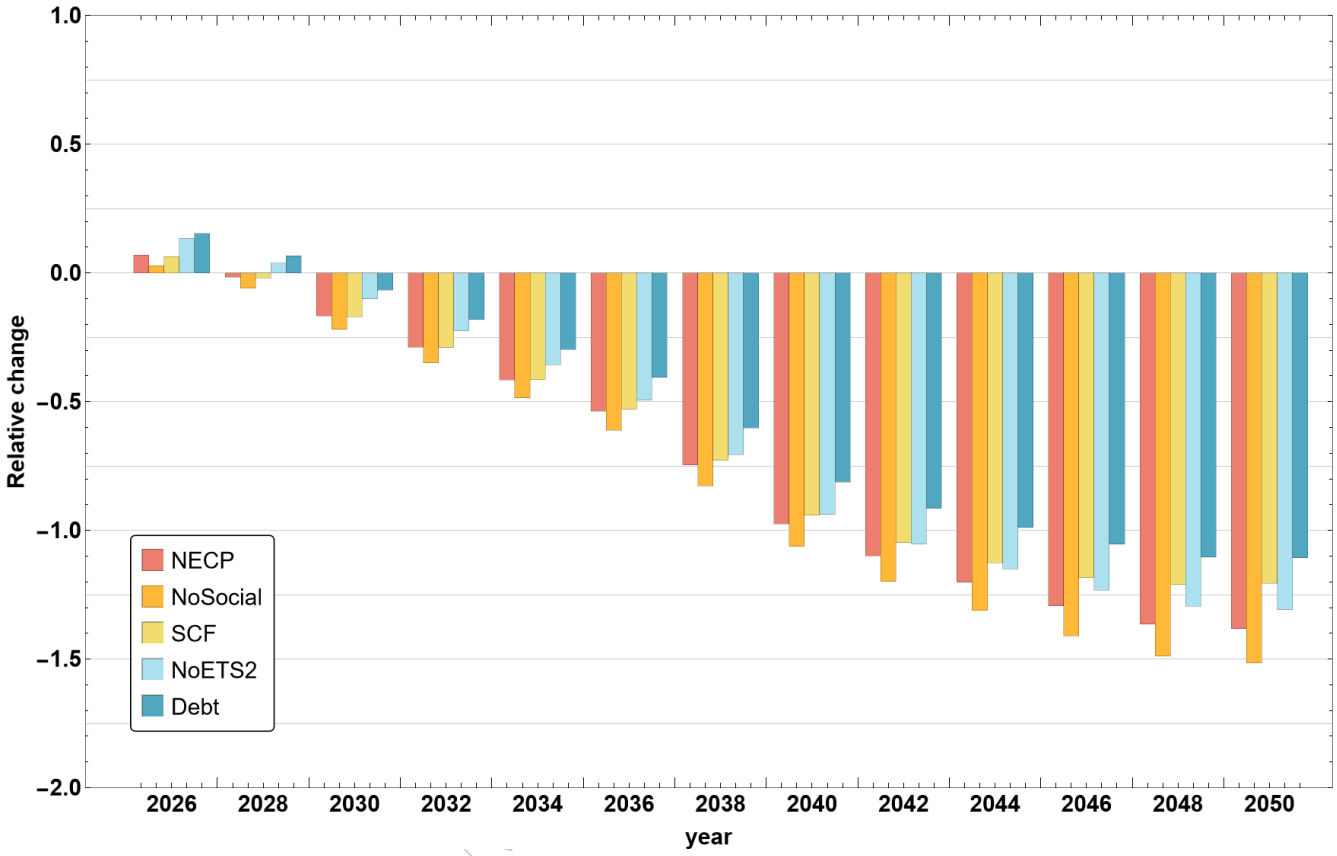


Figure 8: Relative deviation (in %) from baseline - Employment

Figure 9 shows relative changes in wages. Comparing it to 6, one can clearly see that both variables show a similar pattern (see section 4.1). Ultimately, the persistent reduction in output and its negative effect on wages, lead to a slightly depressed level of employment relative to baseline.

The scenario with the strongest impact on the labor market is NoSocial, in which both ETS1 and ETS2 are fully active, and their collected revenue is used exclusively to fund the adoption of investments related to decarbonization. As a result, labor use from industries devoted to the production of energy goods, such as gas or fuels, is roughly 1 percentage point lower for most periods under the NoSocial scenario than under the Debt scenario, the best performing (in terms of employment) among all the scenarios considered, relative to WEM as a result of the aforementioned results in aggregate output. In fact, the "ordering" of the scenarios, in terms of the relative magnitude of their effects with respect to

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WEM is the same for aggregate employment and aggregate output, confirming that the economy-wide effect of the National Climate and Energy Plan on employment is a scaled effect on output, while the magnitude of this effect is given by the substitution possibilities between labor and capital as determined by relative price changes between (primarily) wages and the rental price of capital.

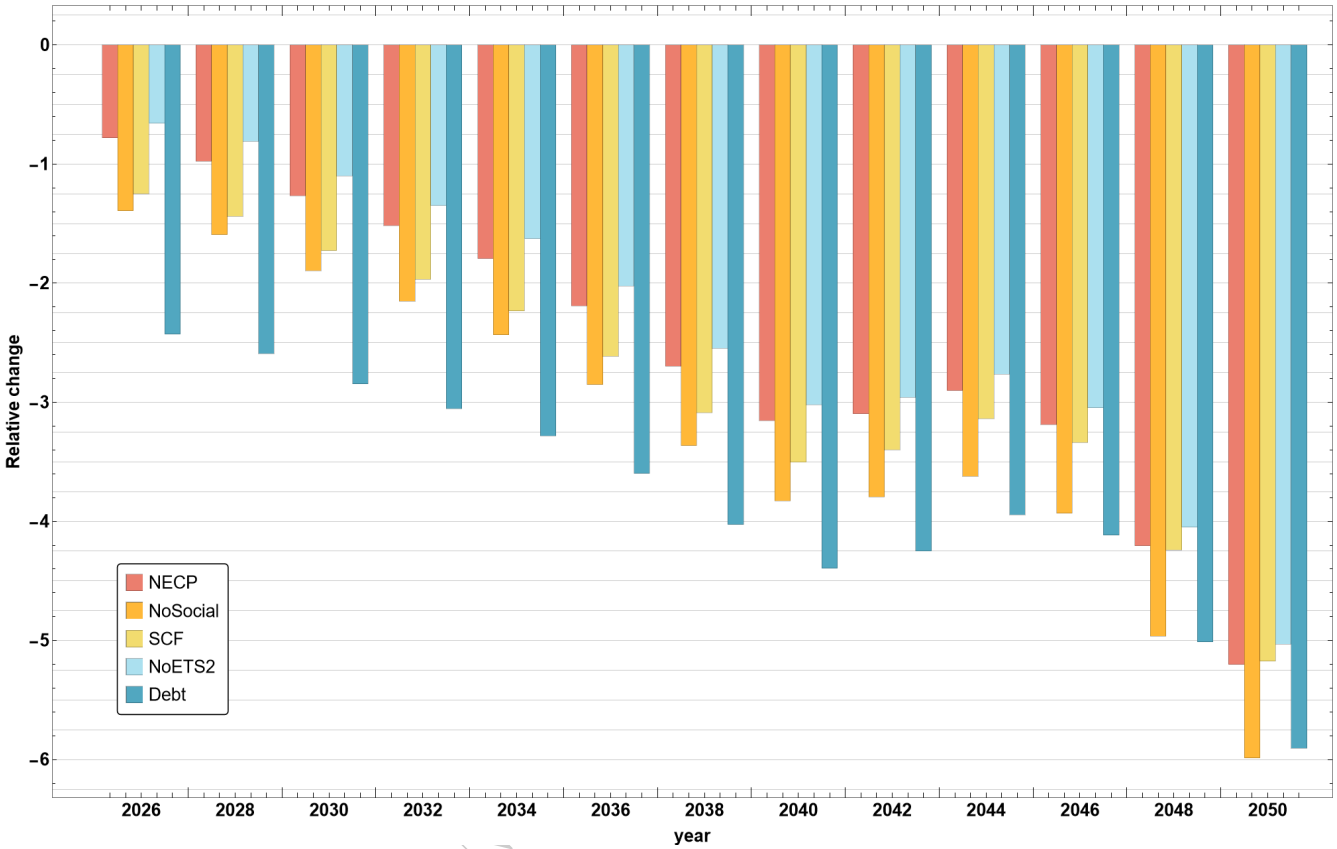


Figure 9: Relative deviation (in %) from baseline - Wages

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## Consumption

Household consumption shows more pronounced short-term volatility than aggregate production or investment, with alternating periods of expansion and contraction reflecting the interaction between carbon pricing, revenue recycling policies, and transitional sectoral shifts. Over the long term, scenarios diverge sharply based on the extent of household support in the policy mix.

In the initial years 2025-2030, most scenarios see modest consumption gains (0.5% to 1.5%) relative to WEM, driven by social support that offsets early increases in energy costs. The Debt scenario is an exception, showing little to no improvement, as revenues are used exclusively for debt reduction rather

than household support. Scenarios with more generous transfers (NECP, SCF) show the strongest early gains.

As carbon prices rise and the first wave of industrial restructuring takes hold during the 2030-2034 period, household consumption drops below the baseline in all scenarios (–0.5% to –2%). Higher energy and goods prices outpace the mitigating effect of transfers, particularly in scenarios without targeted household support (NoSocial, Debt).

The period around 2035 sees a rebound, with gains of up to +3% in scenarios with significant household transfers and BEV subsidies. The ban on new combustion-engine passenger vehicles, coupled with efficiency improvements, shifts spending toward lower-operating-cost technologies, freeing disposable income for other consumption. The Debt scenario again lags, with smaller peaks due to the absence of demand-side stimulus.

After 2040, consumption declines sharply (–1% to –4%) during this period as emission allowance prices reach their highest levels and the economy undergoes the final stages of coal phase-out and industrial restructuring. Scenarios with no direct household transfers (NoSocial, Debt) experience the steepest drops, as high energy and goods prices erode real incomes without compensatory measures.

By the end of the projection period, household consumption rises in all scenarios, with relative gains exceeding +7% in NECP, SCF, NoSocial, and NoETS2, and only slightly lower in Debt. Even in the Debt scenario—despite the absence of household transfers during the transition—long-run efficiency improvements, lower operating costs for vehicles and housing, and a stabilized energy price environment boost real incomes. This suggests that while lack of early demand support delays benefits, the structural cost savings of a decarbonized economy eventually raise consumption across the board.

NECP scenario appears to bring the highest benefits to households throughout the period. Strong early and late gains are due to comprehensive revenue recycling, although mid-transition price pressures cause temporary dips. SCF has a slightly smaller early boost than NECP due to diversion of some transfers into BEV and efficiency subsidies, but stronger mid-transition resilience as these investments lower household costs over time. NoSocial lacks early gains, but achieves strong late-stage growth once efficiency savings accumulate. Moderate mid-transition losses occur in NoETS2 thanks to lower carbon costs in transport and buildings, but late-stage gains are smaller than in NECP/SCF. Finally, Debt scenario brings consistently lowest household consumption due to absence of direct or indirect household support.

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### Government Spending

Government spending (in the form of the provision of a public good) is modeled as a Leontief composite financed through several forms of taxes (labor, capital, energy, excise, consumption, etc.). As such, Relative changes in government spending are primarily determined by changes in government income. Changes in Government income under all WAM scenarios follows a similar downward trend, generally falling by 8 percentage points between 2025 and 2050 for any given scenario, a similar magnitude as the one characterizing government spending in Figure 11.

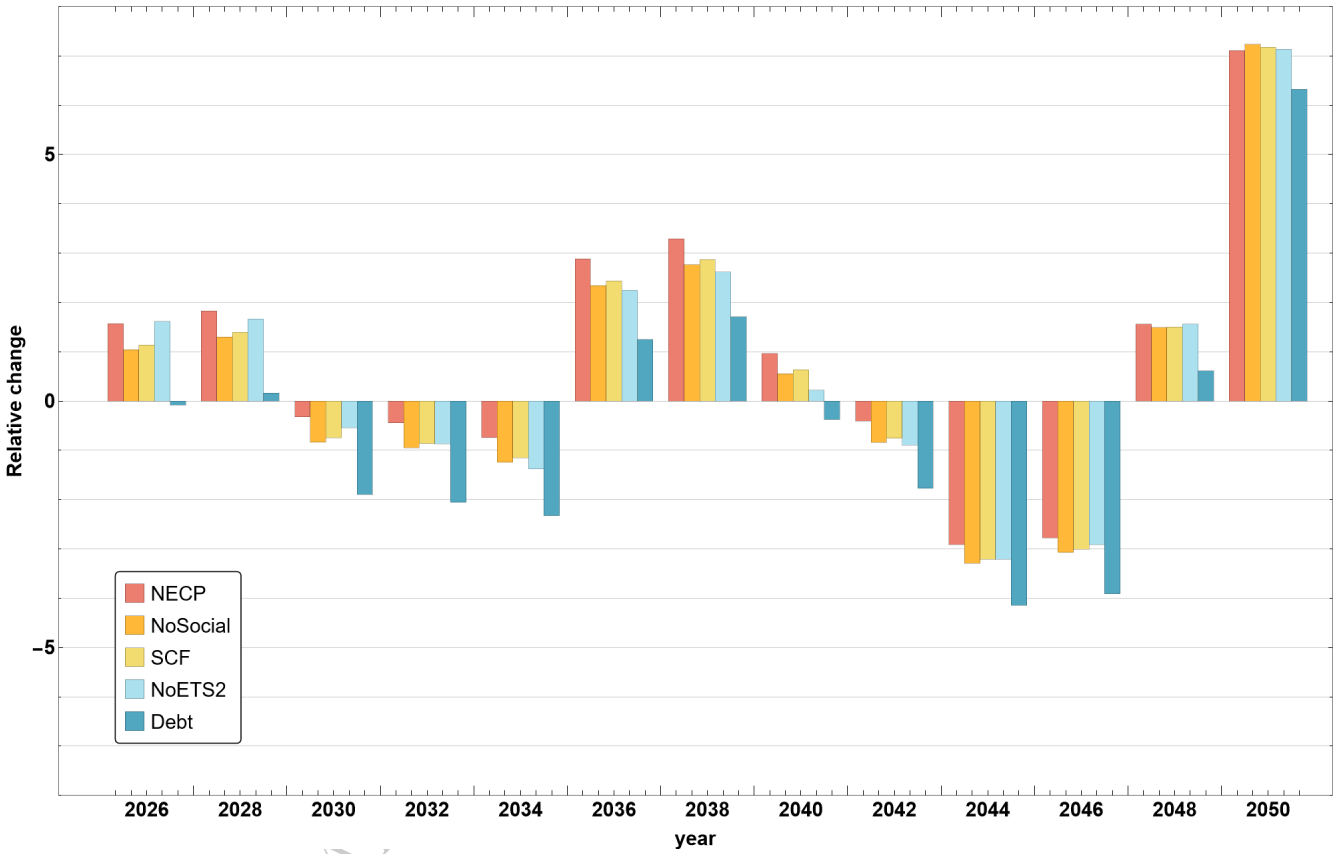


Figure 10: Relative deviation (in %) from baseline - Aggregate Consumption (Households)

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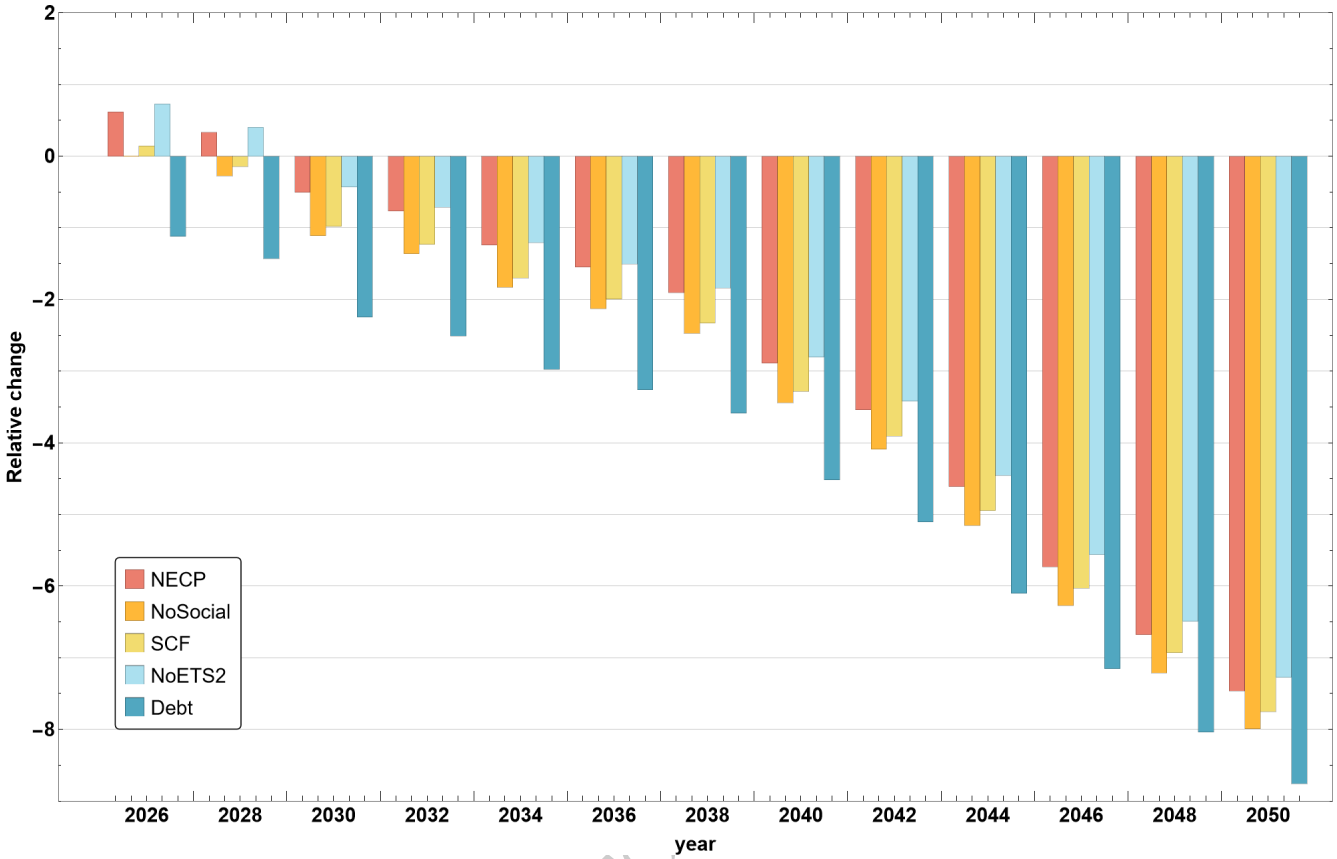


Figure 11: Relative deviation (in %) from baseline - Government Spending

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In general, all scenarios show a significant downfall in the revenue from excise tax on fossil fuels for sectors (TYE). For example, under the WAM_NECP scenario, revenue from excise tax on fossil fuels for sectors decreases by almost 50% in 2045, in line with the reduced output of the corresponding sectors (COAL, CRUDE, GAS, fuels). The increased electrification under all WAM scenarios is insufficient to compensate for the loss of government revenues due to the higher EUA ETS prices under WAM. Labor Tax (TL) experiences moderate fluctuations around -5% throughout the modeling horizon, indicating shifts in labor income and changes in labor tax policies over the years, as a tool used for part of the recycling of revenues stemming from the EU ETS. The diesel fuel excise tax (TD) shows a notable decrease after 2035 by about -20% , reflecting reduced diesel usage due to environmental policies and market trends shifting the demand for personal individual transport towards alternative fuel vehicles. The petrol fuel excise tax (TMO) decreases less swiftly and reaching an approximate 15% reduction by 2045, as petrol cars are phased out at a slower rate than diesel cars (see Figure 12).

Ultimately, the ordering of the scenarios in terms of their relative impacts on government spending depend on how beneficial each scenario is in terms of additional government revenue. Hence, with no

surprises, the results of government spending mirror changes in GDP.

### 4.2 Vehicle fleet and New registrations

Figure 12 shows the new yearly registrations of private vehicles by technology for both WEM and all WAM scenarios. In general, both WEM and WAM scenarios are characterized by a rapid replacement of newly registered internal combustion vehicles from 2035 onward. From 2025 to 2035, AFVs account for less than 2% in the WEM scenario, and for about 10 to 20 percent of yearly new registrations in WAMs, with petrol vehicles accounting for the vast majority of new purchases in all scenarios.

While all scenarios are characterized by essentially only battery electric cars in 2050 purchases, the adoption of alternative fuel vehicles takes place at a significantly faster rate in WAM variations compared to WEM. In WEM, the replacement of ICEs by AFVs in new registrations after 2035 occurs gradually, with AFVs representing roughly 68% of total new vehicle purchases in 2035 and increases every year by about 2 pp, whereas in WAM scenarios, AFVs registration reach 94% right after 2035.

The relatively accelerated adoption of AFVs in WAMs is reflected in the stock of private vehicles shown in Figure 13. As a result of the progressive phase-out of ICEs in favor of AFVs in new registrations following the 2025-2035 period, and the retirement of old vehicles, all scenarios experience a gradual maturing of the AFV fleet in the Czech Republic, which attains the 50% mark by 2046 and 2044 in WEM and WAM scenarios, respectively.

### 4.3 Emissions

Year-on-year reductions in CO2 emissions are presented in Figure 14. The WAM_NECP scenario is characterized by pronounced emission reductions in the power sector, where year-on-year emission reductions surpass the 60% mark after 2040 as a result of a strong decrease in electricity generation from coal and natural gas. In addition, emissions from individual transportation show a continuous decrease among all WAM scenarios with respect to WEM, as a result of a higher presence of new registrations of BEVs as seen in Figure 12. The decrease in yearly emissions from private transport plateaus around 2038-2043 for all WAM scenario variations, when the relative difference in the number of BEVs between WEM and WAMs is the highest. After this period, the adoption of electric vehicles in WEM accelerates until attaining a similar number of newly registered cars as in the WAM scenarios. As the fleet of AFVs in both scenarios matures over time, the year-on-year emission reductions in the individual transport sector slow down.

At the economy-wide level, continuous emission reductions take place throughout the entire modeling period and for all WAM scenarios relative to WEM. Not surprisingly, the NoETS2 scenario is characterized by slower emission reductions relative to WEM, compared to all other WAM scenarios considered, as the lack of an EU ETS2 system lessens the pressure to reduce the intermediate consumption of dirty fuels. By 2050, year-on-year emissions are 5 percentage points lower in the WAM_NECP scenario compared to WAM_NoETS2. In general, all WAM scenarios with an operating EU ETS2 behave similarly. However, the NoSocial scenario, characterized by allocating the highest share of the EU ETS1 and ETS2 revenue towards the promotion of energy efficiency, attains the highest year-on-year emission reductions. On the

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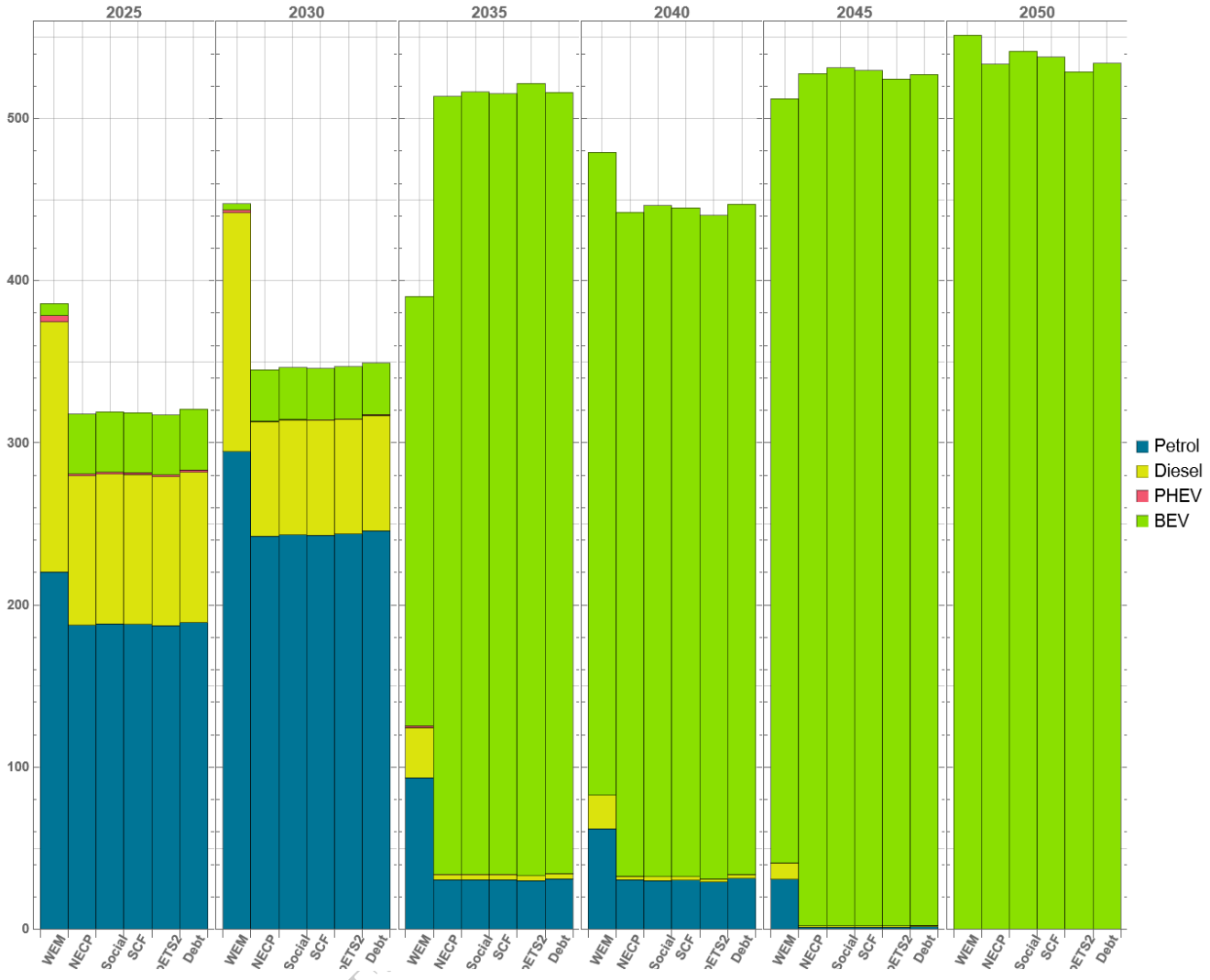


Figure 12: New registration of private vehicles by technology (thousands)

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other hand, both the NECP and the SCF scenarios allocate a share of the revenue collected from carbon pricing to the provision of lump-sum transfers to households and to the provision of public goods (Figures 10 and 11). As a result, they perform slightly worse in emission reductions.

# 5 Post-Keynesian versus Neoclassical modeling approach

To better understand the role of climate policies in achieving an efficient and successful green transition, macroeconomic models are routinely used and developed within research institutes and large supranational

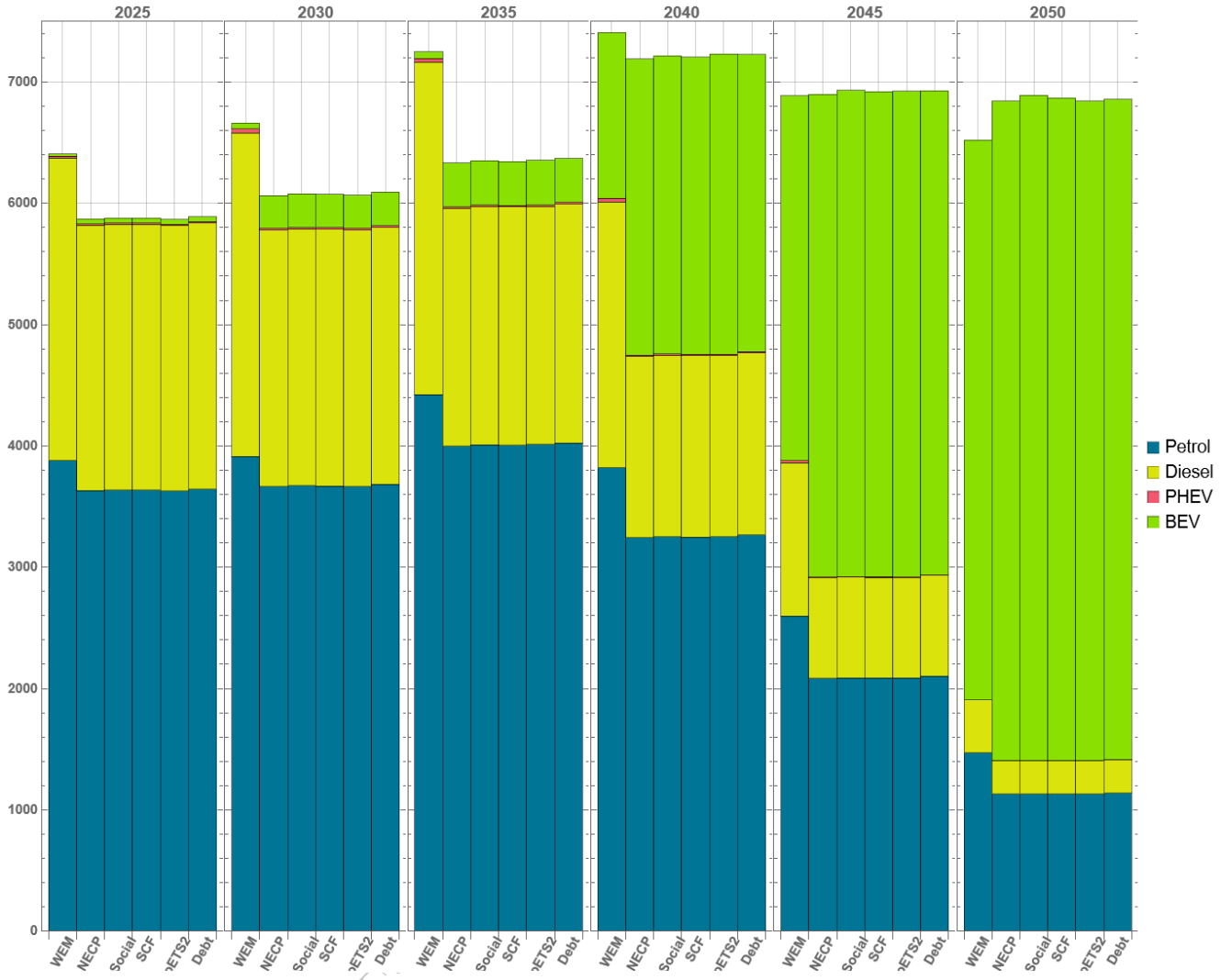


Figure 13: Stock of private vehicles by technology (thousands)

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and national bodies. The popularity of these types of models in climate economics research stems from the deep societal transformations required to meet climate and energy targets as set out under the Paris Agreement (Williges et al. 2022).

When a piece of regulation is expected to affect several sectors, and hence influence aggregate macroeconomic variables such as employment, economy-wide models provide a systemic perspective for analyzing and identifying indirect and unintended policy effects that sectoral or partial-equilibrium models might overlook (Carbone et al. 2022).

Due to the complexity of socio-economic systems, the economy-wide effects of environmental regulation

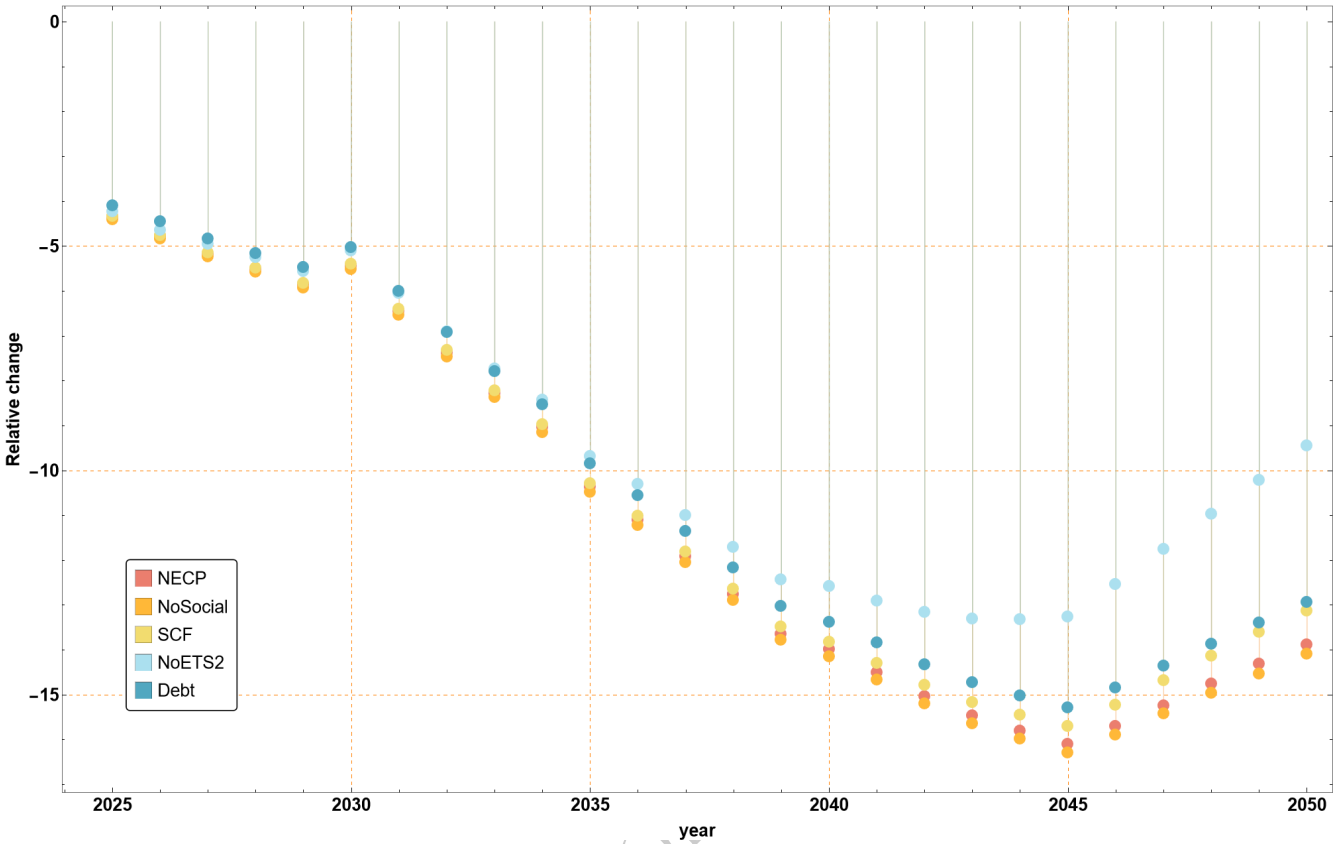


Figure 14: Relative deviation (in %) from baseline - Total CO2 Emissions

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are subject to various kinds of uncertainty. Here, uncertainty is understood in its Knightian sense—an immeasurable lack of knowledge (Knight 1921)—and can be categorized in many different ways. A relevant distinction in the science–policy interface, discussed by Bachner et al. (2020) drawing on the work of Reilly and Willenbockel (2010), identifies three broad types of uncertainty: technical, methodological, and epistemological. Of particular interest here, epistemological uncertainty refers to "changes in human behavior and values, technological surprises, and high impact-high uncertainty events, but also to deeper uncertainty such as randomness and surprises" (Bachner et al. 2020). When models based on different economic theories, behaviors, and relationships are available, multi-model comparisons provide a powerful framework for addressing epistemological uncertainty (Bachner et al. 2020; Hartvig et al. 2025; Gillingham et al. 2018).

In the context of economy-wide E3 (energy, economy, environment) modeling, two broad economic schools of thought have been operationalized: equilibrium economics and non-equilibrium economics Mercure et al. 2019. Under equilibrium economics, based on Post-Walrasian neoclassical economics, the actions of all agents are coordinated through flexible prices that adjust according to market-clearing conditions for production factors such as labor or capital. The decisions of representative agents (firms,

households, government, etc.) are such that, given technology and resource constraints, and market imperfections (such as pre-existing tax systems), all remaining actors are fully employed in the most efficient way. Given these central mechanisms, equilibrium-based models are also referred to as *supply-led* models.

While the non-equilibrium economics school of thought is very diverse (see (Proctor 2023) for a recent review), we focus our attention in the remainder of this section to the Post-Keynesian paradigm.

In a complex world with fundamental (Knightian) uncertainty, it is not possible for agents to make optimal decisions. This deep uncertainty introduces a deficient effective demand, as a share of revenue (from households, for example) is saved in case of future unexpected emergencies. When a portion of the economy's income is saved rather than spent, the economy ultimately operates below full capacity utilization (Econometrics 2022), and production is determined by aggregate demand rather than aggregate supply as in equilibrium-based models. In such cases, additional demand stimulus can activate available resources, generating additional output and income.

This fundamental difference between supply and demand-led models is particularly relevant in the context of deep decarbonization scenarios, where significantly higher levels of investment, compared to a business-as-usual scenario, are expected in certain key sectors, such as power generation or transportation. In an equilibrium-based system, the allocation of investment (determined as a fixed proportion of income) among industries/activities takes place in a market, in which firms compete for this scarce resource. The demand for money by different sectors at the same time is cleared by the interest rate, meaning that firms/industries may be outbid by the willingness to pay of others, thus generating what is called a *crowding-out* effect.

In a non-equilibrium model, such as E3ME, by contrast, the presence of spare resources allows investment to be unconstrained, determined instead by industries' willingness to invest and banks' willingness to lend. In such settings, crowding-out is not a systematic outcome, and positive effects on aggregate employment and economic activity—as measured through GDP—may arise in the short to medium term.

To illustrate the differences in the results, the rest of the section shows the impacts of WAM scenario variations on GDP and Employment in the E3ME model.

The relative change graph in Figure 15 shows how Czechia's GDP deviates from the baseline across five WAM scenarios from 2026 to 2050 in the E3ME model. Its demand-led structure highlights how differences in ETS revenue recycling directly affect growth trajectories.

NECP, noSocial, SCF, and noETS2 all deliver early GDP gains of around +1.5% to +2.2% over baseline until 2034, driven by strong investment and spending multipliers from ETS revenue recycling. Debt lags significantly and even dips negative in 2034. By diverting revenues to debt repayment, it removes spending from the economy, dampening demand in a period when green investment could be most expansionary.

GDP gains peak in the phase 2036–2040, with noETS2 reaching +3.8% in 2038, benefiting from the absence of additional ETS costs in transport and buildings, which preserves short-term household and business spending power. NECP, noSocial, and SCF follow closely (+3% to +3.3%), showing that both

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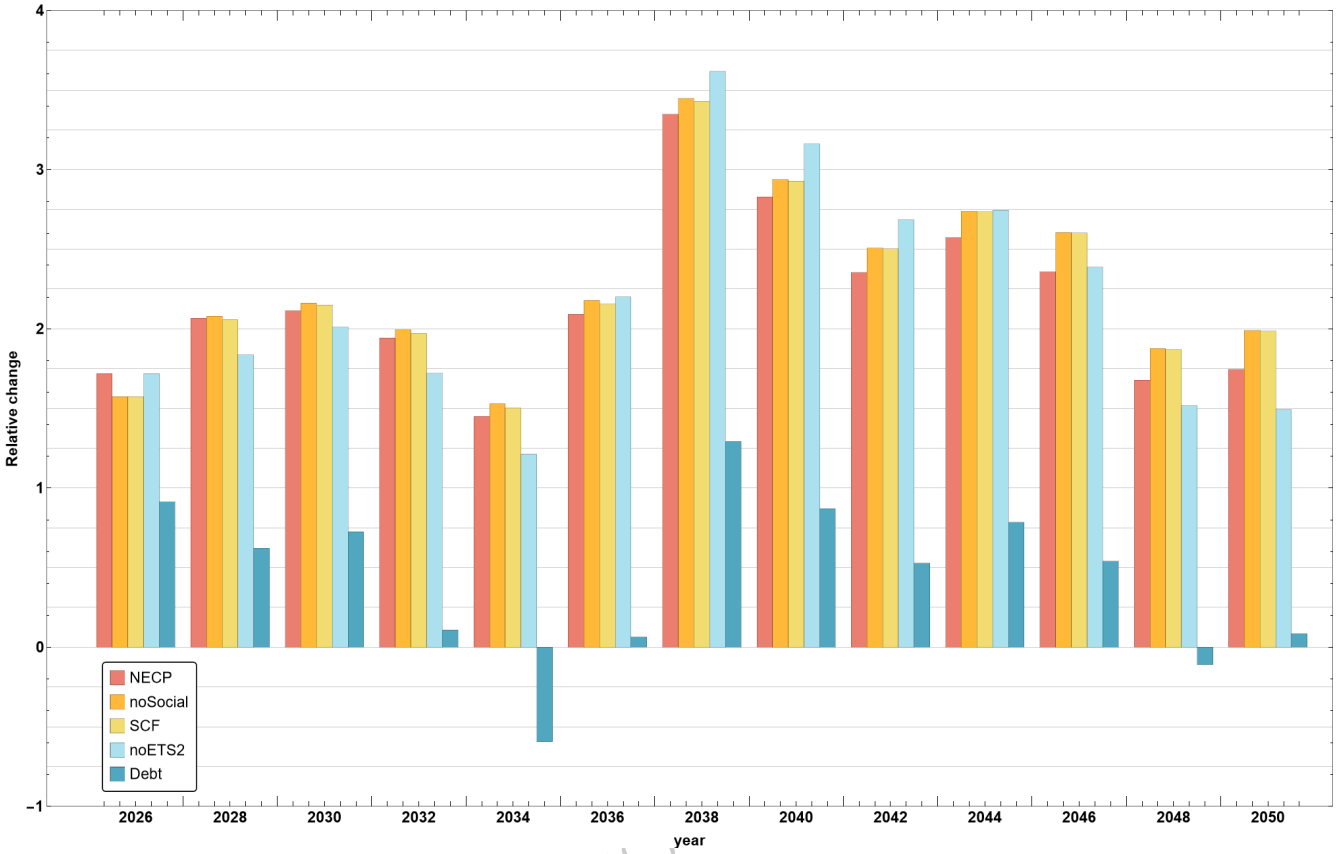


Figure 15: Relative deviation from baseline (in %) - GDP E3ME

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green investment–only (noSocial) and mixed social-investment strategies (NECP, SCF) can sustain strong growth momentum once low-carbon infrastructure and technologies scale up. Debt remains the weakest performer, with gains of only +1.2%, highlighting the opportunity cost of not reinvesting carbon revenues.

After 2040, GDP gains gradually decline from their peak but remain positive in all scenarios except a small negative blip for Debt in 2048. NECP, noSocial, and SCF converge around 2% by 2050, indicating that long-run growth benefits from earlier investment are maintained. noETS2 also converges toward these levels, suggesting that its early advantage diminishes once other sectors fully decarbonize and efficiency gains are realized. Debt closes some of the gap late in the period but still finishes well below the investment-heavy scenarios.

In the E3ME demand-led framework, recycling ETS revenues into productive green investment and/or household support is consistently associated with higher GDP over the transition period. Pure green investment (noSocial) maximizes long-run GDP but may risk short-term social equity concerns. Balanced strategies (NECP, SCF) maintain almost the same GDP benefits while also cushioning households against transition costs, potentially improving political durability. Debt repayment strategies offer no comparable

macroeconomic or social advantage, showing that withholding green investment during the transition undermines economic resilience.

Figure 16 shows the relative changes in employment. Across all WAM variations, employment shows an overall relative increase compared to the WEM baseline until the early 2040s, followed by a gradual decline. The peak gains occur around 2029–2039, with relative changes of about +1.5% to +2.1% in most green-investment scenarios. Post-2040, all scenarios experience a convergence towards lower gains, and some—particularly Debt—turn negative by the late 2040s.

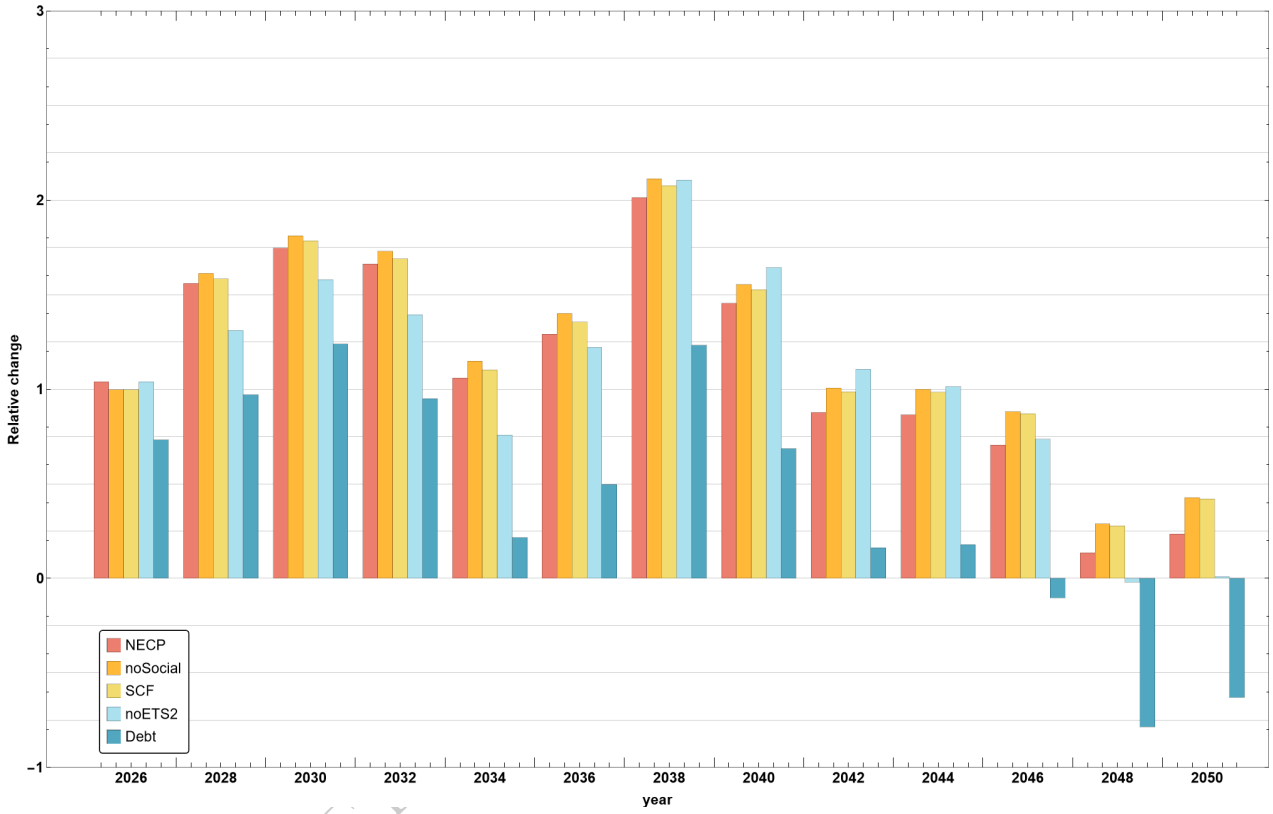


Figure 16: Relative deviation from baseline (in %) - Employment E3ME

NECP, noSocial, and SCF maintain the highest employment gains through most of the projection period. Debt shows the weakest performance—gains are smaller in the early years and turn negative by 2048–2050. This reflects the opportunity cost of diverting ETS revenues away from productive investment into debt repayment, leading to lower economic activity and job creation. The noETS2 scenario produces slightly weaker employment gains compared to NECP, especially before 2040. Without ETS2, revenue recycling is smaller and the incentive for energy efficiency in households and transport is weaker—leading to lower induced investment and job creation. SCF yields employment outcomes very close to NECP—sometimes marginally higher in peak years—suggesting that reallocating transfers towards targeted sectoral measures can be slightly more labor-intensive. The fall in relative gains after

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the early 2040s coincides with completion of major transition investments, stabilization of the low-carbon economy, and demographic/automation pressures. In Debt, this decline is steep—turning negative—while in green-investment scenarios, it remains positive but gradually narrows to under +0.5% by 2050.

In summary, scenarios that reinvest ETS revenues into decarbonization and supportive social measures (NECP, noSocial, SCF) deliver the most sustained employment benefits. Excluding ETS2 reduces—but doesn't eliminate—these gains. Diverting funds to debt reduction not only forgoes potential job creation during the transition but also risks long-term employment losses compared to the baseline.

# 6 Conclusion

This report has assessed the macroeconomic, environmental, and distributional consequences of alternative strategies for recycling revenues from the EU ETS and ETS 2 in the Czech Republic, using a detailed hybrid Computable General Equilibrium model (MERCI-CZ) enriched with sectoral detail and behavioral components. The analysis confirms that carbon pricing, when combined with carefully structured revenue use, can deliver both emissions reductions and economic co-benefits, but that policy design choices create significant trade-offs between short-term economic stability, long-term structural change, and social equity.

Across all scenarios, the transition to climate neutrality by 2050 entails notable macroeconomic adjustments, with GDP in 2050 projected to be 4.5–6% below a no-Fit-for-55 baseline (WEM). The magnitude and timing of these effects strongly depend on revenue allocation. Scenarios such as WAM NECP and WAM SCF—characterized by a balanced mix of social support and targeted green investments—manage to limit early GDP losses and even produce small short-term gains before the economy faces stronger pressures from rising allowance prices after 2035. These approaches also achieve steady improvements in household consumption, reflecting both direct support measures and the longer-term cost savings from energy efficiency and electrification.

By contrast, the WAM NoSocial and WAM Debt scenarios highlight the risks of excluding household demand stimulus. While these approaches may avoid some of the fiscal outlays associated with transfers, they also dampen consumption in the early years, deepen mid-transition output losses, and delay the social benefits of the green transition. Notably, the Debt scenario—where ETS revenues are used to reduce public debt—performs worst in terms of GDP and consumption in the first half of the transition, although structural cost reductions in later years eventually narrow the gap.

From an environmental perspective, all scenarios with ETS2 achieve significant and sustained emissions reductions, with the NoSocial scenario performing best due to its highest share of revenues devoted directly to energy efficiency and technology adoption. However, these additional reductions come at the expense of weaker short-term economic performance and less direct support for vulnerable households. The NoETS2 scenario shows that excluding transport and buildings from carbon pricing reduces economic costs but slows the pace of decarbonization in these key sectors.

Overall, the findings underline that there is no single "best" recycling strategy, but rather a need for balance. Revenue allocations that blend household support with targeted investments in low-carbon technologies can mitigate distributional impacts, sustain political acceptability, and still deliver deep

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emissions cuts. Conversely, strategies focusing exclusively on fiscal consolidation or technology investment risk undermining social acceptance or slowing economic recovery. The analysis reinforces the importance of aligning carbon pricing with broader fiscal, social, and industrial policy, ensuring that the path to climate neutrality remains both economically viable and socially inclusive.

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# A Appendix: Integration of the discrete choice model into the CGE model

Following (Truong and Hensher 2012), the DC model is used to derive the demand for overall vehicle purchases $\overline{D_i}$, and aggregate vehicle choice probabilities, which are used to split up the demand for overall vehicle purchases into demand for the vehicle purchase choice alternatives.

The deterministic part of the indirect utility $V_{h,}$ of buying a vehicle of type $i$ is given in equation (6), with $x_{k,1}$, being the vector of initial levels for the attributes (see e.g. Train, 2003). [11]

$$V_{kj} = \beta_{kj}^{\mathrm{mc}} x_{h,j}^{\mathrm{mec}} + \beta_{h,}^{\mathrm{c}} x_{hj}^{\mathrm{E}} + \beta_{kj}^{p} x_{kj}^{pp} + \beta_{h,}^{\mathrm{p}} x_{hj}^{\mathrm{p}} + \beta_{h,j}^{\mathrm{n}} x_{hj}^{\mathrm{m}} + \alpha_{kj} \quad \forall h, \forall i \tag{A.1}$$

where purchase price (pp), fuel cost (fc), maintenance cost (mc), engine power (ep), and driving range of BEVs (ra) are the exogenous vehicle specific attributes, $\beta_{k,\lambda}$ represents marginal utilities of these attributes, and $\alpha_{hj}$ is the alternative (i.e. technology) specific constant, or base-preference, denoting a part of the utility for all other characteristics of a given alternative not explicitly described in the DC model. [12]

Following a random utility model (McFadden, 1981) and assuming that the error term $\varepsilon$ is i.i.d standard type I extreme value, the probability $\mathbb{P}_{h,j}$ of agent $h$ to choose alternative $i$, given the prior decision to purchase any vehicle at all, is given as

$$\mathbb{P}_{h,i} = \frac{\exp\left(V_{h,i}\right)}{\sum_i \exp\left(V_{h,i}\right)} \quad \forall h, \forall I. \tag{A.2}$$

Thus, also the probability to choose alternative $i$ contributes to the likelihood to choose alternative $i$ in the conditional logit model (Train, 2003). In the CGE model, these probabilities are interpreted as market shares of vehicles. The endogenous share of purchases of vehicle $i$ in the total vehicle purchases of household $h, \theta_{h,}$, is hence

$$\theta_{h,j} := \mathbb{P}_{h,j} \quad \forall h, \forall i \tag{A.3}$$

In contrast to (Truong and Hensher 2012), (A.1) contains three monetary variables instead of one. Thus, we introduce an aggregated money cost variable, $x_{h,l}^{\mathrm{money}}$, defined as the shadow-price weighted average of all monetary variables

$$x_{h,i}^{\mathrm{moncy}} := \frac{\beta_{h,i}^{\mathrm{mc}}}{\beta_{h,i}^{\mathrm{money}}} x_{h,i}^{\mathrm{mc}} + \frac{\beta_{h,i}^{\mathrm{fc}}}{\beta_{h,i}^{\mathrm{money}}} x_{h,i}^{\mathrm{fc}} + \frac{\beta_{h,i}^{\mathrm{pp}}}{\beta_{h,i}^{\mathrm{money}}} x_{h,i}^{\mathrm{pp}} \quad \forall h, \forall I, \tag{A.4}$$

where we define $\beta_{k,j}^{\mathrm{money}} := \beta_{h,j}^{mc} + \beta_{h,j}^{\mathrm{fc}} + \beta_{h,\lambda}^{\mathrm{pp}}$ as the unique marginal utility of money for each agent $h$. Expressing $V_{hj}$ in terms of $\beta_{h}^{\mathrm{money}}$ and (A.4) yields

$$V_{h,j} = \beta_{hj}^{\mathrm{ever}}\, x_{hj}^{\mathrm{mex}} + \sum_{\mathrm{sher}} \left( \beta_{h,j}^{\mathrm{onher}}\, x_{h,j}^{\mathrm{oher}} \right) + \alpha_{kj} \quad \forall h, \forall i, \tag{A.5}$$

where the index other stands for other non-monetary variables and coefficients. Since $\beta_{kj}^{\mathrm{moey}}$ is gener-

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ally unique for each agent (the disutility of any euro spent is the same for all goods), it does not depend on technology and the subscript $i$ can be omitted,

$$\beta_h^{\text{money}} := \beta_{hj}^{\text{money}} = \beta_h^{\text{money}} \quad \forall i, j, \forall h \tag{A.6}$$

Following (Truong and Hensher 2012), we set an effective price $P_{kj}^{e13}$ as an abstract aggregate price variable inferred from $V_{h,}$. Using this concept, the indirect utility function could be rewritten as:

$$V_{hj} = \beta_k^{\text{money}} P_{kj}^c + \alpha_{kj} \quad \forall h, \forall i i.^4 \tag{A.7}$$

Rearranging (A.7) and using (A.1) for $V_{k,1}$, we get the effective price as the sum of the implicit willingness to pay (defined as $\frac{\beta_{h,i}^n}{\beta_h^{\text{money}}}$ ) for each attribute $x_{hj}^*$ times its value:

$$P_{hj}^e = \sum_n \frac{\beta_{hj}^e}{\beta_k^\infty} x_{hj}^* \quad \forall h, \forall i \tag{A.8}$$

where the index $n$ runs over all vehicle attributes.

To derive the aggregate price $\bar{P}_k$ of purchasing any type of vehicle $i$, we follow (Truong and Hensher 2012) and define the logsum, or inclusive value, $\overline{V_k}$ of all vehicle types as

$$\overline{V_h} := \ln \sum_{kel} \exp\left(V_{kj}\right) \quad \forall h. \tag{A.9}$$

The aggregation procedure cannot follow a simple CES logic, since purchase shares of different vehicle types will change endogenously, also according to non-monetary vehicle attributes. The logsum represents total consumer surplus associated with all choices for a particular choice set, and indicates the expected maximum utility for these choices. Using (A.2), the total differential of this inclusive value equals

$$\mathrm{d}\overline{V_h} = \sum_{i=1} \mathrm{P}_k \, \mathrm{d}V_{hj} \quad \forall h \tag{A.10}$$

Substituting (A.7) for $V_{kj}$ yields

$$\begin{aligned} \mathrm{d}\bar{V}_h &= \sum_{i \in I} \mathbb{P}_{h,i} \, \mathrm{d}\left(\alpha_{h,i} + \beta_h^{\text{money}} P_{h,i}^e\right) \\ &= \beta_h^{\text{money}} \sum_{i \in I} \mathbb{P}_{h,i} \, \mathrm{d}P_{h,i}^e \quad \forall h, \end{aligned} \tag{A.11}$$

and defining the change in the aggregate price for vehicle purchases $\overline{P_A}$ as the sum of the probability-weighted changes in the vehicle types' effective prices

$$\mathrm{d}\overline{P_h} := \sum_{i \in I} \mathbb{P}_{h,i} \, \mathrm{d}P_{h,i}^e \quad \forall h, \tag{A.12}$$

yields

$$\mathrm{d}\overline{V_h} = \beta_h^{\text{money}} \, \mathrm{d}\overline{P_h} \quad \forall h. \tag{A.13}$$

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By integrating (A.13) we have

$$\overline{P_h} = \frac{\overline{V_h}}{\beta_h^{\text{money}}} + c_h \quad \forall h, \tag{A.14}$$

The constant $c_k$ is determined in the calibration procedure such that the equation holds with the initial values of the other variables and parameters.

We now define the price for the IT composite as an endogenously adapting Leontief composite of $\overline{P_h}$ and the price for the use of existing vehicles, $\Theta_h^{\text{prit}}(t)$ denotes the endogenous share parameter of monetary expenditures on vehicle purchases in total expenditures for IT for houschold $h$ in period $t$. This implies a qualitative change in the Leontief consumption nest over time; as new vehicle purchases rise and fall, and as the vehicle stocks build up or shrink, also the expenditures on, and hence the price for, the overall IT composite changes. [16] The determination of the endogenous share parameter $\Theta_h^{\text{pur}}(t)$ in equation (20) depends on both the aforementioned unit demand variables,

$$\Theta_h^{\text{pur}}(t) = \frac{\sum_i e_{hj}^{\text{pur}}(0) D_{kj}^{\text{pur}}(t)}{\sum_j \left[ e_{k,j}^{\text{ver}}(0) D_{h,j}^{\text{pur}}(t) + e_{h,j}^{\text{wee}}(0) D_{k,j}^{\text{wex}}(t) \right]} \quad \forall h, \forall t, \tag{A.15}$$

where $e_{h,j}^{\text{uef}}(0)$ denotes monetary expenditures on fuel and services in the starting period. We assume the use of vehicles $D_{k,j}^{\text{uee}}(t)$ to develop in a constant relationship to the size of their stock. Thus the change in $D_{hj}^{\omega ex}(t)$ will be determined by the change in the stock as

$$D_{h,i}^{\text{use}}(t) = \frac{st_i(t)}{st_i(0)} \quad \forall h, \forall i, \forall t. \tag{A.16}$$

$D_{kj}^{\text{use}}(t)$ is further modified by a demand elasticity for fuel use ( $\eta^{fuel}$ ) that depends on the level of the mineral oil tax to model the effects of fuel exports ("tank tourism"). [17] The share $\Theta_h^{\text{pur}}(t)$ will hence rise in times when more new vehicles are bought, as compared to a steady state development of purchases and the size of the stock, and shrink in times when fewer new vehicles are bought, and will be influenced by the level of mineral oil taxes.

The share $\theta_{k,\prime}^{\prime t}(t)$ in equation (20) is the share of the size of the stock of vehicles of type $i$ in the total stock of vehicles owned by household $h$,

$$\theta_{h,j}^{st}(t) = \frac{st_i(t)}{\sum_j st_j(t)} \quad \forall h, \forall i, \forall t \tag{A.17}$$

with

$$\sum_i \theta_{hj}^{st}(t) = 1 \quad \forall h, \forall t \tag{A.18}$$

This share is known at the beginning of each period $t$, since the vehicle stock $st_i(t)$ is known at the beginning of each period by our convention, see equation (3).

The price for individual transportation, $P_k^{(1\pi}(t)$, can be used to determine overall demand for IT in

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the standard manner by Shephard's Lemma: differentiating the unit expenditure function $\hat{e}_k$ of each household with respect to the price for IT yields unit demand for IT,

$$D_h^{\Pi\pi}(t) = \frac{\partial \hat{e}_h\left(p_x, p_x, \ldots, P_k^{IT}(t)\right)}{\partial P_k^{IT}(t)} \quad \forall h. \tag{A.19}$$

This can also be done at one deeper level, and yields unit demand for purchases of any kind of vehicle as

$$\overline{D_h}(t) = D_h^{\mathrm{IT}}(t)\frac{\Theta_h^{\mathrm{pur}}(t)}{\Theta_h^{\mathrm{pur}}(0)} \quad \forall h \tag{A.20}$$

since the only additional inner derivative when applying Shephard's Lemma at this level (differentiating (20) with respect to $\overline{P_k}$) just yields the share $\Theta_h^{\mathrm{pur}} \cdot \Theta_h^{\mathrm{pur}}(0)$ is the base-year value of this share, which remains constant for all time periods.

The reason for this share to be in the denominator in (26) is because all unit demand variables have to equal the reference growth path in the initial steady state: If the demand variables were expressed in real monetary terms, say

$\overline{\mathbb{D}_h}$ and $\mathbb{D}_h^{\pi}$, then (A.7) would become

$$\overline{\mathbb{D}_h}(t) = \mathbb{D}_h^{\Pi}(t)\Theta_h^{\Gamma\pi}(t) \quad \forall h, \forall t, \tag{A.21}$$

since $\Theta_k^{\mathrm{nur}}$ is a monetary expenditure share. However, since in the initial steady state we have

$$\overline{D_h}(t) = \frac{\overline{D_h}(t)}{\overline{D_h}(0)} \quad \text{and} \quad D_h^{IT}(t) = \frac{\mathbb{D}_h^{IT}(t)}{\mathbb{D}_h^{IT}(0)} \quad \forall h, \forall t \tag{A.22}$$

and, as a special case of (A.20),

$$\overline{\mathbb{D}_h}(0) = \mathbb{D}_k^{\mathrm{IT}}(0)\Theta_k^{\mathrm{pur}}(0) \quad \forall h \tag{A.23}$$

it becomes clear that (26) is the correct formula to use for unit demand variables. More details on calibration to the initial steady state are in section 3.1 and in the SI section A.9.

Combining (26) with (7) and (8) yields the unit demand for purchases of vehicles of type $i$ :

$$D_{hj}^{\mathrm{pur}}(t) = \overline{D_h}(t)\frac{\theta_{hi}(t)}{\theta_{hi}(0)} \quad \forall h \tag{A.24}$$

The price $\overline{P_k}$, the demand $\overline{D_h}$ for overall vehicle purchases, and the demand for purchases of each vehicle type $D_{kj}^{\mathrm{er}}$, depend on exogenous consumer preferences $\beta_{hj}$ and vehicle attributes $x_{hj,}$ which can be exogenously varied in scenario simulations. However, these three variables, $\overline{P_h}, \overline{D_h}$ and $D_{h,j}^{\mathrm{pur}}$ , are also truly endogenous variables, since they depend on the money costs of each choice alternative in particular. This monetary cost is the sum of maintenance, purchase, and fuel costs, all of which are endogenous price variables in the CGE model, determined in the overall economic equilibrium.

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