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Socially Fair Decarbonization Pathways for Housing and Mobility – Insights from a Multi-model Analysis for Austria

TransFair-AT Working Paper #2

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Abstract

The (supposed) regressivity of (primarily price-based) climate protection policy instruments often hampers an evidence-based discussion at the political level and is used as an argument against the implementation of corresponding measures. To assess the distributional implications of decarbonization, we developed climate policy scenarios for the buildings and mobility sectors including targeted compensation measures in close cooperation with stakeholders to identify socially acceptable pathways. Subsequently, three bottom-up sectoral models (for transport demand, vehicle choice and the building stock) were linked to a macroeconomic model to analyze the emission impact, the macroeconomic and distributional effects of the policy portfolios on different household types. The modeling of climate policy scenarios shows that decarbonization of housing and mobility in Austria by 2040 is achievable, but requires a comprehensive policy portfolio and rapid implementation. While climate policies have positive macroeconomic effects, they also exacerbate inequality between different income groups. Therefore, a just transition requires targeted compensation for low- and middle-income households, such as recycling of revenues from carbon pricing, to mitigate adverse effects on income distribution and enable investments in renovation and new heating systems.

Keywords: decarbonization, residential buildings, passenger transport, just transition

JEL codes: Q43, Q54, Q58

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1 Introduction

In line with the Paris Agreement the Austrian government strives for achieving greenhouse gas (GHG) neutrality by 2040. In 2022, total GHG emissions in Austria amounted to 73 $MtCO_2e$[1]. Sectors not covered by the EU Emission Trading System (EU ETS) accounted for 46.2 $MtCO_2e$ of which 26% were caused by individual motorized transport and 10% by residential buildings. While emissions from housing have declined continuously since 1990, emissions from individual motorized transport have increased by almost 60% and have only begun to decline recently (Umweltbundesamt, 2024). Achieving a complete decarbonization by 2040 will be challenging for both sectors: In the transport sector the trend must be reversed; in the housing sector, the building stock must be thermally improved and heating systems must completely shift towards renewable energy sources. The decarbonization will hence require the implementation of a broad range of policy instruments for climate change mitigation – i.e., economic instruments like carbon pricing, subsidies or road pricing, command-and-control policies like building standards or bans of combustion engines and fossil fuel-based heating systems, as well as infrastructure investments.

The introduction of these policy instruments will, however, entail varying effects on different household groups, depending on particular (socio-economic) aspects such as their income, respective work situation (e.g. distance to workplace), financial background (e.g. affordability of a car), household composition, the place of residence (e.g. availability of public transport and other amenities), leisure activities, the home's thermal quality, and the heating system used. The (presumed) regressivity of policy instruments – most notably fiscal measures – very often impedes an evidence-based discussion on the political level and is used as an argument against the implementation of respective measures, especially in times of low economic development.

So far, there is limited evidence on the distributional effects of climate policies beyond carbon pricing. Table 1 provides an overview of previous studies that evaluated the impacts of various climate policies in the passenger transport and buildings sectors on different income groups. With respect to transport, the literature suggests that vehicle standards and subsidies tend to be regressive, disproportionately burdening lower-income households (Baldenius et al., 2021; Levinson, 2019; Lucas and Pangbourne, 2014; Zachmann et al., 2018). For instance, vehicle efficiency standards and energy efficiency programs often place a heavier financial load on poorer households, as they are less likely to benefit from the advantages associated with new vehicles. Policies like eco-driving and fuel economy standards also tend to be regressive, with the benefits skewed towards those with higher mileage or newer vehicles. Findings regarding infrastructure expansion and support measures in transport are mixed. Public investments in low-carbon infrastructure can vary in their impact depending on whether they cater to low-income or high-income households. For example, while public transport fare reductions are progressive, benefiting low-income households who rely more on public transport (Zachmann et al., 2018), an assessment of cycling infrastructure investments in Scotland shows a more complex picture (Lucas and Pangbourne, 2014): Although there is demand for cycling infrastructure, low-income households are less likely to cycle, suggesting that careful planning is needed to ensure equitable access. Commuting allowances present a dual perspective: Evidence from Germany suggests that they are regressive, benefiting higher-income households more (Heuermann et al., 2017; Jacob et al., 2016). A study by Steinsland et al. (2018) shows, however, that in Norway residents

[1] All figures excluding emissions from land use, land use change and forestry (LULUCF).

from the least affluent, rural communities benefit most strongly from commuting allowances. For Austria, findings are in line with those for Germany, showing that commuter allowances are biased towards wealthier households (Kletzan-Slamanig et al., 2022). Conversely, public transport fare reductions are progressive, as low-income households depend more on public transport options (Lucas and Pangbourne, 2014). Road pricing is generally seen as imposing a heavier financial burden on lower-income households, as the tolls and fees represent a larger percentage of their income compared to higher-income groups. For instance, Eliasson (2016), Santos and Caranzo (2022) and Safirova et al (2004) emphasize that road pricing disproportionately affects those with lower incomes, making it a regressive policy. The complexity of road pricing impacts is further illustrated in the study by Heyndrickx et al. (2021), which suggests that the effects depend on use of revenues from road pricing. While certain government expenditures and progressive tax credits can mitigate regressive impacts, other measures, such as earned income tax credits and regional surcharges, may exacerbate the burden on lower-income households.

The analyses of policies in the building sector reveal a similar pattern of regressive impacts. Building energy codes may disadvantage lower-income households by decreasing the value of their homes or forcing them into smaller apartments (see Brügge et al., 2018, for Canada). With respect to subsidies, evidence is mixed: For Germany, Jacob et al. (2016) find that subsidies for refurbishment are progressive and benefit low-income households. However, many energy-related subsidies tend to favor high-income households, underscoring the need for policies that ensure equitable support across different income levels (Borenstein and Davis, 2016; Fernández et al., 2024; Lekavičius et al., 2020; Zachmann et al., 2018).

To address these challenges, this paper comprehensively evaluates the impacts of two distinct policy mixes for decarbonizing passenger transport and housing[2] on different household types. The first policy mix focuses on the achievement of full decarbonization by 2040 without addressing (potential) distributional issues, while the second policy mix is designed to simultaneously achieve emission reduction targets and compensate particularly vulnerable groups, so that income inequality does not increase. These policy mixes were developed through the integration of stakeholder knowledge and are analyzed using a novel methodological approach. For the analyses of the policy packages, we iteratively link the macroeconomic model DYNK with three bottom-up models – the Invert/EE-Lab model for buildings, the MARS model for transport demand, and the SERAPIS model for vehicle propulsion technology choice. This approach accounts comprehensively and simultaneously for heterogeneous transportation demand behavior, heterogeneous residential energy demand for heating, and economy-wide feedback. While our main focus lies on vertical inequality, i.e., differences between household income groups, we also consider horizontal inequality, i.e., examining how household characteristics such as public transport accessibility and regional disparities shape the outcomes of these policies.

2 In the proposal the following terms are used synonymously to denote the two sectors under consideration: passenger transport, transport sector, mobility sector as well as residential buildings, buildings sector, housing, residential sector.

Table 1. Overview of studies analyzing distributional effects of climate policy instruments in the sectors mobility and housing (excluding carbon pricing)

Policy instrument	Distributional Effect/Mechanism	Source	Country	Period	Method
Transport					
Vehicle standards					
CO_2 emission standards	Regressive: More regressive than fuel taxes	Zachman et al. (2018)	NA	NA	Impact chain analysis
CO_2 emission standards	Regressive: LI-HH smaller vehicles, burden relative to income higher	Baldenius et al. (2021)	DE	2017	Micro-data analysis
Fuel economy standards	Regressive: More regressive than fuel taxes	Levinson (2019)	US	2009	Micro-data analysis
Fuel economy standards	Mixed: Mildly progressive for new vehicles, mildly regressive for old ones	Davis & Knittel (2016)	US	1979-2012	Econometric
Infrastructure expansion					
Public investment in low carbon infrastructure	Mixed: Depends on whether it increases demand for capital or low-skilled labor or used by LI-HH (buses) or HI-HH (high speed rail)	Zachman et al. (2018)	NA	NA	Impact chain analysis
Public investment in cycling infrastructure	Mixed: LI-HH are less likely to cycle, but there is demand, expansion should be prioritized in LI areas	Lucas & Pangbourne (2014)	GB-SCT	NA	Multi-criteria assessment
Commuting allowance					
Commuting allowance	Regressive: Reduces tax burden predominantly for HI	Jacob et al. (2016)	DE	NA	Microsimulation model
Commuting allowance	Regressive: Reduces tax burden predominantly for HI	Heuermann et al. (2017)	DE	2004-08	Micro-data analysis
Commuting allowance	Regressive: Reduces tax burden predominantly for HI	Kletzan-Slamanig et al. (2022)	AT	2016-20	Micro-data analysis
Abolition of commuting allowance	Regressive[1]	Steinsland et al. (2018)	NO	NA	Transport demand model
Public transport fare reductions					
PT fare reductions	Progressive: LI-HH already depend more on PT	Lucas & Pangbourne (2014)	GB-SCT	NA	Multi-criteria assessment
Subsidies					
Subsidies for PT	Mildly progressive: Discounts for students, retired	Börjesson et al. (2020)	Stockholm	2015	Micro-data analysis
Subsidies for e-vehicles	Regressive: Subsidies mainly go to HI-HH	Zachman et al. (2018)	NA	NA	Impact chain analysis
Subsidies for e-vehicles	Regressive: HI-HH drive e-vehicles	Baldenius et al. (2021)	DE	2017	Micro-data analysis
Subsidies for e-vehicles and CNG-vehicles	Regressive: E-vehicles for HI-HH	Reanos & Sommerfeld (2018)	DE	NA	Econometric
Tax credits for e-vehicles	Very progressive: 90% HI-HH	Borenstein & Davis (2016)	US	2006-16	Micro-data analysis
Road Pricing					
Road pricing	Regressive: Imposes a burden representing a higher share of income for LI-HH	Santos & Caranzo (2022)	UK	NA	Micro-data analysis
Road pricing	Regressive: HI pay more tolls, but less as a share of income	Eliasson (2016)	SE	2011-2013	Survey
Road pricing	Regressive: HI pay more tolls, but less as a share of income	Safirova et al. (2004)	US	NA	Microsimulation model
Road pricing (fuel/street/period)	Depends on recycling scenario. Government expenditures und progressive tax credits are progressive, earned income tax credit and regional surcharge discounts are regressive. The impact on individual household income is very heterogeneous.	Heyndrickx et al. (2021)	NL	NA	CGE/Microsimulation
Road pricing	Regressive	Steinsland et al. (2018)	NO	NA	Transport demand model
Road pricing commuting	Progressive: Higher rates tend to be worse for HI because they do not switch to PT	Bureau & Glacant (2008)	FR	2001-2002	Econometric

Policy instrument	Distributional Effect/Mechanism	Source	Country	Period	Method
Other policy instruments					
Bonus-Malus for vehicle insurance	Progressive: For LI-HH bonus is higher relative to income	Baldenius et al. (2021)	DE	2017	Micro-data analysis
Vehicle bans in cities	Slightly progressive. Moreover, high costs for rural areas because of worse public transport	Baldenius et al. (2021)	DE	2017	Micro-data analysis
Change of regulation regarding private use of company cars	Progressive: HI-HH commute more, Recycling: Progressive for increase in basic tax-free allowance, regressive for proportional tax reduction	Jacob et al. (2016)	DE	NA	Microsimulation model
Eco-driving	Regressive: Groups with higher mileages (HI) will benefit the most	Lucas & Pangbourne (2014)	GB-SCT	NA	Multi-criteria assessment
Buildings					
Standards					
Building energy codes	Regressive: House value for LI-HH decreases, LI-HH get smaller apartments	Brügge et al. (2018)	CA	2009-15	Econometric, diff-in-diff
Subsidies					
Increase existing subsidies for refurbishment	Progressive: LI-HH live in worse houses and benefit more from energy costs savings	Jacob et al. (2016)	DE	NA	Microsimulation model
Tax credits for solar and home improvement	Regressive: Credits go to HI-HH	Borenstein & Davis (2016)	US	2006-16	Micro-data analysis
Subsidies for exchange of heating system	Regressive: Subsidies mainly go to HI-HH	Lekavicius et al. (2020)	LT	NA	Microsimulation
Subsidies for PV installation	Regressive: Subsidies mainly go to HI-HH	Lekavicius et al. (2020)	LT	NA	Microsimulation
Subsidies for refurbishment and rooftop-solar	Regressive: Subsidies mainly go to HI-HH	Zachman et al. (2018)	NA	NA	Impact chain analysis
Subsidies for refurbishment	Regressive: Favors owner-occupied housing (HI-HH)	Fernandez et al. (2024)	NL	NA	Econometric
Subsidies for refurbishment	Regressive [2]	Drivas et al. (2019)	GR	2011-15	Econometric

Source: Own representation. HH: households; LI: low income; HI: high income; PT: public transport. [1]In Norway, residents from the least affluent, rural communities benefit most strongly from commuting allowances. [2]However, LI-HH increase participation more strongly when subsidies are raised.

The structure of the paper is as follows: In section 2, we present the stakeholder integration approach that we used to develop the policy packages and provide a short description of the modeling approach. We then present the results of our model simulations regarding the development of CO_2 emissions, the macroeconomic effects, and the distributional impacts. After a discussion of our results in section 4, we present conclusions to be drawn from our analyses in section 5.

2 Methods

2.1 Integrating stakeholder knowledge in the design of policy packages

Involving stakeholders in the design of policy mixes for model simulations can significantly enhance the representation of real-world challenges and solutions (Hirsch Hadorn et al., 2006). This is particularly important given the social and political complexities associated with climate policies (Green and Healy, 2022; Williges et al., 2022). Furthermore, stakeholder engagement can help identify and address issues that lie beyond the scope of modeling frameworks (van Dijk et al., 2023). Recognizing these benefits, we sought to integrate stakeholder knowledge into the design of our policy scenarios to

1. incorporate stakeholder insights regarding the effectiveness and fairness of proposed policy measures, and
2. enhance the likelihood of policy mix acceptance when disseminating the results.

To achieve this, we organized, due to COVID restrictions at that time, an interactive online workshop, inviting key stakeholders from Austrian NGOs, public administration, advocacy groups, and research institutions. A total of 18 stakeholders participated. To ensure seamless and constructive online engagement, we utilized the platform **Miro**, which allows participants to contribute ideas and comments collaboratively on a virtual whiteboard. The Miro boards were prepared and rigorously tested in advance by the project team to ensure usability.

Stakeholders were divided into two groups based on their area of expertise – one focusing on passenger transport and the other on housing. Participants were then tasked with the following activities, considering both climate mitigation measures and compensation mechanisms:

1. Brainstorming: Identifying potential measures across pre-defined categories, such as taxes and duties, legal frameworks, regulations, bans, information campaigns, consulting and training, spatial planning, infrastructure, or investment subsidies.
2. Ranking: Evaluating and prioritizing measures based on their perceived importance, effectiveness, and fairness.
3. Discussion: Providing detailed comments on the advantages and disadvantages of the proposed measures.

This process generated a wealth of valuable information that significantly informed the design of our policy packages. Table 2 provides an overview of the stakeholders' recommendations and indicates that most of their suggested measures were subsequently incorporated into our policy mixes (for further details on the implementation of these measures, see the next section).

Measures that were excluded from the model simulations were generally outside the scope of the modeling framework. Examples include education and training initiatives, changes to legal requirements, policies ensuring rent neutrality, protecting social milieus against gentrification, and strengthening consumer rights. One notable exception was the suggestion to reduce the Value Added Tax (VAT), which we replaced with a climate bonus transfer. The latter has been demonstrated in prior studies to be a more progressive approach to carbon tax revenue recycling (Kettner et al., 2024; Kirchner et al., 2019; Mayer et al., 2021).

Table 2. Outcomes of the stakeholder workshop

Sector	Category	Measure	Points[1]	Simulated
Mobility	Mitigation	Tax measures	9	Yes
		Expansion of non-motorized individual and public transport	8	Yes
		Spatial planning measures	6	No
		Road toll	4	Yes
		Education	4	No
		Ban on fossil-fueled vehicles	4	Yes
		Speed limit	3	Yes
	Compensation	Increase investments in public transportation	8	Yes
		Eco-bonus	6	Yes
		Make public transportation cheaper / free of charge	6	Yes
		Reduce VAT	4	No
		Eco-social reform of commuter allowance	4	Yes
Housing	Mitigation	Ban on fossil fuel heating systems	7	Yes
		Change legal requirements	6	No
		Infrastructure improvements	5	Yes
		Subsidies	4	Yes
		Tax measures	4	Yes
		Renovation obligation	4	Yes
		Training of qualified personnel	2	No
		Limitation of the maximum living space per person	2	Yes
	Compensation	Transfers	11	Yes
		Promote fossil fuel phase-out	6	Yes
		Rent neutrality	4	No
		Social milieu protection against gentrification	3	No
		Strengthening consumer rights	2	No

[1] Each stakeholder was given three points, which they could assign to the most important measures

2.2 Policy packages in the simulation scenarios

Based on a comprehensive literature review and the results from the stakeholder process, three scenarios were defined for the model simulations (see Table A - 1 for a mapping of measures proposed by the stakeholders to the scenarios). Table 3 gives an overview of the three scenarios: the reference scenario (REF), the decarbonization scenario (CLIM), and the compensation scenario (COMP). In the reference scenario, a CO_2 price for the current Non-ETS sectors is assumed to follow the national pathway, increasing from 30 €/t CO_2 in 2022 to 55 €/t CO_2 in 2025, and 66 €/t CO_2 in the period 2026 to 2040. The national carbon price is accompanied by a flat-rate climate bonus, i.e., lump-sum payments paid to all residents on a per capita equivalent basis. The reference scenario follows a gradual approach to decarbonization across all sectors, with limited measures aimed at promoting thermal refurbishment, energy efficiency, and a shift to renewable heating systems in residential buildings, and moderate shifts to e-mobility, biofuels, and active mobility in passenger transport.

In contrast, the CLIM scenario introduces a more ambitious CO_2 price for the current Non-ETS sectors, increasing linearly to 480 €/t CO_2 in 2040, and a more comprehensive set of decarbonization measures for residential buildings and passenger transport. For residential buildings, measures are assumed to be driven by regulatory policy: The expansion of living space is limited, and renovation rates and the thermal quality of new buildings increase compared to reference scenario. In addition, a ban on new fossil fuel boilers is assumed to be introduced in 2025, and a general operating ban on oil- and gas-based heating systems is assumed for 2035 and 2040, respectively. With respect to mobility, the decarbonization scenario CLIM assumes an improvement of public transport and non-motorized transport services, alongside the introduction of a distance-based road toll and a reduction of speed limits[3], to discourage unnecessary car travel. In addition, the implementation of price-based instruments, i.e., an increase in the mineral oil tax rate and the expansion of parking fees, is assumed. Moreover, the scenario includes the greening of the commuter allowance and an increased share of battery electric vehicles (BEVs).

The COMP scenario builds upon the CLIM framework by incorporating targeted compensation measures, particularly for lower-income households in quintiles Q1 to Q3. It retains the ambitious CO_2 price but limits climate bonus payments to lower-income households. For residential buildings, the COMP scenario assumes that decarbonization measures are primarily driven by subsidies, including an expansion of funding budgets, separate funding pots for detached houses and multi-family houses (MFH), and socially differentiated subsidy rates, with higher support rates for lower- and middle-incomes. Moreover, a stringent examination of alternatives in the event of heating system changes is assumed. For passenger transport, the same measures as in the CLIM scenario are assumed, but commuter allowance is limited to the first three income quintiles (Q1 to Q3) and public transport ticket prices are reduced.

Despite the absence of ambitious spatial planning in both scenarios, we contend that this instrument remains a crucial tool in the effort to combat climate change. However, we also determined that the impact of such policies on the analyzed indicators over the 20-year time span is rather low, given the long life cycle of the built environment. To maintain simplicity, we did not place emphasis on spatial planning measures.

A detailed description of the measures is provided in Table A - 2 in the Annex.

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3 Motorways 100 km/h instead of 130 km/h, non-urban roads 80 km/h instead of 100 km/h and urban roads 30 km/h instead of 50 km/h from 2025 onwards

Table 3. List of policies in the simulation scenarios

Reference scenario (REF)[1]	Decarbonization scenario (CLIM)	Compensation scenario (COMP)
All sectors		
CO_2 price according to national pathway, flat-rate climate bonus	CO_2 price **with ambitious increase**, flat-rate climate bonus	CO_2 price as in **CLIM**, **climate bonus for Q1-Q3**
Residential buildings		
	Measures driven by regulatory policy[2]	**Measures driven by funding policy**
Thermal refurbishment	**Limited expansion of living space[2]**	**Higher funding budgets**
Increasing energy efficiency	**Higher renovation and qualities of new buildings[2]**	**Socially differentiated subsidy rates**
Shift to renewable heating systems	**No liquid & solid fossils in new buildings[2]**	**Separate funding pots for detached TFH and MFH**
	Operating ban on fossil heating systems[2]	**Stringent examination of alternatives in the event of a heating system change**
Mobility		
Promoting electromobility and increasing vehicle efficiency (CO_2 fleet targets for cars and LNF EU)	**Improvement of public transport & non-motorized individual transport services**	Same assumptions as in **CLIM**, but
Use of biofuels in transport	**Speed limit reduction**	**Restriction of commuter allowance to Q1 to Q3**
Promotion of active mobility and mobility management	**Introduction of a distance-based road toll**	**50% reduction of the public transport ticket price**
	Mineral oil tax (MÖSt) increase	
	Expansion and increase of parking fees	
	Greening of commuter allowance	
	Share of BEV increases	

[1]Based on With Existing Measures (WEM) Scenario of the Federal Environment Agency (2023). [2]Based on With Additional Measures (WAM) Scenario of the Federal Environment Agency (2023). TFH: two-family houses, MFH: multi-family houses.

2.3 Modeling approach

For analyzing the policy packages, the macroeconomic top-down model DYNK is linked with three bottom-up models – the Invert/EE-Lab model for buildings, and two mobility models, the MARS model covering transport demand and the SERAPIS model for vehicle propulsion technology choice. In the following, we provide a brief description of each model and sketch our approach for linking. For more comprehensive model descriptions and details on model linkage, please refer to Gühnemann et al. (2024). For a description of the data sources used by each model, please refer to the respective model references.

The Dynamic New Keynesian model **DYNK** (Kettner et al., 2024; Kirchner et al., 2019; Sommer and Kratena, 2017) covers the interconnections of the Austrian economy based on Input-Output Tables complemented by several modules that include econometrically estimated behavior functions of firms (production function) and household groups (consumption), some of which focus on energy demand. A central feature of DYNK is the ability to apply measures that affect emissions, such as carbon pricing, and to derive the resulting emissions while taking into account various economic feedbacks. For the policy simulations here, we allow certain elements in DYNK, such as the energy consumption of households, to be determined exogenously by inputs from other models. Thereby, the economic feedback of energy demand changes on prices and economic activity can be simulated. DYNK's elaborated household module is flexible in the number of household groups. Each household group then features distinct characteristics in form of income structure (based on non-financial transactions) and consumption patterns (based on consumption surveys). Elasticities of prices and income are uniform over all households. The saving rates (ratio between disposable income and expenditures) of the households are an endogenous result of these applied elasticities. However, in our analyses this is only the case for the reference scenario. In the counterfactual scenarios the saving rates are forced to the level of the reference scenario by endogenously adjusting expenditures on non-durable and non-energy commodities. This allows a clearer evaluation of the scenarios.

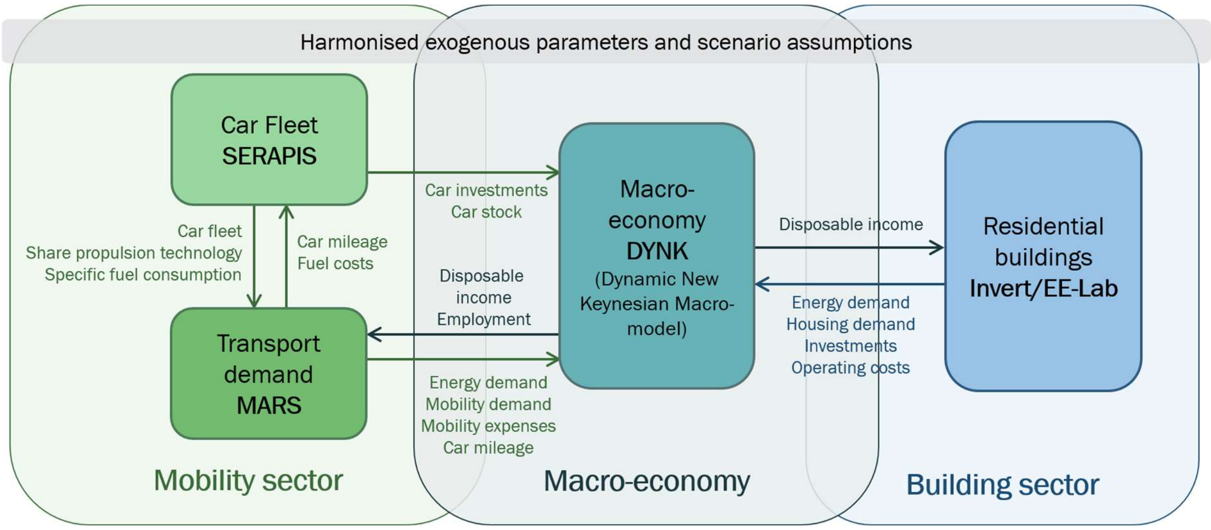
The building stock model **Invert/EE-Lab** (Müller, 2015; Müller et al., 2024, 2019; Steinbach, 2016) simulates the evolution of the building stock and its energy supply for heating and cooling. The model calculates the energy consumption using a physics based approach, investment decisions are anticipated using a logit-model which optimizes decisions for agent specific utility functions under uncertainty, and explicitly allows heterogeneous agents (different types of investors/users) and consistently tracks the housing situation, investment needs, energy costs, emissions, etc. of the defined agents throughout the simulation. While the model supports multi-objective utility functions that can include intangible costs and preferences (environmental impact, comfort, etc.), we here restrict the utility function to costs and prices in order to focus on the impact of costs and prices only: Each agent's utility function is based on the total cost of heating, using an investor specific capital recovery function (CRF). In previous analyses (Fries et al., 2017; Müller, 2015; Müller et al., 2019), we assigned different types of investors a constant CRF, partly derived from discrete choice experiments (regarding time and risk preferences), accompanied by estimated cost of capital (interest rate for loans) for different income groups. In the case of owner-occupied multi-family dwellings, we took into account that, in the case of decisions that have to be made jointly by several households, a higher weight is given to those households that prefer low or no investment. Therefore, we assumed a higher CRF for this building type. So far, we have not explicitly considered capital constraints, i.e., lack of efficient access to capital, in the Invert/EE-Lab model. This limitation has been addressed in this analysis: We have extended the model so that instead of an investor specific constant CRF (single value), the decision is now made under the premise that the CRF increases with rising investment needs once an investment exceeds a given household savings rate. In this project, we derived an estimate of this savings rate from household specific income and expenditure rates.

MARS (Emberger & Pfaffenbichler, 2020; Pfaffenbichler, 2017, 2011; Pfaffenbichler et al., 2010, 2008) simulates the travel demand, destination and mode choice of the Austrian population subdivided into 116 spatial zones representing the Austrian political districts (Statistics Austria, 2021). The car fleet stock-flow model **SERAPIS** (Pfaffenbichler et al., 2024, 2011) complements MARS and simulates the development of the car fleet by propulsion technology (internal combustion engine, plug in hybrid and battery electric). In both models, the mobility-relevant decisions of households are represented by means of multinomial LOGIT models. Both models are policy sensitive. In MARS, the utility functions are calculated on the basis of travel times and costs of the different parts of a trip. For instance, for a public transport trip, this includes access and egress time to public transport stops, waiting, changing, in-vehicle times and fares. For a car trip, the relevant utility elements are access and egress time to and from parking places, parking place searching and in-vehicle time, parking and road charges, fuel, and other costs. Supply side policies which can be simulated with MARS are density of the public transport network, frequency of public transport services, road traffic calming and improvements of walking and cycling infrastructure. Potential monetary and fiscal measures include public transport fares, fuel price and fuel taxes, carbon prices, parking and road charges and commuter allowances. Regulatory policies which can be simulated with MARS are speed limits and land use regulations.

In SERAPIS, the utility is defined by different elements of which some are direct vehicle characteristics, e.g., purchase price, energy consumption, range, while others are describing infrastructure elements, e.g., costs for wall boxes or the density of public charging stations, charges for parking and road use or exemptions from other regulations (Pfaffenbichler et al., 2024). Specifically, the utility is made up of gross investment costs (car, wall box) including value added tax and purchase, tax, operating costs (fuel/energy, parking charge, road charge), variety of makes and models, density of service stations, range, and time savings (e.g., due to bus lane access or preferential parking). Policies which can be simulated include technological aspects (energy consumption, range, variety of makes and models), infrastructure aspects (supply with public charging and fuel stations), monetary and fiscal aspects (energy price, purchase price, fuel tax, purchase tax, annual tax, VAT, direct subsidies) and regulatory aspects (exemptions for bus lane access, preferential parking).

The models MARS and SERAPIS have to be iterated using a soft linking approach (Gühnemann et al., 2024). The model SERAPIS provides information about the development of the car fleet by propulsion technology as an input for the model MARS. MARS uses this information to calculate average fuel costs which influence the utility of using a car. The main outcome of MARS are mode specific origin-destination trip matrices. These are used to calculate annual vehicle mileage and fuel costs. These constitute inputs for the model SERAPIS and have an influence on the utilities there. The two models already tend to converge in the second iteration (Gühnemann et al., 2024). The mode specific origin-destination trip matrices of MARS are used energy demand, CO_2 emissions and other indicators used as input for the model DYNK (Figure 1).

Figure 1. The modeling framework for TransFair-AT and potential linkages between the models

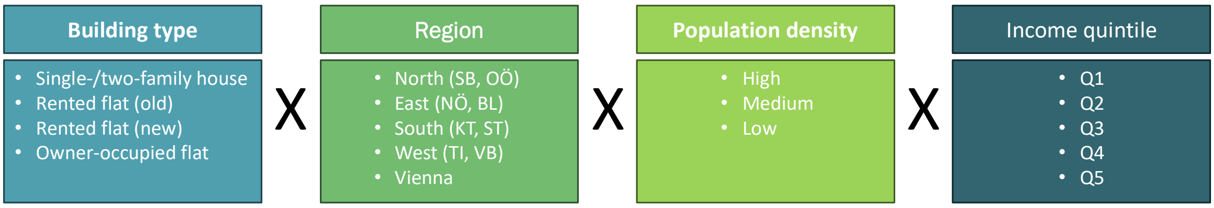


Source: Gühnemann et al.(2024) .

Initially, each model comprised a different structure of household groups. For linking the models, household structures were harmonized. A soft link between the models was established, iteratively exchanging variables between them (see Gühnemann et al., 2024). The main input that DYNK provided to MARS and SERAPIS is disposable household income that drives the budget for mobility, as well as the development of employment. MARS in turn delivers mobility demand (i.e., transport performance measured in passenger kilometers), car mileage, final energy demand by energy source (with implicit emissions) and mobility expenses to DYNK, whereas SERAPIS delivers car investments and the yearly composition of the car stock. Likewise, the interface variables between DYNK and Invert/EE-Lab are disposable income provided by DYNK as well as housing demand (by residential floor area), investment and operating costs for residential buildings and residential energy demand (i.e., delivered energy for heating and hot water by energy source in physical terms and related CO_2 emissions) provided by Invert/EE-lab to DYNK. The consistency of behavioral reactions in DYNK and the bottom-up models is guaranteed due to the direct bilateral data exchange. Elements of DYNK that are covered by the bottom-up models (e.g., heat energy or mobility demand) are deactivated and replaced by the exchanged data.

To investigate the distributional impacts of the decarbonization pathways, household characteristics were harmonized across models. The household types were differentiated by building type, region, population density of the place of residence, and income quintile (see Figure 2). This resulted in more than 230 household types. DYNK differentiated income and consumption structures of all types, Invert/EE-Lab followed the same structure but aggregated the two highest income quintiles (Q4 and Q5), and the mobility models differentiated according to the region.

Figure 2. Household types for the model simulations



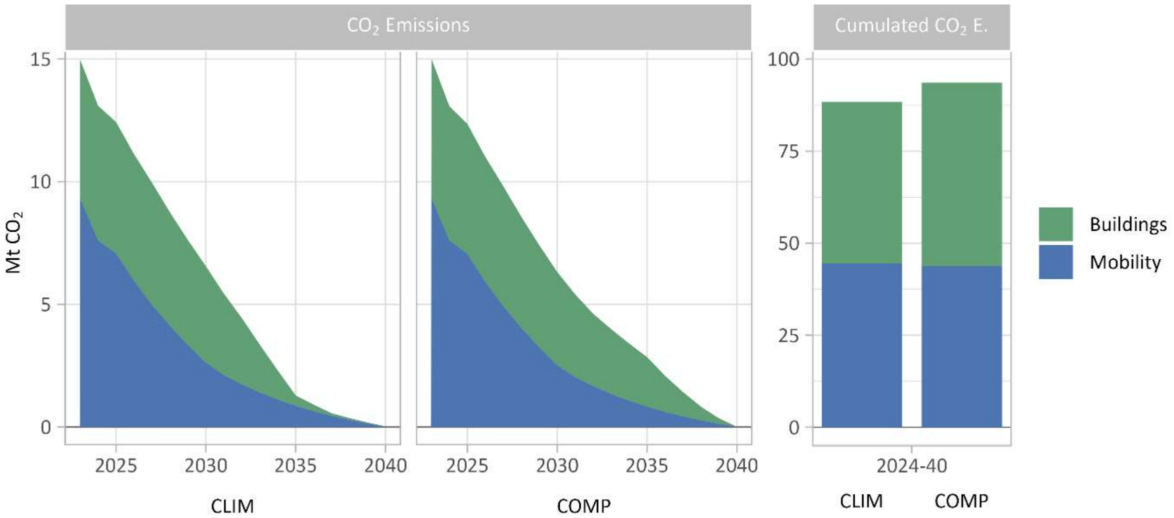
3 Results

3.1 Development of CO_2 emissions and final energy consumption

The development of CO_2 emissions from residential buildings and passenger transport in the CLIM and COMP scenarios is illustrated in Figure 3. In both scenarios, complete decarbonization is achieved in both sectors by 2040. For passenger transport, cumulated emissions in the period 2024 to 2040 are roughly the same in both scenarios; for buildings, cumulated emissions in the COMP scenario are 6 Mt (13.5%) higher than in the CLIM scenario. The higher emissions of the buildings sector in COMP reflect that this scenario is primarily based on subsidies (see section 2.1), whereas CLIM mainly assumes the use of regulatory instruments. This leads to lower abatement in COMP as compared to CLIM.

In passenger transport, the strongest emission reductions occur until 2030. This reflects two different aspects of the policy definition: First, around 4.5 million cars with internal combustion engines are being phased out of the vehicle fleet over the entire period 2023-2040. Two thirds of this are attributable to the period 2023-2030 while only one third is attributable to the period 2031-2040. Second, for the majority of the policy instruments, a linear phase-in between 2023 and 2030 was assumed (Table 3). After 2030, all policy instrument levels are assumed to remain constant.

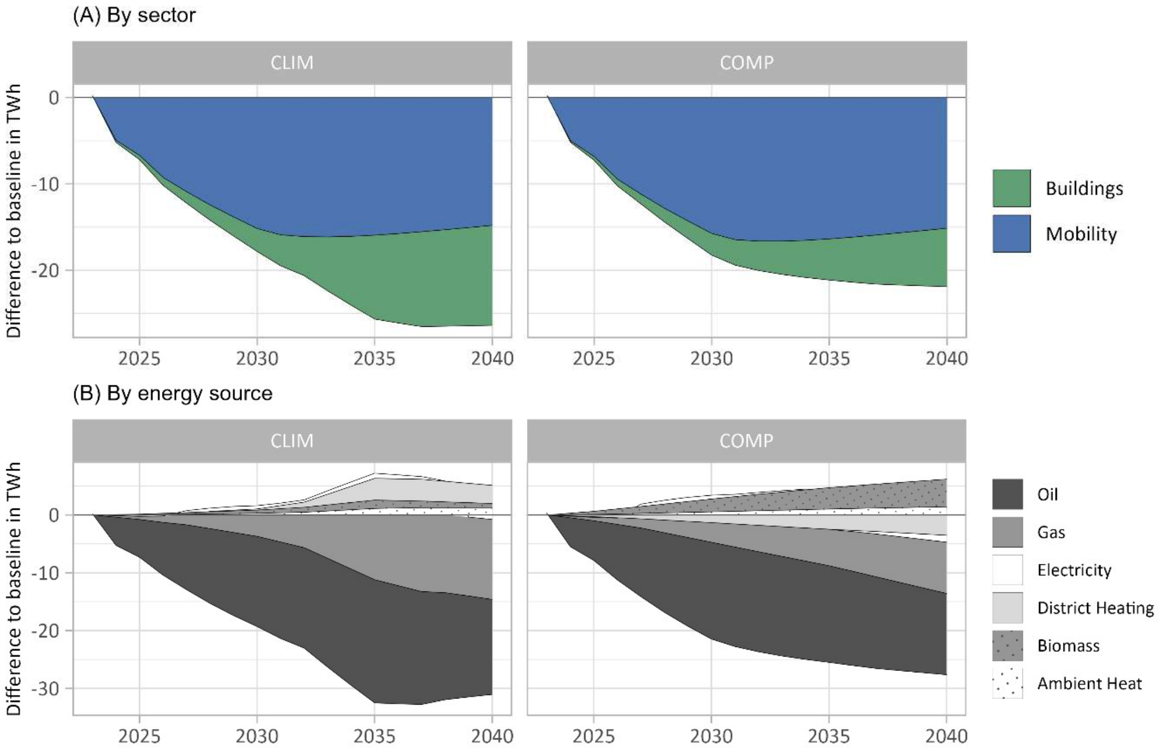
Figure 3. Development of CO_2 emissions



These emission reductions reflect the impact of policy measures on increasing energy efficiency and a shift towards renewable energy sources. Figure 4 (A) shows that final energy consumption in residential buildings and passenger transport in 2040 is 26 TWh (28%) lower in CLIM than in the baseline scenario; in COMP final energy consumption is reduced by 22 TWh (23%). As for CO_2 emissions, energy savings in the mobility sector are higher than in the building sector, amounting to a reduction of about 15 TWh by 2040, which corresponds to a decline of 60% compared to the baseline, and reflects both a shift towards active mobility and public transport and the higher efficiency of electric drives. Energy savings in residential buildings amount to 12 TWh in CLIM and to 7 TWh in COMP, which corresponds to percentage changes of -16% and -10% compared to the reference scenario, respectively.

With respect to the energy mix in the building sector, CLIM shows a stronger decline of oil and gas than COMP, which is reflected in the different extent of CO_2 emission reductions, as discussed above. In both scenarios there is a shift towards renewable energy sources, i.e., biomass and ambient heat. A key difference between the scenarios lies in the development of district heating. In CLIM district heating increases compared to the reference scenario, while it gradually declines in COMP. This result is due to different policy assumptions in the CLIM vs. COMP scenario. In both scenarios, we have included district heating priority areas in the urban region, where users must be connected if district heating is available and economical. In the CLIM scenario, we assume lower investment subsidies, which makes district heating more attractive than heat pumps in these urban areas. In comparison, the high investment subsidies in the COMP scenario shift the preference towards heat pumps and thus towards lower expansion and connection to district heating.

Figure 4. Development of energy mix (2024-40)



3.2 Macroeconomic effects

Figure 5 illustrates the changes in macroeconomic indicators in the two policy scenarios, CLIM and COMP, compared to the reference scenario. The left panel focuses on the changes in real GDP and its components, the right panel shows the employment impacts.

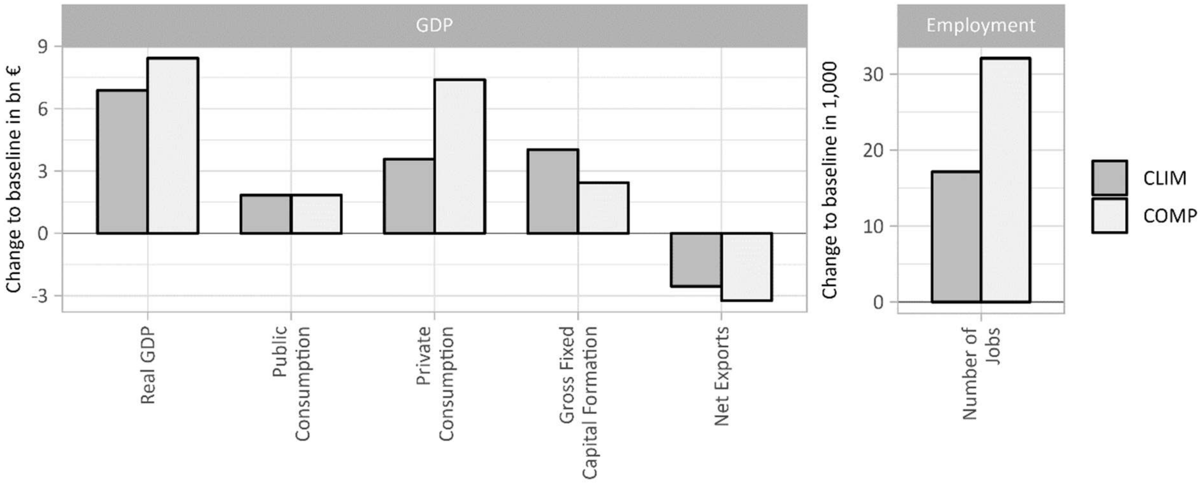
In the CLIM scenario, real GDP shows an average annual increase of 6.8 bn € or 1.5% in the period 2024 to 2040 compared to the baseline, driven mainly by increases in gross fixed capital formation (4 bn €, most notably climate-related investments) and private consumption (3.6 bn €, following from increasing household income). Reductions in net exports (2.6 bn €) due to demand-related increasing imports and marginally decreasing exports[4] mitigate the positive impact on GDP. The COMP scenario, by contrast, exhibits a more substantial positive change in real GDP amounting to 8.4 bn € (1.9%). With respect to the individual components, private consumption makes the largest contribution in this scenario (7.4 bn €), while gross fixed capital formation now increases by only 2.4 bn €. This reflects that first households' consumption possibilities are expanded due to higher subsidization of decarbonization measures, second investments in the buildings sector are reduced (also implying higher energy spending) since regulatory measures are replaced by subsidies, and third demand is boosted by

4 Exports in nominal terms is pre-determined over the whole simulation period for all scenarios. Exports in real terms is changing in accordance with the price level of production with a price elasticity of -1. I.e., when price levels increase compared to the reference scenario, real exports decrease. This assumption reflects the loss of competitiveness due to rising prices.

compensation measures targeted at lower-income households who have a higher propensity to consume. Net exports show a slightly higher decline than in CLIM.

On average over the period 2024 to 2040, the CLIM scenario delivers 17,200 additional jobs compared to the reference scenario, implying an increase in employment by 0.4%. In the COMP scenario, the increase in jobs amounts to 31,100. The reason for the relatively higher impact on employment in COMP is, on the one hand, the higher real demand and, on the other hand, the setup of the wage bargaining module. A lower development of the consumer price index – due to strong subsidies in COMP – leads to lower pressure for wage bargaining. Thereby, wage rates are at a lower trajectory in comparison to the CLIM scenario which leads to higher demand for employment.

Figure 5. Average annual macroeconomic effects (2024/40, in real terms)



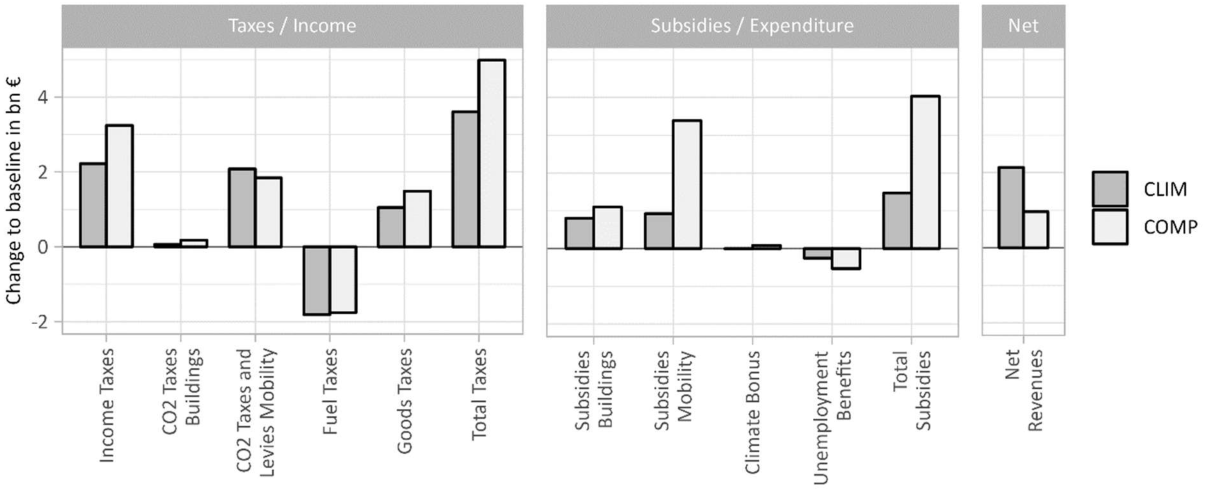
Private consumption also includes consumption of Non-profit institutions serving households (NPISH).

Figure 6 shows the average changes in government income and government expenditure as well as the net effect in the policy scenarios CLIM and COMP compared to the reference scenario in the period 2024 to 2040.

In the CLIM scenario, total taxes increase by 3.6 bn € (2.1 %) compared to the reference scenario. This increase is mainly driven by rising revenues from income taxes (2.2 bn €) and CO_2 pricing and levies related to mobility (2.1 bn €) and to a lesser extent by an increase in revenues from goods taxes (1.1 bn €); fuel tax revenues, by contrast, show a decrease of 1.8 bn € due to the decarbonzation. On average over the period 2024 to 2040, total subsidies in CLIM increase by 1.5 bn € compared to the reference scenario, which corresponds to an increase by 123%. Subsidies related to buildings and public transport increase by 0.8 bn € and 0.9 bn €, respectively, while unemployment benefits can be reduced by 0.3 bn €. The net effect on government revenues (total tax revenues less total subsidies) is positive, amounting to roughly 2.1 bn €.

The COMP scenario shows the same pattern as the CLIM scenario, but with generally higher levels. The increase in tax revenues compared to the reference scenario amounts to 5 bn € and subsidies increase by 4 bn €. This results in a net increase of revenues of 1 bn €.

Figure 6. Average annual change in public revenues and expenditure (2024/40, real)



3.3 Changes in real household consumption and real household income

In the following, we present the distributional effects of the policy scenarios, focusing on changes in real household consumption by income quintile. Moreover, we provide insights into horizontal distributional aspects that characterize these changes. Furthermore, we address the regional dimension of the policies, exploring how consumption expenditures related to passenger transport and residential buildings differ between urban, suburban, and peripheral areas in the different scenarios. This multifaceted approach allows for a comprehensive understanding of the implications of decarbonization and compensatory measures on household consumption, emphasizing the importance of equitable policy design.

Changes in real household consumption across different income quintiles (Q1 to Q5) compared to the baseline scenario in the two scenarios CLIM and COMP are displayed in Figure 7 for the simulation period up to 2040, highlighting trends and variations in consumption changes for different income groups. In the CLIM scenario, we find an increase in real household consumption as well as real household income, across all household income groups, but its distributional effect is regressive. For lowest-income households (Q1), household consumption increases by approximately 2.2% compared to the baseline in 2040. In contrast, highest-income households (Q5) experience a more substantial increase of about 2.8% in 2040. Conversely, in the COMP scenario real consumption expenditures rise at a similar rate for all income quintiles, for lowest-income households (Q1) by 3.9% in 2040, and for highest-income households (Q5) by 3.8%. Overall stronger increases in real consumption in COMP reflect larger increases in income in this scenario (see section 2.2, since in the policy scenarios we assume the same saving rates as in the reference scenario).

In the CLIM scenario, real household consumption of all income quintiles peaks in 2036, in line with the development of household income. The growth in household income compared to the baseline scenario decreases after 2036, reflecting lower growth in paid income as decarbonization measures have largely been implemented and reductions in climate bonus payments are in line with increasing decarbonization. In the COMP scenario, we find different patterns for lower- and middle-income households (Q1 to Q3) and higher-income households (Q4 and

Q5). The earlier peaks for lower- and middle-income households reflect the increased climate bonus payments for these households in COMP which start to decrease with accelerating decarbonization. This indicates that the progressive distribution effect in COMP is largely driven by climate bonus payments. Since climate bonus payments approach zero in 2040, so does the progressive distribution effect.

Figure 7. Change in household consumption expenditure by income quintile (2024-40, in real terms)

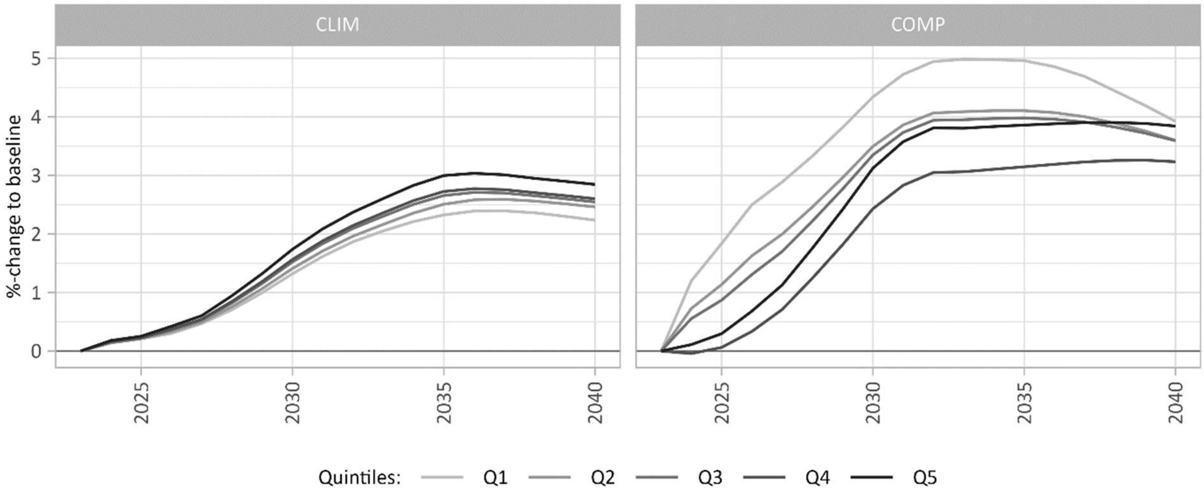
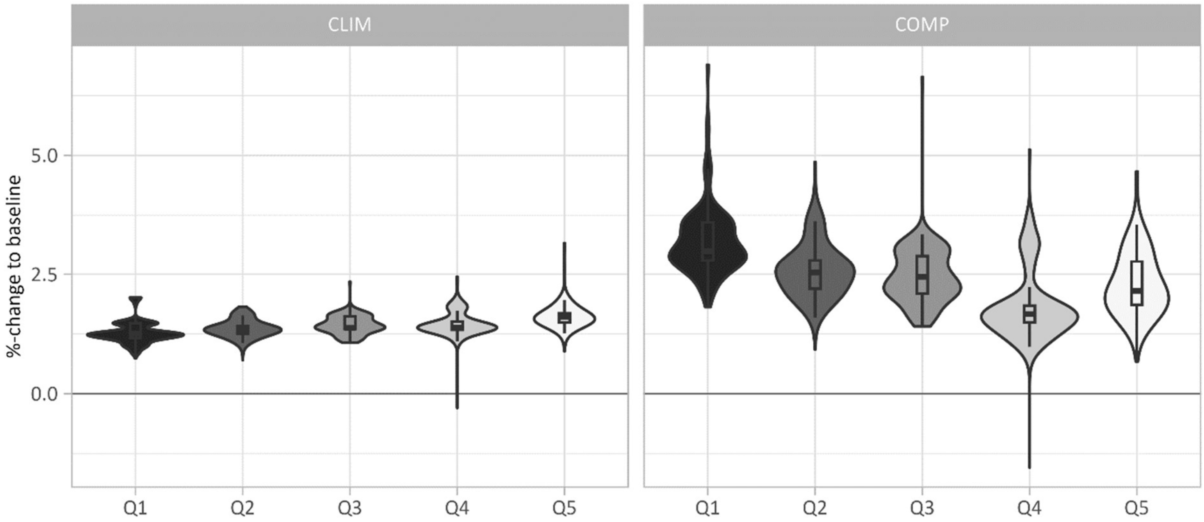


Figure 8 shows the distribution of average changes in real household incomes in the period 2024 to 2040 by income quintile. In the CLIM scenario, as shown above, the increase in real household consumption (including annuities for thermal refurbishment) grows with income. For instance, the highest-income households (Q5) experience a weighted median increase of approximately 1.6% (with increases ranging between 0.9% and 3.2% depending on the household type), while the lowest-income households (Q1) see a more modest median increase of about 1.3% (with increases ranging between 0.7% and 2.0% depending on the household type) compared to the baseline. This trend suggests that wealthier households benefit more from the changes associated with decarbonization, most notably through increasing incomes (see section 3.2), and implies growing income inequality. Conversely, the COMP scenario presents a different picture. Here, lower-income households (particularly Q1) show a significant weighted median increase of 3.1% (minimum: 1.8%, maximum: 6.9%) compared to the baseline, indicating that these households particularly benefit from compensatory measures directed at low- and middle-income households in the COMP scenario. In comparison, higher-income households have lower growth rates (Q4 1.7%, Q5 2.2%), compared to the baseline, suggesting that while higher-income households do see improvements, the most substantial gains are realized by the lowest-income households.

Overall, Figure 8 highlights the importance of the horizontal dimension of distribution, showing a large spread within all income quintiles, especially in the COMP scenario.

Figure 8. Average annual change in household consumption by income quintile (2024/40, in real terms)



The regional dimension of the decarbonization is illustrated in Figure 9. With respect to the change in real consumption expenditures related to passenger transport and residential buildings, in the CLIM scenario, we find reductions only in urban areas and increases in suburban and peripheral regions[5]. In the COMP scenario, we see reduced expenditures on housing and mobility in urban areas, and – except for the highest-income households (Q5)[6] – also in peripheral regions. Decreasing expenditures on mobility and housing imply that households can shift their consumption towards other goods and services, while conversely increasing expenditures on mobility and housing imply that households have to constrain other consumption expenditures, unless their income increases, since we assume the same saving rates as in the reference scenario.

The most pronounced reductions in household consumption show for non-durables related to mobility in urban areas. In these regions, savings in fuel costs and parking fees through behavioral changes by large exceed the additional expenditure on public transport and the mileage-based road toll. In suburban and peripheral regions, we find higher fuel cost savings, but these are considerably dampened by the costs for the mileage-based road toll and to a lesser extent by additional expenditure on public transport; for the richest households, the increases even overcompensate the savings. Spending on vehicles (durables related to mobility) is slightly reduced across all household types in line with the shift towards public transport. The combined effect leads to the highest cost increases in suburban areas.

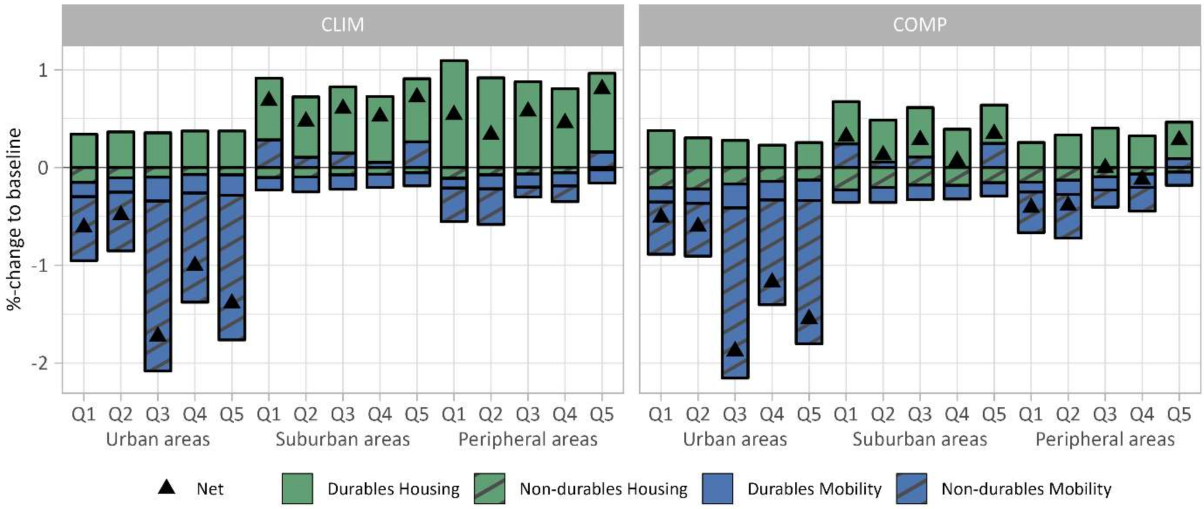
With respect to residential buildings, non-durable consumption, i.e., expenditure on heating and electricity as well as taxes, decreases slightly for all household types. In the CLIM scenario, these reductions are, however, lower than in the COMP scenario since there is a shift towards district heating (see section 3.1), which is

[5] Urban areas: density of at least 1,500 inhabitants per km^2 and a minimum population of 50,000; suburban areas: density of at least 300 inhabitants per km^2 and a minimum population of 5,000; peripheral areas: all other regions.

[6] In the COMP scenario, for Q5 households living in peripheral areas, savings related to fuel costs and vehicles are overcompensated by the annuities for thermal refurbishment and higher expenditure on road toll and parking fees.

comparably more expensive. Consumption expenditures related to the exchange of heating systems and annuities for thermal refurbishment increase in both scenarios compared to the reference scenario, reflecting an increase in refurbishment and replacement rates. The increase is, however, lower in COMP than in CLIM due to higher subsidization.

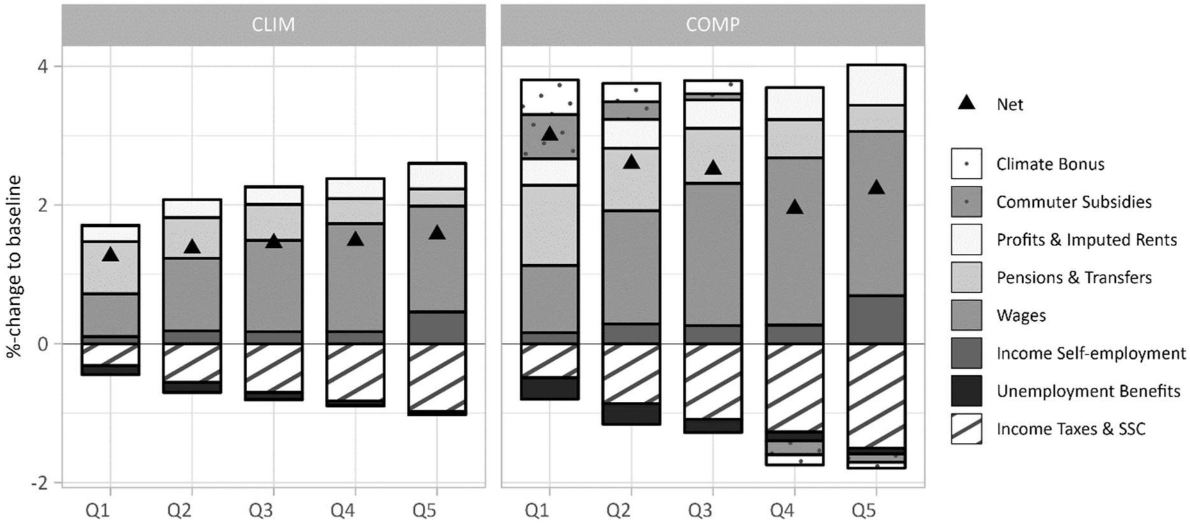
Figure 9. Average annual change in household consumption by income quintile and region (2024/40, in real terms)



The average change in household income in the policy scenarios compared to the reference scenario over the period 2024 to 2040 is shown in Figure 10 for the five income quintiles. In CLIM, increases in household income are mainly based on rises in wages and pension payments and social transfers[7], for the highest incomes also profits and imputed rents show a sizeable increase. In line with rising employment also unemployment benefits decrease while income taxes rise, dampening the net growth in incomes. With respect to wages, pension payments and social transfers, profits and imputed rents, unemployment benefits and taxes, we see the same patterns in COMP, albeit at higher levels. However, for the lower three income quintiles, income is boosted by increases in climate bonus payments and commuting subsidies. Conversely, the exclusion from climate bonus payments and commuting subsidies reduces net income increases for the two top income quintiles.

[7] This is because pensions and transfers are indexed, i.e., pensions rise with the wage rate and transfers rise with GDP.

Figure 10. Average annual change in household income by income quintile and income component (2024/40)

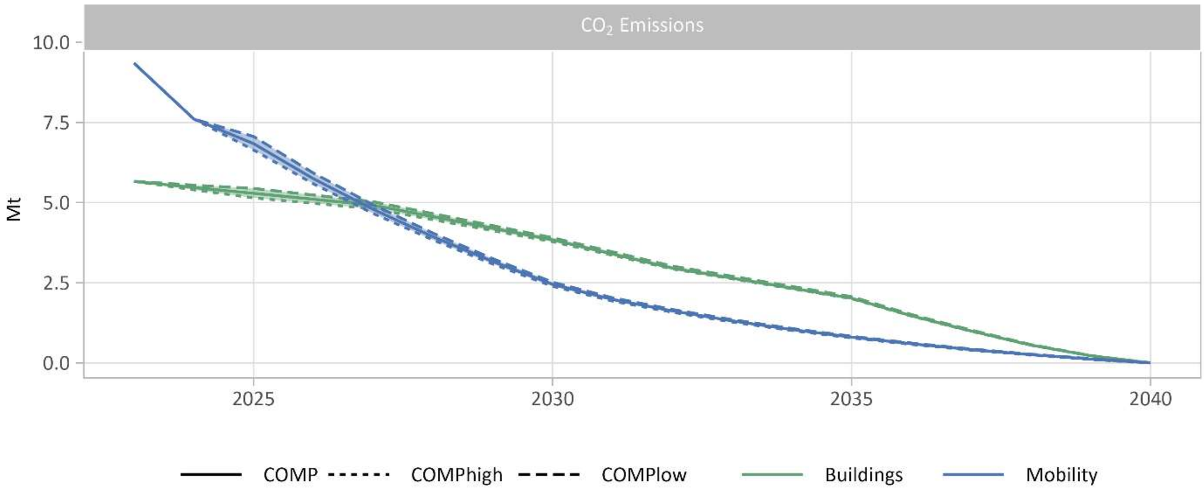


3.4 Sensitivity analyses

To explore the impacts of exogenous assumptions on our results, we performed sensitivity analyses with respect to changes in energy prices. We compare the results of a 25% increase in the prices of fossil fuels and electricity (COMPhigh) and a 25% decrease in the prices of fossil fuels and electricity (COMPlow) with our initial COMP scenario. In the following, we show the effects of these energy price changes on CO_2 emissions, macroeconomic indicators, and household consumption.

Figure 11 shows the development of CO_2 emissions from passenger transport and residential buildings under the different energy price assumptions in the period 2024 to 2040. We see only minor deviations from the COMP emission paths for both sectors in the sensitivity scenarios. A price increase of 25% leads to an additional reduction in CO_2 emissions of up to 3% both from residential buildings and mobility. An energy price reduction results in a change of about the same magnitude in the opposite direction. It has to be noted that a variation of the energy price by +/-25% changes the average car operating costs per kilometer by only +/-2% to +/-3%, with the lower values occurring in the later years. The price elasticity of greenhouse gas emissions in the mobility sector ranges from around -0.9 to -0.5, with the lower elasticity occurring in the later years. At the same time, the elasticity of energy price increases is slightly lower than that of energy price reductions. The results reflect also one of many drivers relevant for adopting emission-friendly technologies and lifestyles. This is particularly true for scenarios that aim for zero emissions, as achieving such a target requires a comprehensive set of measures and instruments.

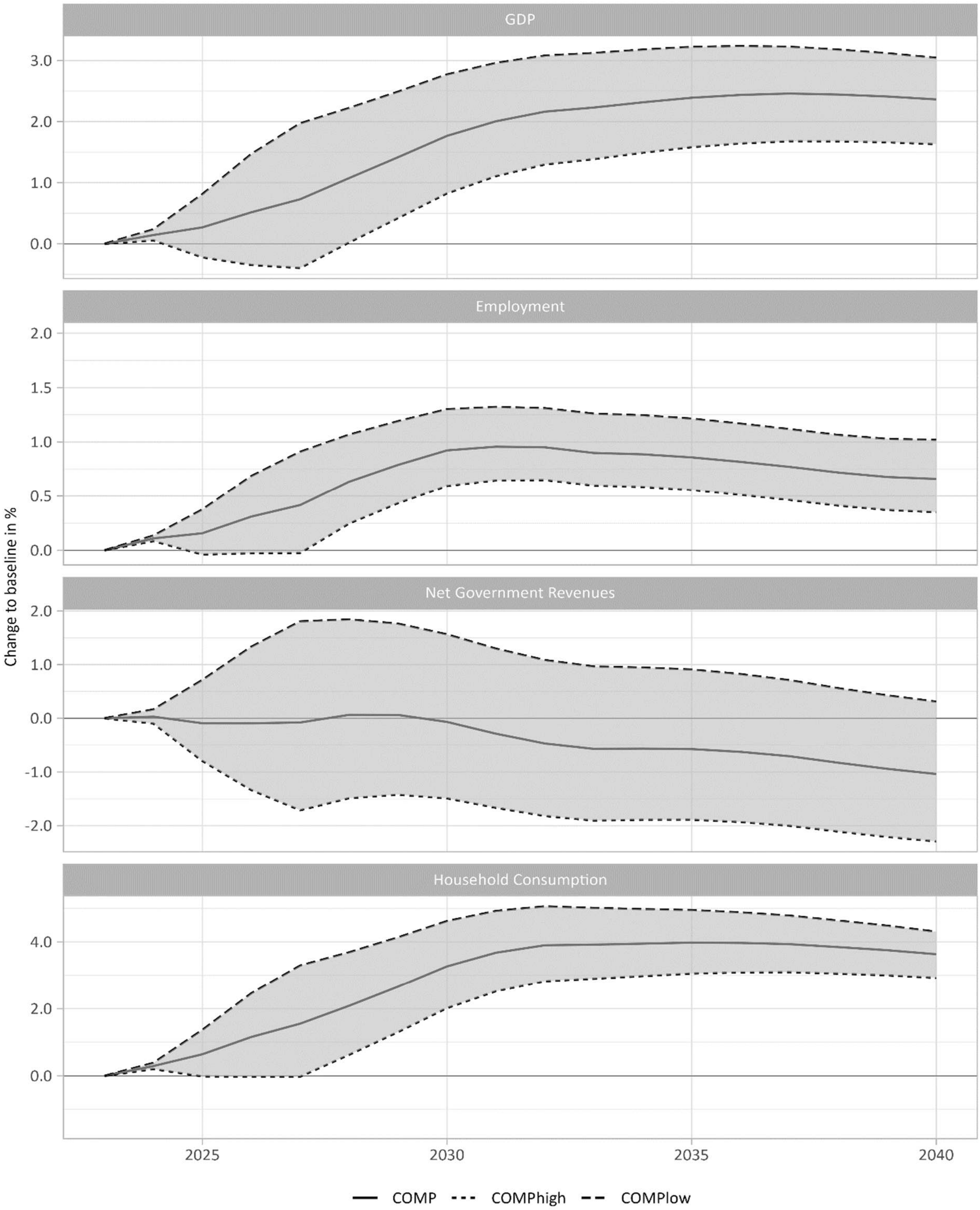
Figure 11. Effects of changes in energy prices on CO_2 emissions



Impacts on macroeconomic indicators and household consumption resulting from the variations in energy prices compared to the COMP scenario are illustrated in Figure 12. As expected, lower energy prices in COMPlow translate into higher real GDP growth, employment and net government revenues, and are also associated with higher household consumption. On average over the whole period, GDP in COMPlow is 0.8 percentage points higher compared to the baseline. GDP is particularly boosted by higher private and public consumption in this scenario (see Figure A - 1 in the Appendix). With respect to government revenues (which increase by 1.4 percentage points), we find small changes in public expenditure, but considerable positive impacts on revenues resulting from increased labor tax revenues resulting from employment growth (additional 0.3 percentage points compared to the baseline, see Figure A - 2). The deviations in real household consumption (Figure A - 4) amount to 1 percentage point and mainly reflect changes in energy prices and consequently changes in consumer prices and real income: Under the assumption of lower energy prices as in COMPlow, the simulations show particularly strong increases in wages (accompanied by a comparably smaller reduction in unemployment benefits) as well as in pensions and transfers. Higher income households benefit most from higher wages, while lower incomes benefit more strongly from increases in pensions and transfers (Figure A - 3). As a result, higher income households show larger gains in a situation with lower energy prices than lower income households.

For an increase in energy prices (COMPhigh) we find opposite effects in the same order of magnitude.

Figure 12. Effects of changes in energy prices on macroeconomic indicators and household consumption (GDP, Net Government Revenues and Household Consumption in real terms)



4 Discussion

In the following section, we discuss technical aspects and limitations of the modeling approach applied in our analysis and the definition of the scenarios.

A first methodological point relates to the mainstreaming of household types between models. While household types have been mainstreamed between DYNK and Invert/EE-Lab, the link between DYNK and MARS only considers the households' region of residence, differentiating between five groups of federal states (Vienna, North, East, South, West). Consequently, a lot of information is lost. In the data flow from DYNK to MARS, the development in income of over 230 household groups is aggregated to the five regions. The data that flows from MARS to DYNK is disaggregated from five regions to over 230 household groups. This means, for instance, that all households in a region receive the same percentage change in their variables as expenditures for fuels. This narrow match of households hinders important details with respect to the distributional effects.

A second methodological point relates to the representation of the labor market in the macroeconomic model DYNK. Here, two issues are relevant for the analysis. First, the labor market module in DYNK currently does not distinguish between different skill levels. However, the demand for different skills may change significantly in the course of transformation. Depending on how skills are distributed across income quintiles, the respective wage shares in income will show more or less pronounced increases as the economy grows due to transformation activities. The second issue relates to the distribution of income. In the current version of DYNK, there is no information on the sectors in which the members of each household group are employed. This means that the sum of the economy-wide labor income is aggregated and allocated to the households as in the base year, irrespective of sectoral developments. Hence, the economic growth in a specific sector that would benefit a certain household group, does not only increase the labor income of that group, but of all households by the same percentage growth. The implementation of more detailed data for both issues could change the distributional pattern of this analysis.

A frequently debated issue regarding energy efficiency measures in the housing sector is the landlord-tenant dilemma, which relates to a third methodological issue. While the owner (landlord) of a building needs to provide the necessary investments for energy efficiency measures, such as building renovations or the installation of energy-efficient heating systems, tenants subsequently benefit from reduced energy expenditures. In countries like Germany, landlords can transfer the additional costs of modernizing a building, including energy efficiency measures, to their tenants within existing rental contracts. However, under Austria's current legal framework, such cost transfers are not permitted under most circumstances, which significantly reduces landlords' motivation to make such investments. Despite the limited ability to pass on costs to tenants under existing leases, the building owner may be able to pass on the investment to new tenants and needs to ensure that the building is up to an appropriate state-of-the-art standard to attract new tenants. If not, he can be expected to lose out on potential future earnings. To account for this in our model, we have assumed that a certain proportion of investment is considered to be for the purpose of maintaining future earning potential. Based on our assumptions, landlords are able to pass on an average of 60% of refurbishment costs to tenants in post-1945 buildings. In Austria, the rent per m² in apartment buildings built before 1945 is limited by law ("Richtwertmietzins") to a maximum of 6.09 €/m² (2023, Burgenland) to 10.25 €/m² (2023, Vorarlberg), with 6.67 €/m² for Vienna. This further restricts the ability to pass on modernization costs to tenants. We have therefore assumed that only 35% of the investment can be passed on to tenants for this type of buildings.

The policy portfolios in the scenarios were defined in a way that they are compatible with full decarbonization of mobility and residential buildings. The scenarios differ, however, in the consideration of social issues, i.e., the compensation of vulnerable households, and in the composition of the policy portfolios for the buildings sector. These differences have to be considered when comparing the impacts of the scenarios. In the housing sector, our assumptions differ not only in terms of distributional effects across income and household groups, but also more fundamentally between regulatory and financial measures, with the CLIM scenario focusing on the former and the COMP scenario on the latter. In our scenario implementation, this has a profound impact on renovation rates as well as on the choice of heating systems. On the one hand, given sufficient financial support, monetary instruments tend to show effects more quickly than regulatory instruments, as the latter typically require longer implementation periods to give investors and building owners sufficient time to cope with the required regulations. On the other hand, it is more difficult to address late adopters with financial instruments than with regulatory measures. Regarding the installation of heating systems, the regulatory measures implemented in the CLIM scenario tend to favor district heating by prioritizing district heating in dedicated zones, while the financial instruments favor heat pumps, which are more costly to invest in. However, it is important to note that this behavior is not necessarily inherent to the type of instruments, but also depends on the actual design of the policies.

In our innovative approach, we simultaneously consider the distributional impacts of decarbonization in housing and mobility. The literature on standards in housing and mobility (see e.g. Baldenius et al., 2021, or Levinson, 2019, for mobility and Bruegge et al., 2018, for residential buildings) and pricing in mobility (e.g. Bureau and Glachant, 2008; Eliasson, 2016) shows that these instruments tend to be regressive, when applied individually. Our simulation of policy portfolios shows, however, that in combination with targeted compensation for vulnerable households (i.e., climate bonus payments, socially differentiated investment subsidies, limitation of commuter allowance to low- and middle-income households, reductions in public transport fares), decarbonization can be achieved while reducing income inequalities.

5 Conclusions

A decarbonization of households and mobility in Austria by 2040 is achievable, but it requires a comprehensive mix of policy instruments and rapid implementation. A successful transformation hinges on the implementation of different strategies that integrate command-and-control measures as well as price-based instruments. While climate policies can have positive macroeconomic effects, it is crucial to recognize that they can also exacerbate inequality between different income groups.

Achieving a just transition pathway is possible, but requires targeted compensation measures for low- and middle-income households. In this context, concerns about effectiveness, efficiency, equity, and public acceptance must be balanced. Our analysis suggests that regulatory measures tend to be more effective than subsidies in driving immediate change. If targeted to lower- and middle-income households, subsidies can improve the distributional effects of decarbonization, yet (slightly) dampening macroeconomic performance and emission reductions. The literature shows, however, that subsidies that are not limited to lower income-households (see Table 1) might even worsen distributional outcomes. Nevertheless, despite their potential drawbacks, public acceptability of subsidies is generally higher than for other price-based instruments or regulatory measures, which facilitates their implementation and also makes them attractive options for policymakers (Segerson et al., 2024).

Thus, a nuanced approach that combines different decarbonization measures with targeted compensation strategies will be essential to ensure that the benefits of decarbonization are shared equitably, thereby fostering broader acceptance and support for these necessary transitions.

Subsidies and recycling of revenues from carbon pricing to households should be considered, especially for low-income households, to mitigate adverse effects on income distribution and to enable them to make investments in renovation and new heating systems that they cannot afford on their own. Apart from the segment of single-family houses this also requires the adaptation of legal framework conditions that regulate the decision-making process regarding relevant investments but also the allocation of costs to different actors or the potential to raise rents. Thus, the transformation challenges are different for various regions (with different distributions of heating systems and categories of dwellings in urban and rural areas), which entails the necessity for differentiated policy mixes.

A key aim of integrating stakeholder knowledge was to enhance the potential acceptability of climate mitigation and compensation measures in our policy scenarios. While we were able to engage a diverse group of stakeholders, it was not fully representative of the Austrian population. Surveys indicate that the majority of Austrian citizens support climate change mitigation measures (Eckert et al., 2024). However, specific measures, such as speed limits, wind power projects, and compensation schemes, such as the climate bonus, remain subjects of intense debate in Austrian media and politics. Despite a growing body of research on how to effectively communicate climate change mitigation science to the public and decision-makers, as well as studies on the acceptability of these measures, further research is needed to better understand the barriers to implementation and to develop improved measures and strategies to overcome them.

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Annex

Annex I: Stakeholder-Proposed Measures: Integration into Scenario Simulations

Table A - 1. Integration of Stakeholder-Proposed Measures into Scenario Simulations

Sector	Category	Measure	Pts[1]	REF	CLIM	COMP	Measures
Mobility	Mitigation	Tax measures	9	Yes	Yes	Yes	CO_2 pricing Mineral oil tax increase Parking fees
		Expansion of non-motorized individual transport and public transport	8	Yes	Yes	Yes	Promotion of active mobility & mobility management Improvement of public transport & non-motorized individual transport services
		Spatial planning measures	6	No	No	No	
		Road toll	4	No	Yes	Yes	Introduction of distance-based road toll
		Education	4	No	No	No	
		Ban on fossil-fueled vehicles	4	No	Yes	Yes	Share of BEV increases
		Speed limit	3	No	Yes	Yes	
	Compensation	Increase investments in public transportation	8	No	Yes	Yes	Improvement of public transport & non-motorized individual transport services
		Eco-bonus	6	No	No	Yes	Climate bonus for Q1-Q3
		Make public transportation cheaper / free of charge	6	No	No	Yes	50% reduction of the public transport ticket price
		Reduce VAT	4	No	No	No	
		Eco-social reform of commuter allowance	4	No	Yes	Yes	Greening of commuter allowance
Housing	Mitigation	Ban on fossil fuel heating systems	7	No	Yes	Yes	No liquid & solid fossils in new buildings Operating ban on fossil heating systems
		Change legal requirements	6	No	No	No	
		Infrastructure improvements	5	Yes	Yes	Yes	Thermal refurbishment Increasing energy efficiency Higher renovation and qualities of new buildings
		Subsidies	4	No	No	Yes	Higher funding budgets Socially differentiated subsidy rates
		Tax measures	4	Yes	Yes	Yes	CO_2 pricing
		Renovation obligation	4	No	Yes	Yes	Higher renovation and qualities of new buildings
		Training of qualified personnel	2	No	No	No	
		Limitation of the maximum living space per person	2	No	Yes	Yes	Limited expansion of living space
	Compensation	Transfers	11	No	No	Yes	Socially differentiated subsidy rates
		Promote fossil fuel phase-out	6	No	Yes	Yes	Separate funding pots for detached TFH and MFH
		Rent neutrality	4	No	No	No	
		Social milieu protection against gentrification	3	No	No	No	
		Strengthening consumer rights	2	No	No	No	

[1] Each stakeholder was given three points, which they could assign to the most important measures

Annex II: Detailed description of policies in the simulation scenarios

Table A - 2. Detailed description of policies in the simulation scenarios

Reference scenario (REF)[1]		Decarbonization scenario (CLIM)		Compensation scenario (COMP)	
Measure	**Specification**	**Measure**	**Specification**	**Measure**	**Specification**
All sectors					
CO_2 price according to national pathway, flat-rate climate bonus	After 2025: 66 €/t CO_2	CO_2 price **with ambitious increase**, flat-rate climate bonus	Linearly increase to 480 €/t CO_2 by 2040	CO_2 price as in **CLIM**, **climate bonus for Q1-Q3**	
Residential buildings					
		<u>**Measures driven by regulatory policy[2]**</u>		<u>**Measures driven by funding policy**</u>	
Thermal refurbishment	Trend extrapolation of the renovation rate Declining subsidy budgets. The average thermal renovation rate (envelope related measures) is about 1.25%p.a.	**Thermal refurbishment**	Minimum Energy Performance Standards (MEPS) based on energy needs for heating: The worst 16% of buildings per building category (SFH, row houses, small MFH and apartment buildings) need to reduce the energy needs within 7 years. The average thermal renovation rate (envelope related measures) is about 2.6%p.a.	**Thermal refurbishment**	The average thermal renovation rate (envelope related measures) is about 1.75%p.a.
		Limited expansion of living space[2]	Declining increase of living area per capita as compared to REF	**Higher funding budgets**	Increase of subsidy budgets to up to 0.6 bn €/year (average 2024-2033) for heating systems, and up to 0.6 bn €/year (average 2024-2033) for thermal renovation, declining budgets afterwards. Investment subsidy rates ("default investment subsidy rate") increase to 35% (district heating) and 45% (biomass boilers, heat pumps). For thermal refurbishment, the subsidy rate is 40% (for the highest improvement) until 2026, afterwards the subsidy level declines to 20% (default subsidy rate).
Increasing energy efficiency	New and renovated buildings must meet the OIB 6-2019 regulation, including a 10% underperformance.	**Higher renovation and qualities of new buildings[2]**	Implementation of OIB 6-2023 regulation and strict enforcements	**Socially differentiated subsidy rates**	Q1 gets 200%, Q2 150% of default investment subsidy rates, Q4 and Q5 35% of default subsidy rates.
Shift to renewable heating systems	No liquid & solid fossil boiler installation in new buildings: 2022 Declining subsidy levels and budgets	**No liquid & solid fossils in new buildings[2]**	No liquid & solid fossils in new buildings: 2022	**Separate funding pots for detached TFH and MFH**	Same total funding budget per household for both categories

Reference scenario (REF)[1]		Decarbonization scenario (CLIM)		Compensation scenario (COMP)	
Measure	**Specification**	**Measure**	**Specification**	**Measure**	**Specification**
	New buildings and thermally renovated buildings (envelope-related measures) need to use a at least a low share of renewable energy carriers, which can be fulfilled with either solar energy any other heating system that exploits renewable energy carriers	No new installation of fossils boilers in existing buildings [2]	No new installations of fossil boilers (including replacement): 2025, Hybrid heat pump is allowed		
		Operating ban on fossil heating systems[2]	Heating oil: 2035, natural gas: 2040	**Stringent examination of alternatives in the event of a heating system change**	If heating systems that exploit renewable energy carriers are cheaper than fossil-based systems, then fossil-based systems are banned
		District heating priority areas	If district heating is available and not significantly more expensive (+15%), then district heating needs to be chosen.		
Mobility					
				Same assumptions as in **CLIM**, but	
Promoting electromobility and increasing vehicle efficiency (CO_2 fleet targets for cars and light duty vehicles EU)	Phase in to 100% market share ZEV by 2035, range equal to ICEV in all vehicle categories by 2037, price parity by 2028, linear phase out of BEV subsidies by 2030, near full supply with fast public charging by 2030, vehicle efficiency increases by about 1.5% p.a., resulting in a share of 66% BEVs by 2040	**Share of BEV increases**	Phase in to 100% market share ZEV by 2030, range equal to ICEV in all vehicle categories by 2028, price parity by 2025, continuation of BEV subsidies until 2030, near full supply with fast public charging by 2030, vehicle efficiency increases by about 1.5% p.a., resulting in a share of 88% BEVs by 2040	**Social differentiation of the commuter allowance**	Restriction of commuter allowance to Q1 to Q3
Use of biofuels in transport	4% of final energy consumption in 2030 and 2040	**Improvement of public transport & non-motorized individual transport services**	Linear increase of PT stop density by 50% up to 2030, linear decrease of PT frequency by 50% up to 2030, improving infrastructure for non-motorized transport by 50%	**Reduction of the public transport ticket price**	Linear decrease of PT fees by 50% in 2030
Promotion of active mobility and mobility management	Continuation of the measures of the program klimaaktiv mobil	**Speed limit reductions**	Motorways 100 km/h instead of 130 km/h, non-urban roads 80 km/h instead of 100 km/h and urban roads 30 km/h instead of 50 km/h from 2025 onwards		
		Introduction of a distance-based road toll	Linear phase in to 0.07 €/km by 2030		
		Mineral oil tax (MÖSt) increase	Increase by 50% in both 2025 and 2030.		

Reference scenario (REF)[1]		Decarbonization scenario (CLIM)		Compensation scenario (COMP)	
Measure	**Specification**	**Measure**	**Specification**	**Measure**	**Specification**
		Expansion and increase of parking fees	All short-term public parking spaces subject to fees from 2030 on, linear increase of fees to 1 €/h in rural areas to 5 €/h in Vienna by 2030		
		Greening of commuter allowance	No commuter allowance for car use, double commuter allowance for PT use from 2025 on		
		Speed limits	Reduction of speed limit to 30/80/100 km/h (urban roads, national roads, highways)		
		Modification of spatial planning	Densification of new developments from 2025 onwards		

[1] Based on With Existing Measures (WEM) Scenario of the Federal Environment Agency (2023). [2]Based on With Additional Measures (WAM) Scenario of the Federal Environment Agency (2023). TFH: two-family houses, MFH: multi-family houses, ZEV: zero emission vehicle, ICEV: internal combustion engine vehicle, BEV: battery electric vehicle, PT: public transport.

Annex III: Detailed results of the sensitivity analysis

Figure A - 1. Detailed effects of changes in energy prices on GDP components (annual averages 2024/40, in real terms)

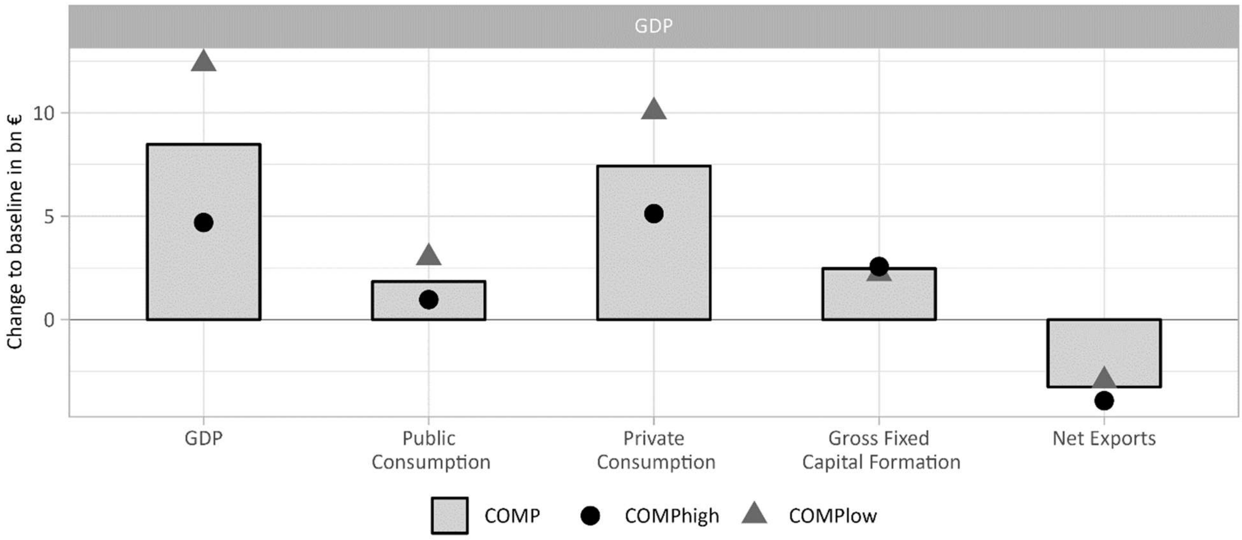


Figure A - 2. Detailed effects of changes in energy prices on public revenues and expenditures (annual averages 2024/40, in real terms)

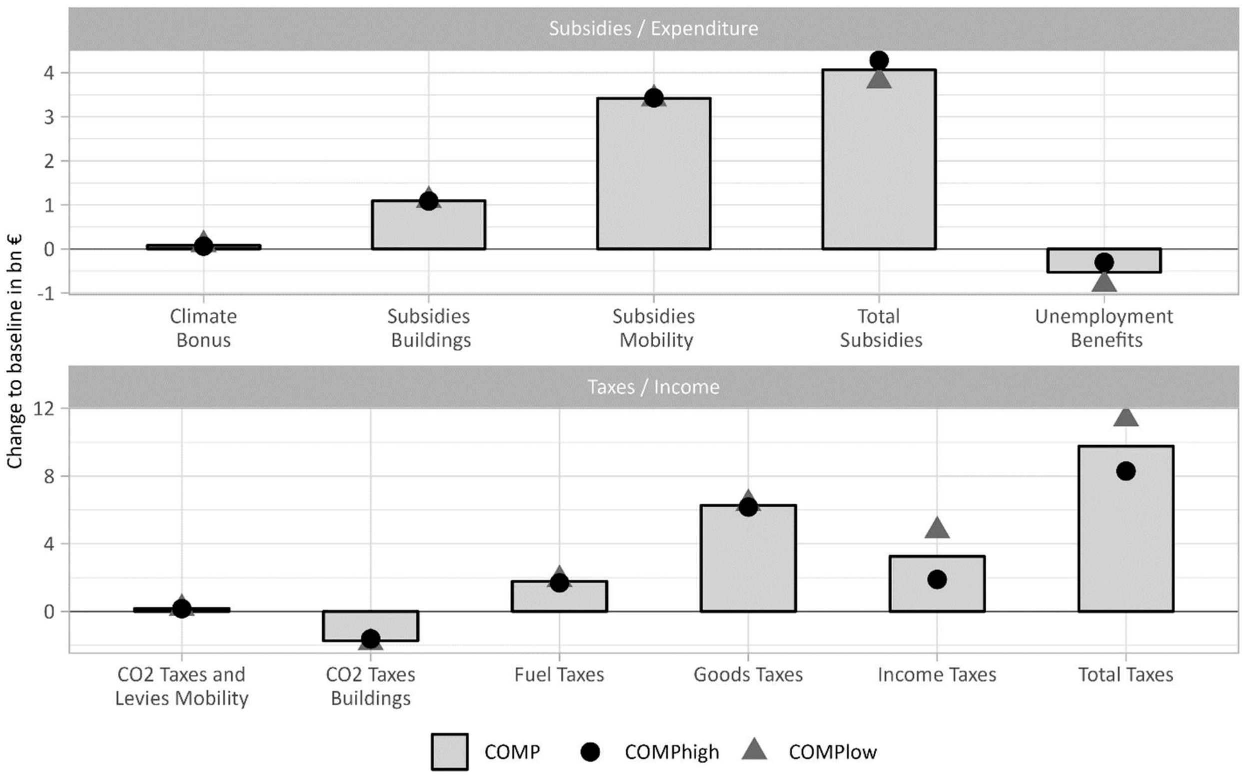


Figure A - 3. Effects of changes in energy prices on household income by income quintile (annual averages 2024/40, in real terms)

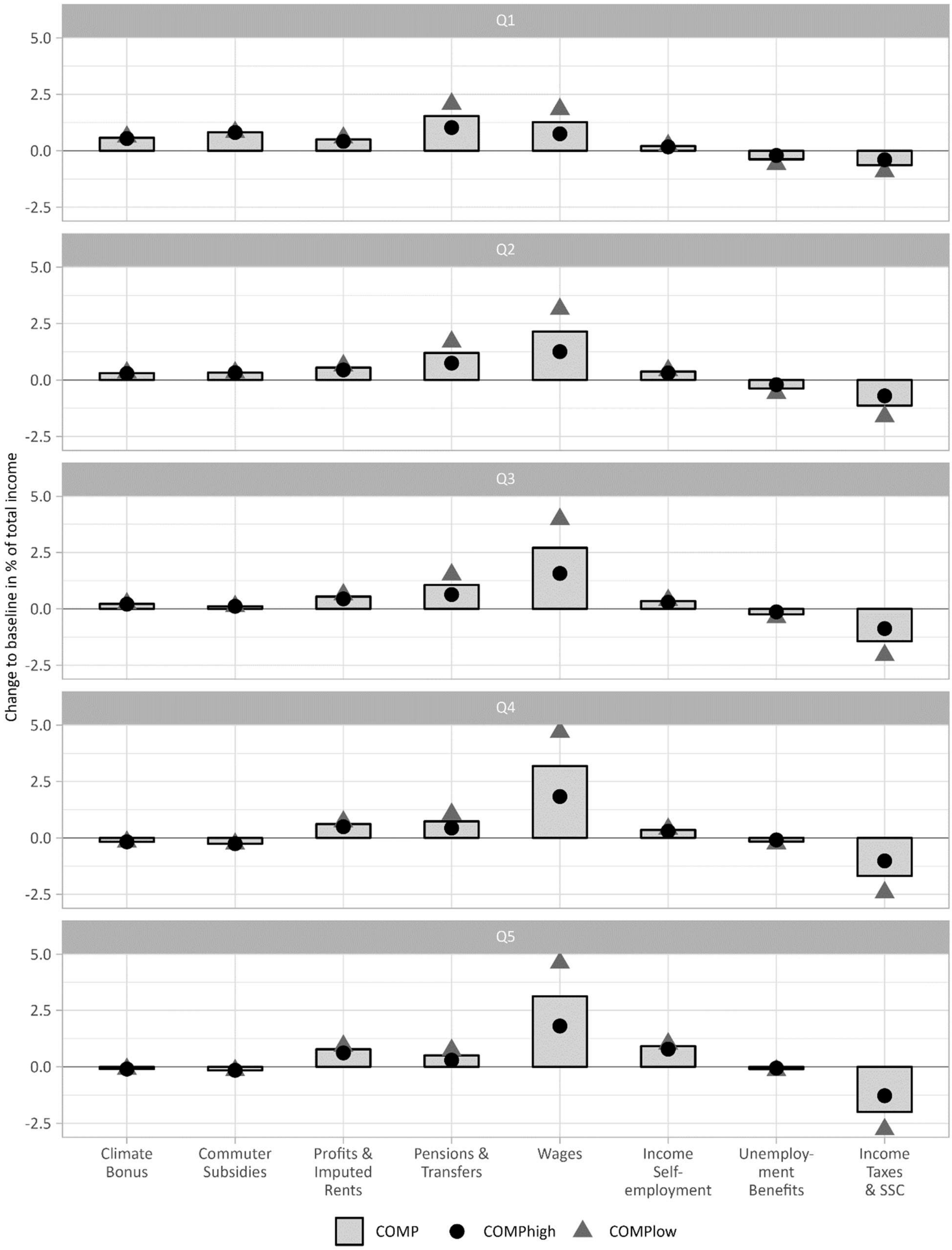
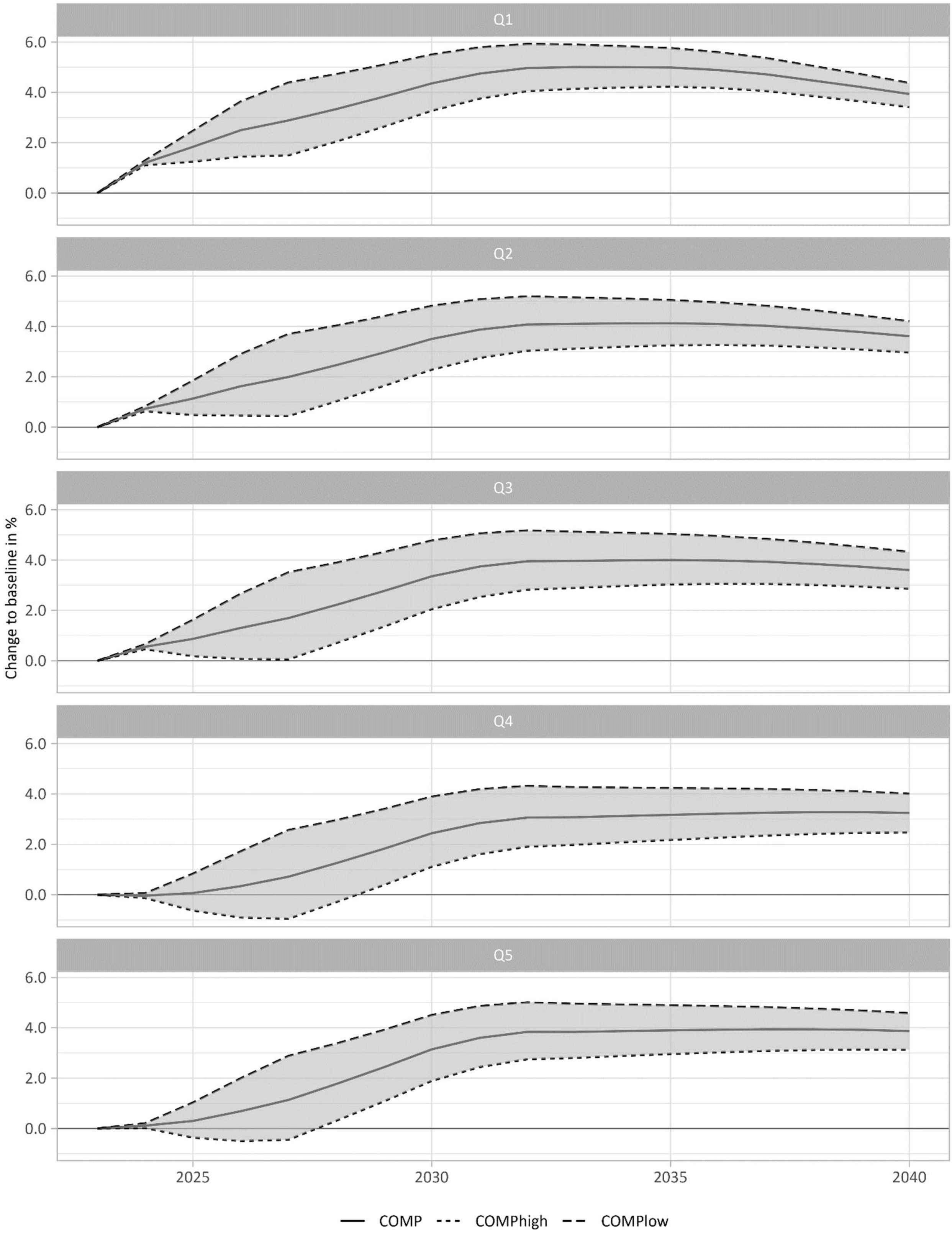


Figure A - 4. Effects of changes in energy prices on household consumption by income quintile (in real terms)



Annex IV: Assumptions on energy and carbon prices

Table A - 3: Assumptions on energy and carbon prices in the main scenarios

Years	Electricity EUR/MWh	Gas EUR/MWh	Oil Brent US$/bbl	Coal US$/t	ETS EUR/t CO_2
2017	34.2	0.0	54.3	86.8	5.9
2018	46.3	0.0	71.2	102.3	16.1
2019	40.1	12.4	64.5	74.9	24.9
2020	33.1	10.0	41.8	63.2	24.8
2021	106.9	46.8	71.2	129.0	59.6
2022	261.4	125.1	99.9	313.4	80.8
2023	127.1	52.6	81.2	280.7	87.5
2024		47.0	74.6	248.1	91.9
2025		41.4	68.0	215.4	96.4
2026		35.8	61.4	182.7	100.8
2027		30.1	54.8	150.0	105.2
2028		24.5	48.2	117.4	109.6
2029		18.9	41.6	84.7	114.0
2030		13.3	35.0	52.0	118.4
2031		13.1	34.5	51.5	123.9
2032		13.0	33.9	51.0	129.4
2033		12.9	33.4	50.5	134.9
2034		12.8	32.8	50.0	140.4
2035		12.7	32.25	49.5	145.9
2036		12.6	31.70	49.0	151.4
2037		12.5	31.15	48.5	156.8
2038		12.3	30.60	48.0	162.3
2039		12.2	30.05	47.5	167.8
2040		12.1	29.50	47.0	173.3

Sources: 2017-2022: Spot prices (EEX for electricity, gas and CO_2; EIA for Oil brent and coal); 2023-2029: Futures (EEX for electricity, gas and CO_2; ICE for Oil brent and WEO for coal); 2030 and 2040 WEO for all energy sources, other years interpolated