Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	TransFair-AT
Langtitel:	Socially Fair Options for a Climate Neutral Transformation of Housing and Mobility in Austria
Zitiervorschlag:	Kettner, C., J. Bock-Schappelwein, D. Kletzan-Slamanig, M. Sommer, A. Gühnemann, P. Pfaffenbichler, L. Hartwig, O. Gold, M. Kirchner, N. Spittler, E. Wretschitsch, L. Kranzl, A. Müller, L. Mayrhuber (2025). Socially Fair Options for a Climate Neutral Transformation of Housing and Mobility in Austria (TransFair-AT). Endbericht. Wien.
Programm inkl. Jahr:	ACRP 13th Call for Proposals (2020)
Dauer:	01.11.2021 bis 31.10.2024
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Schlagwörter:	Dekarbonisierung, Wohnen, Mobilität, just transition
Projektgesamtkosten:	€ 299.934

Allgemeines zum Projekt	
Fördersumme:	€ 299.934
Klimafonds-Nr:	KR20AC0K18007
Erstellt am:	17.04.2025

B) Project overview

1 Kurzfassung

Motivation

Die österreichische Regierung strebt das Ziel der Klimaneutralität bis 2040 an. Eine vollständige Dekarbonisierung innerhalb eines so kurzen Zeitraums stellt sowohl für den Verkehrs- als auch für den Gebäudesektor eine Herausforderung dar: Im Verkehrssektor muss der Trend steigender Emissionen dauerhaft umgekehrt werden, im Gebäudesektor müssen der Gebäudebestand thermisch verbessert und die Heizsysteme auf erneuerbare Energien umgestellt werden. Die Einführung von Politikinstrumenten zur Dekarbonisierung dieser Sektoren wirkt sich aufgrund verschiedener (sozio-ökonomischer) Charakteristika unterschiedlich stark auf einzelne Haushaltsgruppen aus. Die (vermeintliche) Regressivität von Klimapolitikinstrumenten (insb. CO_2 Bepreisung) erschwert sehr oft eine evidenzbasierte Diskussion auf politischer Ebene und wird als Argument gegen die Umsetzung entsprechender Maßnahmen verwendet, insbesondere in Zeiten schwacher Wirtschaftsentwicklung oder volatiler Energiepreise.

Ziele des Projekts

Die Hauptziele von ***TransFair-AT*** waren

1. die Erstellung umfassender und innovativer modellgestützter Analysen der ökonomischen und sozialen Auswirkungen einer vollständigen Dekarbonisierung der Sektoren Wohnen und Mobilität in Österreich bis 2040;
2. die Entwicklung gezielter Kompensationsmechanismen, um die Belastung durch diese klimapolitischen Eingriffe für besonders vulnerable Gruppen abzumildern, wobei sichergestellt ist, dass diese Kompensationsmechanismen mit einer vollständigen Dekarbonisierung vereinbar sind.

Aus diesen Hauptzielen lassen sich die folgenden Teil-Ziele ableiten:

- Entwicklung von Dekarbonisierungsszenarien für die Sektoren Wohnen und Mobilität in enger Zusammenarbeit mit den relevanten Stakeholdern, um sozialverträgliche Klimaschutzoptionen zu identifizieren;
- Iterative Kopplung des makroökonomischen Modells DYNK mit dem Fahrzeugwahlmodell SERAPIS, dem Verkehrsnachfragemodell MARS und dem Gebäudebestandsmodell Invert/EE-Lab zur Analyse der Effekte verschiedener Dekarbonisierungsszenarien auf CO_2-Emissionen, makroökonomische Größen sowie die Verteilung (disaggregiert für unterschiedliche Haushaltstypen);
- Erstellung einer gemeinsamen Haushaltsdatenbank für alle Modelle;
- Identifizierung, Definition und modellgestützte Analyse von Kompensationsmechanismen zur Abfederung der Belastungen durch klimapolitische Maßnahmen für besonders vulnerable Gruppen in enger Zusammenarbeit mit den relevanten Stakeholdern.

Projektstruktur und Methodik

In **WP1** wurden ein abgestimmter Haushaltsdatensatz und gemeinsame Haushaltstypen entwickelt, die als Input für alle Modelle dienen. Es wurden zwei Politikszenarien bis 2040 definiert, die Optionen für eine vollständige Dekarbonisierung von Wohnen und Mobilität in Österreich sowie Kompensationsmaßnahmen für mögliche damit verbundene negative Verteilungseffekte für vulnerable Haushalte darstellen. In **WP2** wurde das makroökonomische Modell mit drei Bottom-up-Modellen gekoppelt: einem Gebäudemodell und zwei Mobilitätsmodellen zu Verkehrsnachfrage bzw. Fahrzeugwahl. In **WP3** wurden die in WP1 definierten Szenarien in Variablen und Parameter für die Modelle übersetzt und Simulationen durchgeführt. Die Modellierungsaktivitäten umfassten ein Basisszenario und zwei Dekarbonisierungsszenarien, wobei eines auch Kompensationsmaßnahmen für vulnerable Gruppen inkludierte. Zur Validierung der Ergebnisse wurden Sensitivitätsanalysen durchgeführt. Auf Basis der Modellierungsergebnisse, einer Literaturrecherche und interaktiven Diskussionen mit Stakeholdern wurden in **WP4** Politikempfehlungen für Österreich entwickelt. **WP5** sorgte für eine kontinuierliche Kommunikation und einen Meinungsaustausch mit den relevanten Stakeholdern, um die Nutzbarkeit der Projektergebnisse für die verschiedenen Stakeholdergruppen zu gewährleisten.

Ergebnisse und Schlussfolgerungen des Projekts

Die Modellierung der klimapolitischen Szenarien in ***TransFair-AT*** zeigt, dass eine Dekarbonisierung von Wohnen und Mobilität in Österreich bis 2040 möglich ist, aber einen umfassenden Mix an politischen Instrumenten und deren rasche Umsetzung erfordert. Eine erfolgreiche Transformation hängt von der Integration von regulativen und preisbasierten Instrumenten ab. Während Klimaschutzmaßnahmen tendenziell positive makroökonomische Effekte haben (je nach Szenario steigt das BIP in der Simulationsperiode im Vergleich zum Referenzszenario durchschnittlich um 1,5% bzw. 1,9% p.a.), können sie auch die Ungleichheit zwischen verschiedenen Haushaltsgruppen verschärfen. Daher erfordert eine gerechte Transformation gezielte Kompensationsmaßnahmen für Haushalte mit niedrigem und mittlerem Einkommen, und einen Ausgleich zwischen Effektivität, Effizienz, Gerechtigkeit und öffentlicher Akzeptanz.

Ausblick und Zusammenfassung

Im Rahmen der interdisziplinären Projektarbeit ist es gelungen, neues Wissen zu generieren, sowohl in Bezug auf die innovative Modellkopplung als auch in Bezug auf die umfassende Analyse von Dekarbonisierungsportfolios einschließlich Kompensationsmaßnahmen für vulnerable Haushalte. In zukünftigen Projekten wollen wir uns auf identifizierte Forschungslücken konzentrieren, wie z.B. eine weitere Verfeinerung der Modellkopplung und die Einbeziehung weiterer Themen (Fernwärme, Mobilitätsmuster und Zeitnutzung, Genderaspekte).

2 Executive Summary

Motivation

The Austrian government strives for achieving greenhouse gas neutrality by 2040. Achieving a complete decarbonization in the transport and the buildings sector within such a short period of time will be challenging for both sectors: In the transport sector, the trend of rising emissions must be permanently reversed; in the buildings sector, in particular the building stock must be thermally improved, and heating systems must completely shift towards renewable energy sources. The introduction of policy instruments to decarbonize housing and mobility will affect different household groups to varying degrees depending on several (socio-economic) aspects. The (presumed) regressivity of policy instruments (most notably fiscal measures) in these areas 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 as during the COVID-19 or energy crises.

Objectives of the project

The overarching objectives of ***TransFair-AT*** were

1. to provide comprehensive and innovative model-based analyses of the economic incidence and social impacts of a complete decarbonization of the sectors residential buildings and passenger transport in Austria by 2040; and
2. to develop targeted compensation mechanisms to mitigate the burden of these climate policies for particularly vulnerable groups, while ensuring that these compensation mechanisms are consistent with full decarbonization.

From these overarching objectives, the following subgoals can be derived:

- development of decarbonization policy scenarios for the housing and mobility sectors in close cooperation with relevant stakeholders to identify socially acceptable mitigation policy pathways;
- iterative linking of the macroeconomic model DYNK with the vehicle choice model SERAPIS, the transport demand model MARS, and the building stock model Invert/EE-Lab to analyze the emission impact as well as the macroeconomic and distributional effects of different decarbonization policy scenarios on different household types;
- definition of a joint household database for all models;
- identification and development (and model-based analysis) of compensation mechanisms to mitigate burdens of climate policies for particularly vulnerable groups in close cooperation with relevant stakeholders.

Project structure and methodology

In **WP1**, a matched household dataset and shared household types were developed that serve as inputs for all models. Two policy scenarios until 2040 were developed depicting options for a full decarbonization of passenger transport and residential buildings in Austria as well as policies for mitigating potential negative distributional effects of climate policy measures for vulnerable households. In **WP2,** the macroeconomic model was linked with three bottom-up models – a model for buildings, and two mobility models, one covering transport demand and one model for vehicle choice. In **WP3**, scenario parameters defined in WP1 were translated into variables and parameters used by the models and subsequently simulation runs were carried out. The modelling activities comprised a baseline scenario and two decarbonization strategies and their underlying policies, the latter including compensation policies for vulnerable groups. Moreover, a sensitivity analysis was conducted. In **WP4**, policy recommendations for Austria were developed based on the modelling results, a literature review and interactive discussions with stakeholders. **WP5** ensured continuous communication and exchange of views with relevant stakeholders, utilizing synergies and ensuring the usefulness of project results for the various user groups.

Results and conclusions of the project

The modelling of climate policy scenarios in ***TransFair-AT*** shows that a decarbonization of households and mobility in Austria by 2040 is achievable but requires a comprehensive mix of policy instruments and their rapid implementation. A successful transformation hinges on the integration of command-and-control measures and price-based instruments. While climate protection measures can yield positive macroeconomic effects (depending on the scenario, GDP increases by an average of 1.5% or 1.9% p.a. in the simulation period compared to the reference scenario), it is crucial to recognize that they may also exacerbate inequality among different income groups. Therefore, a just transition pathway requires targeted compensation measures for low- and middle-income households and concerns regarding effectiveness, efficiency, equity, and public acceptance must be balanced. A nuanced approach that combines various decarbonization measures with targeted compensation strategies will be essential to ensure that the benefits of decarbonization are equitably shared, thereby fostering broader acceptance and support for these necessary transitions. Subsidies and recycling of carbon pricing revenues 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. In addition to supporting investments, e.g., in renovation or new heating systems also the adaptation of legal framework conditions is called for.

Outlook and summary

Our interdisciplinary collaboration succeeded in generating knowledge and results beyond the state of the art, both related to the innovative model linkage and the comprehensive analysis of decarbonization policy portfolios including compensation measures for vulnerable households. In future projects we intend to focus on identified research gaps like enhancing the model linkage and incorporating further issues (district heating, mobility patterns and time use, gender aspects).

3 Background and objectives

Background

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- definition of a joint household database for all models;
- identification and development (and model-based analysis) of compensation mechanisms to mitigate burdens of climate policies for particularly vulnerable groups in close cooperation with relevant stakeholders.

4 Project content and results

WP1. Foundations

One main objective of WP1 was the construction of a common household database to be used in all models employed in the project. The database combines data from the Austrian Household Budget Survey with individual data of the EU-SILC dataset.

The second main objective of WP1 was the identification of representative household types that fulfil certain criteria in terms of income, energy expenditure and mobility options. These households were regarded as vulnerable to climate policy interventions and were the focus of the modelling analysis in WP3. The definition of policy instruments and compensation measures specifically considered the impacts on the groups of vulnerable households. The identification of household types in a first step was based on a comprehensive literature survey. Initially, it was planned to combine the results of the desk research with a hierarchical cluster analysis. As this latter approach did not produce a balanced set of household types, we decided to apply another approach, that is theory-based and incorporates findings from literature. In addition, it was validated by discussions with the **Scientific Advisory Board (SAB)** and Stakeholders. For presentation purposes, the results were also presented in the form of a composite index based on four dimensions considered relevant for mapping the vulnerability of households to rising costs of fossil fuels: income vulnerability, energy vulnerability, housing vulnerability, and mobility vulnerability. A total of six indicators were selected for the four categories to be considered in the structuring of vulnerable households and ultimately to construct an index:

- Income vulnerability:
  - Equivalized disposable household income below 140% of the national median equivalized disposable income
- Energy vulnerability:
  - Use of fossil fuels in the home
  - Perceived as unaffordable to keep the apartment adequately warm
- Housing vulnerability:
  - Households living in rent
  - Households living in multi-family buildings
- Mobility vulnerability:
  - Households living in peripheral areas

To calculate the composite index for Austria, we matched data from EU-SILC and the Austrian Household Budget Survey (HBS; with supplementary information on public transport quality matched to Austrian HBS data in a special evaluation by Statistics Austria). The reference year is 2019.

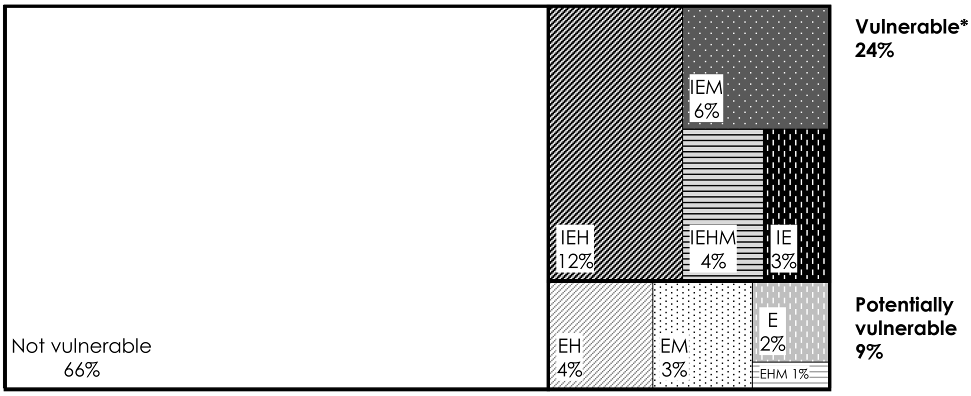
In total, 16 different combinations of household types can be derived from the four categories used. Some households are affected by only one category, others by two or three. One group of households is affected by all four categories and one group is not exposed to any risk. Four of these 16 household types can be identified as vulnerable:

- Type IE: households that are income vulnerable (I) and energy vulnerable (E)
- Type IEH: households that are income vulnerable (I), energy vulnerable (E), and housing vulnerable (H)
- Type IEM: households that are income vulnerable (I), energy vulnerable (E), and mobility vulnerable (M)
- Type IEHM: households that are income vulnerable (I), energy vulnerable (E), housing vulnerable (H), and mobility vulnerable (M)

Vulnerable households are characterized by being affected by both income vulnerability (I) and energy vulnerability (E), following the definition used by Matzinger et al. (2018) that only those at risk of income poverty can also be energy poor. In addition, vulnerability can arise from housing vulnerability (H) or from mobility vulnerability (M), or from both. Four additional groups of households can be classified as potentially at risk because, although they are currently not at risk of income vulnerability, they are at high risk of energy vulnerability as they use heating systems that are particularly vulnerable to decarbonization. These households may also be at risk of housing vulnerability or mobility vulnerability, or of both.

From the available HBS and EU-SILC data and the defined indicators, the following results can be derived: Almost one quarter (24%) of all households in Austria can be described as vulnerable (Figure 1). This means that these households will be particularly affected by rising prices of fossil fuels, for instance, because of carbon pricing. Within the group of vulnerable households, the largest group (12% of all households) is characterized not only by income and energy vulnerability but also by housing vulnerability. This is mainly due to the comparatively high prevalence of fossil fuel heating systems in Austrian households. 6% of households are characterized by income vulnerability, energy vulnerability and mobility vulnerability, 4% are vulnerable with respect to all four dimensions, and 3% of all households are characterized by income and energy poverty. A further 9% of households can be classified as potentially vulnerable to rising energy and carbon prices. Although not currently impacted by income vulnerability, they are potentially affected by energy vulnerability as they heat with fossil heating systems.

Figure 1. Vulnerable and potentially vulnerable households

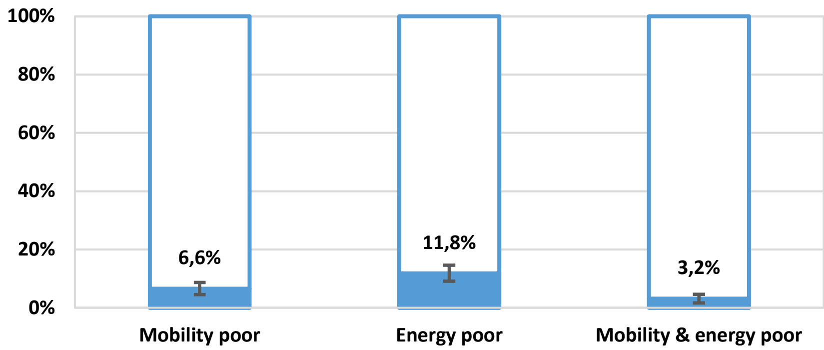


Source: HBS, EU-SILC; own calculations. *Based on 140% income threshold. All values rounded to the nearest integer.

Detailed results have been published in a research brief and a book chapter (Bock-Schappelwein and Kettner, 2023, 2024).

In addition, data from a combined mobility and consumer expenditure survey have been used to analyze and compare the characteristics of mobility and energy poor households in Austria. According to the results of this analysis about 7% and 12% of the Austrian households can be classified as mobility and energy poor respectively in terms of affordability (Figure 2).

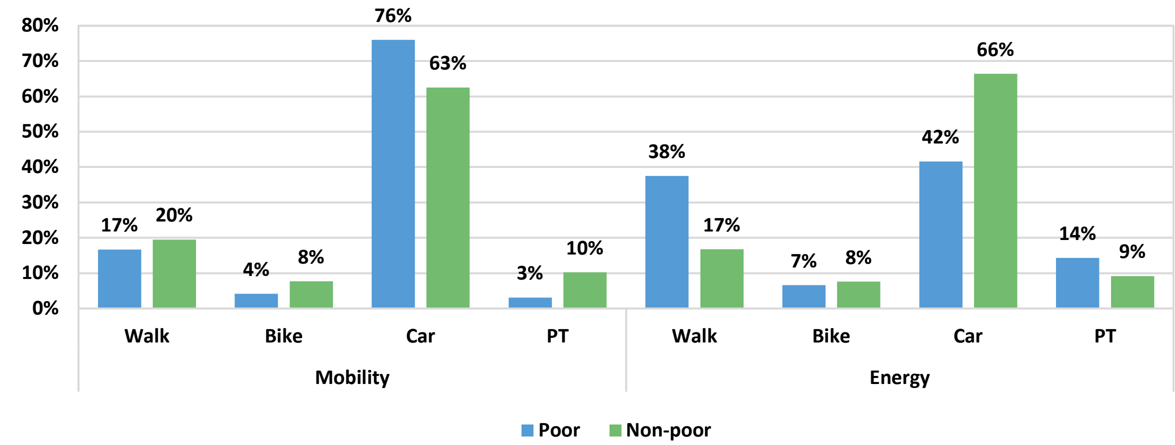
Figure 2. Share of vulnerable households in terms of affordability by category



Source: Consumer expenditure and mobility survey Austria 2019-2020, own calculations. N = 532.

Key findings concerning socio demography are that both, mobility and energy poor households are smaller, have less children, are predominantly female and have lower educational levels and employment rates. On the other hand, mobility and energy poor households differ significantly in mobility behavior. Mobility poor households have lower shares of walking, cycling and public transport trips and a higher share of car trips. Energy poor households, on the contrary, have higher shares of walking and public transport, a lower share of car trips and about the same share of cycling trips. As an example, Figure 3 shows the results concerning modal split. The full results are documented in a publicly available research brief (Pfaffenbichler et al., 2023).

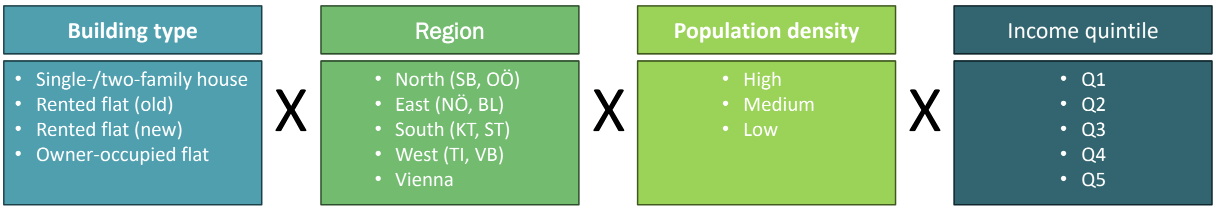
Figure 3. Modal split of mobility and energy poor households



Source: Consumer expenditure and mobility survey Austria 2019-2020, own calculations.

To be able to conduct more detailed quantitative analyses on the impacts on low-income households, it was decided to differentiate household types by income quintile for the model-based analyses. Since a key variable in the MARS model is the location of residence, we included the variable federal state of residence (Figure 4). Out of the 300 possible combinations 238 were applied since some combinations were not filled by data (e.g. no low population density areas in Vienna).

Figure 4. Household types for the model simulations



Based on a literature review, discussions with the SAB and the stakeholders as well as data availability and the feasibility of model integration a list of measures was compiled. A reference scenario and two policy scenarios, CLIM and COMP, were developed on the basis of this list. A detailed description of the measures is provided in Kettner et al. (2025). Raising the carbon price is a “cross-cutting” approach that affects both sectors. Furthermore, specific measures for mobility and housing are listed. These include other market-based approaches (e.g. changes in fuel taxes, road tolls, specific subsidies) as well as command-and-control measures (bans or obligations) or (public) infrastructure investments. Although ambitious spatial planning is not considered in the climate policy scenarios, this instrument remains a crucial tool for combatting climate change. However, supplementary analyses showed 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.

With respect to other, exogenous, model parameters most notably future energy prices, we drew from recent findings (e.g. IEA, 2022) and aligned our assumptions with other projects that study decarbonization scenarios (***NetZero2040***, ***SectorCoup***).

WP2. Model Preparation and Linking

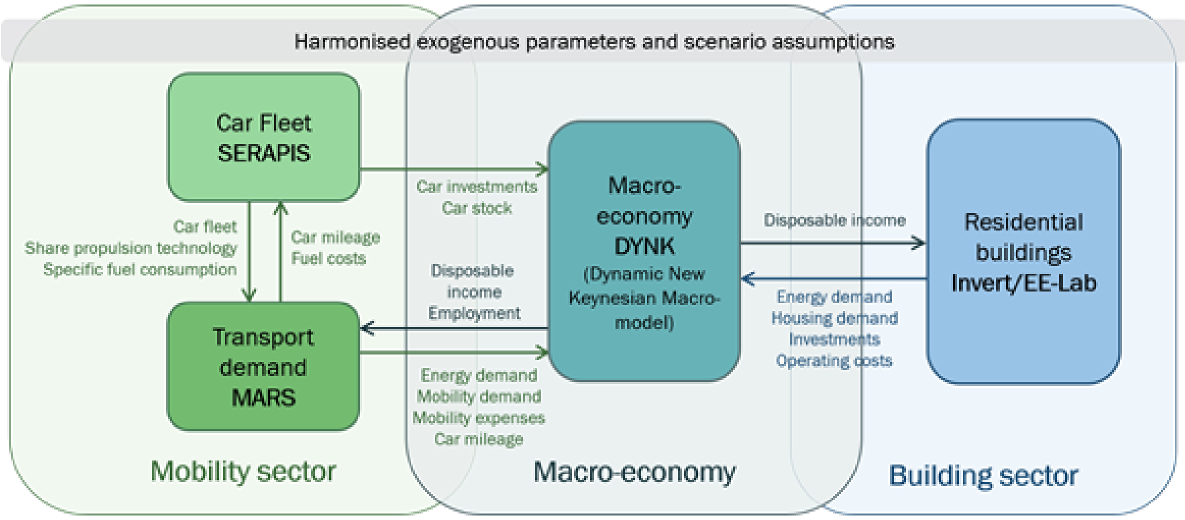
Prior to linking the models each of the three modelling groups revised their models and updated them with the most recent data available. Selected exogenous parameters and scenario assumptions were harmonized in this process. Additionally, modifications necessary to tackle the topic of the project were implemented. E.g., the composition of household types in the models was adjusted to fit the requirements of the project, i.e., household types were aligned. Subsequently, a coordination group with one representative of each modelling team was set up.

Three out of four models used in ***TransFair-AT*** (DYNK, MARS and Invert/EE-Lab) were used in biannual reports on emission projections for 2030 und 2050 (Umweltbundesamt, 2017; Krutzler et al., 2023b). Usually the models DYNK, MARS and Invert/EE-Lab were applied independently in these reports. However, on these previous occasions the models have been linked in a simple unidirectional manner. I.e., no feedback mechanisms and iterations have been implemented. In addition, variables such as operation costs were not exchanged between the models and especially the financial implications of different policy measures on different household groups have not been assessed.

From this starting point, a literature review was carried out in order to assess the status quo of linking top-down and bottom-up models. A first insight of this process was that linking top-down CGE models with bottom-up models is a well-established practice in the energy sector. Early examples for linking bottom-up and top-down were found in references dating back to the beginning of the millennium (Savard, 2003; Böhringer and Rutherford, 2008). However, no example for linking bottom-up models of passenger transport demand and household supply with space heating and hot water with a top-down macroeconomic model was found in the literature review. It can therefore be reasonably concluded that the approach used in the ***TransFair-AT*** project represents an innovation in the field. The key findings of the literature study can be summarized as follows: There exist three different approaches to linking top-down and bottom-up models: soft-linking, hard-linking and full integration. The key element of soft-linking is that the user is fully responsible for processing and transferring the information between models. This characteristic provides a certain flexibility. In contrast, all information processing and transfer is fully formalized and handled by computer programs in the hard-linking approach. Finally, in the integrated approach all involved models are combined into one single model. Therefore, different parts cannot run independently anymore. Due to major structural differences between the sector models in addition to some technical obstacles a soft-linking approach was chosen in ***TransFair-AT***. While some parts of the data exchange have been automated, substantial manual work from the user is still required. Full automation would have consumed too many resources and was therefore beyond the scope of the project.

Figure 5 shows the basic structure and the interface variables of the ***TransFair-AT*** model linkage.

Figure 5. TransFair-AT model linkage – basic structure and interface variable



Convergence of models is usually measured by monitoring differences in key variables between two successive iterations. In ***TransFair-AT*** all interface variables which are exchanged between the models were used to monitor convergence. The difference between iterations can be computed by using a variety of indicators. The project ***TransFair-AT*** employs two indicators: "maximum absolute relative difference" and "root mean square of the relative difference". Concerning the tolerance for convergence, values in the range of 10^{-4} to 10^{-3} seem to be most common in the literature. Hence, this value range is used as a benchmark for convergence in ***TransFair-AT***.

The process of iterating the bottom-up models MARS/SERAPIS and Invert/EE-Lab with the top-down model DYNK was organized as follows: Each model iteration started and ended with a run of the top-down model DYNK. Iterations between the top-down model DYNK and the bottom-up models MARS/SERAPIS and Invert/EE-Lab were carried out in sets of five iterations. After five iterations convergence was analyzed and decisions were made whether a new set of five iterations was started or not. Structural changes of the models DYNK and Invert/EE-Lab became necessary between iteration 4 and 5, 10 and 11 and 14 and 15. These changes led to disruptions in convergence. The whole process was finally stopped after a total of 20 iterations.

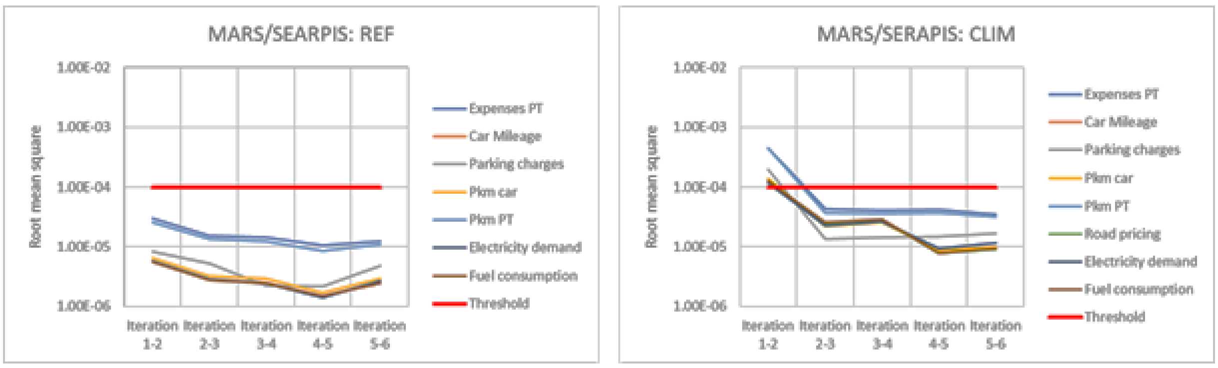
A detailed analysis of the convergence of the top-down model DYNK and the bottom-up models MARS/SERAPIS and Invert/EE-Lab is provided in Gühnemann et al. (2024). In the case of the DYNK model, the convergence indicators drop sharply within the first three iterations (Figure 6). Depending on the scenario, the difference continues to decrease at a slower rate (REF), kind of stabilizes

(CLIM) or increases again slightly (COMP). Structural change leads to a disruption causing an increase in the values of the convergence indicators (iterations 4-5 and 14-15). However, there is a sharp drop again within the next two iterations. Towards the end of the 20 iterations both convergence indicators stabilize roughly in the target range of 10^{-4} to 10^{-3}. Hence, it can be concluded that the model DYNK has reached a satisfying level of convergence after 20 iterations.

Figure 6. Convergence of the indicator Root Mean Square of the interface variables of the model DYNK in the scenarios REF and CLIM

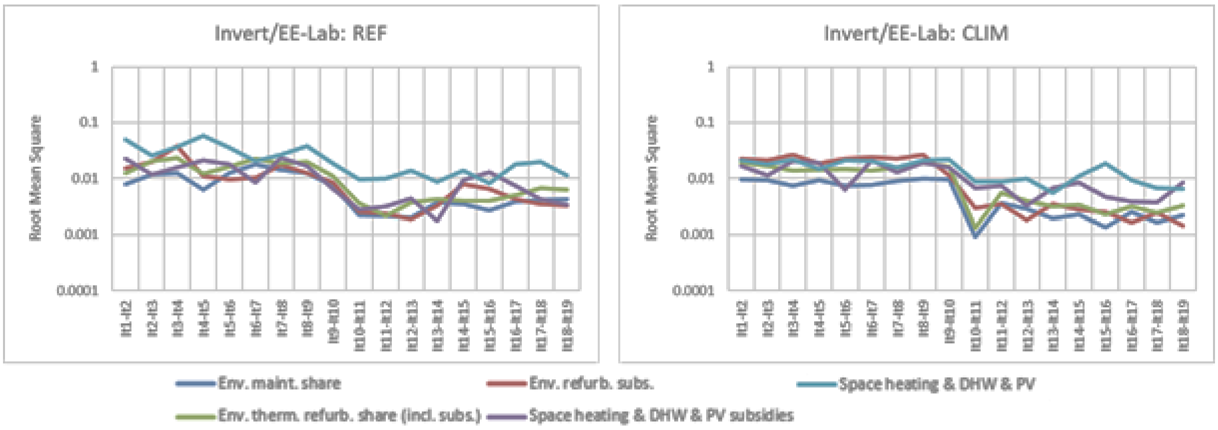
In the case of the model MARS/SERAPIS, convergence indicators also drop sharply in the first three iterations (Figure 7). For the REF scenario both convergence indicators are below the stricter target value of 10^{-4} from the first iterations on. In the CLIM scenario both convergence indicators drop below 10^{-4} after five iterations. It can therefore be concluded that the model MARS/SERAPIS reaches a satisfying level of convergence after five iterations.

Figure 7. Convergence of the indicator Root Mean Square of the interface variables of the model MARS/SERAPIS in the scenarios REF and CLIM



In contrast to the other two models, no clear trend towards convergence was observed in the case of the Invert/EE-Lab model (Figure 8). The Invert/EE-Lab model involves stochastic elements which inherently prevent a convergence between the iterations beyond a certain lower limit. To mitigate this effect, in the later iterations with DYNK results of bundles of five simulations were used instead of results of individual simulations. Although several interface variables seem to stabilize in the target range of 10^{-4} to 10^{-3} (0.01% - 0.1%), some others only stabilize at levels of 10^{-3} to 10^{-2} (0.1% - 1%). Even though no clear convergence could be reached, it can be concluded that the interface variables stabilize at a level which is sufficient for the purpose of ***TransFair-AT***. Nevertheless, future research should analyze the effect of the stochastic elements in more detail.

Figure 8. Convergence of the indicator Root Mean Square of selected interface variables of the model Invert/EE-Lab in the scenarios REF and CLIM



The main finding from linking DYNK with INVERT/EE-Lab and MARS/SERAPIS is that the changes in demand from the bottom-up models did not cause economic disturbances to change disposable income significantly. As a result, the perturbation is only marginally reflected in the next iteration. Besides the rather price-insensitive behavior of the bottom-up models, a key reason for this is the relative robustness of the DYNK demand system. Consumption of non-durable goods is structured in such a way that changes in energy consumption are accompanied by opposite changes in other non-durable goods consumption, i.e. a crowding-out mechanism. In other words, if a household has a surplus of money due to lower energy expenditure, the money is spent on other non-durable goods and the overall change in disposable income remains small[1]. Therefore, in bottom-up models, changes in energy demand have a fairly small effect on disposable income and hence on its use in the next round. This leads to rapid convergence.

[1] Disposable income is primarily affected by domestically generated value added. If the consumption pattern change, this means that another sector mix provides these goods. These other sectors might have a higher or lower value added share. Hence, even if the same monetary amount is consumed, this can result in more or less wages and profits that flow back to the households as income.

WP3. Model-based Analysis of Decarbonization Scenarios

Using the updated and enhanced input data set of the involved models (derived in WP2), we have developed two decarbonization scenarios in addition to a Reference scenario (REF), which is based on current policies and does not achieve a deep CO_2 reduction. The initial decarbonization scenario (CLIM) places a high priority on decarbonization, while concomitantly placing a lower emphasis on distributional effects. Conversely, the second scenario (COMP) is oriented towards mitigating the adverse monetary impacts that may arise from decarbonization for vulnerable households in the short or medium term, while maintaining decarbonization of the analyzed sectors until 2040. An overview of the implemented policy assumptions is given in Table 1. For further information on the implemented policy assumptions, see Kettner et al. (2025).

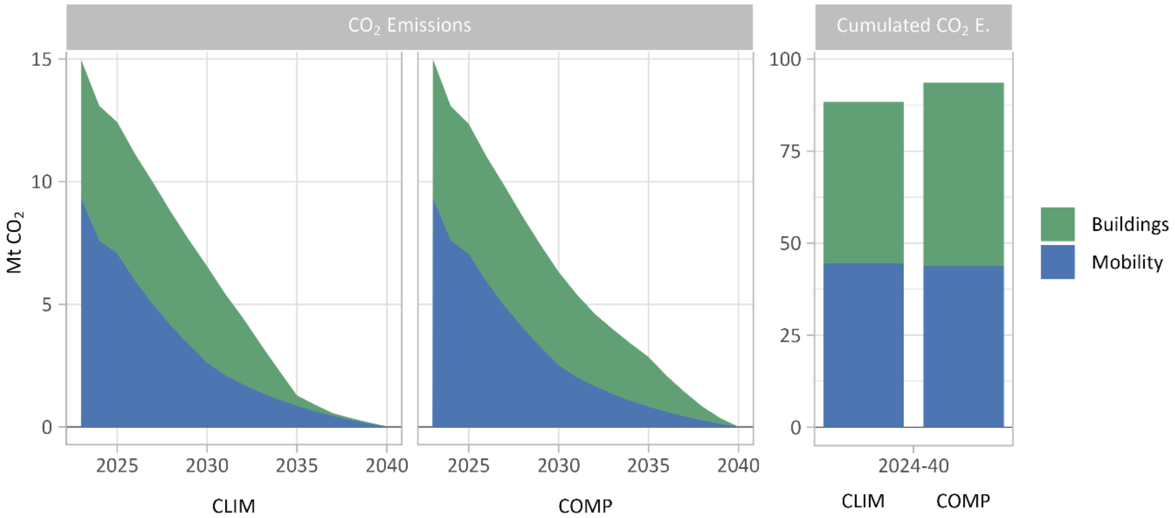
Table 1. List of policies in the simulation scenarios

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 battery electric vehicle (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.

The development of CO_2 emissions from residential buildings and passenger transport in the CLIM and COMP scenarios is illustrated in Figure 9. In both scenarios, a 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 leading to lower abatement than the regulatory instruments assumed in the CLIM scenario.

Figure 9. Development of CO_2 emissions

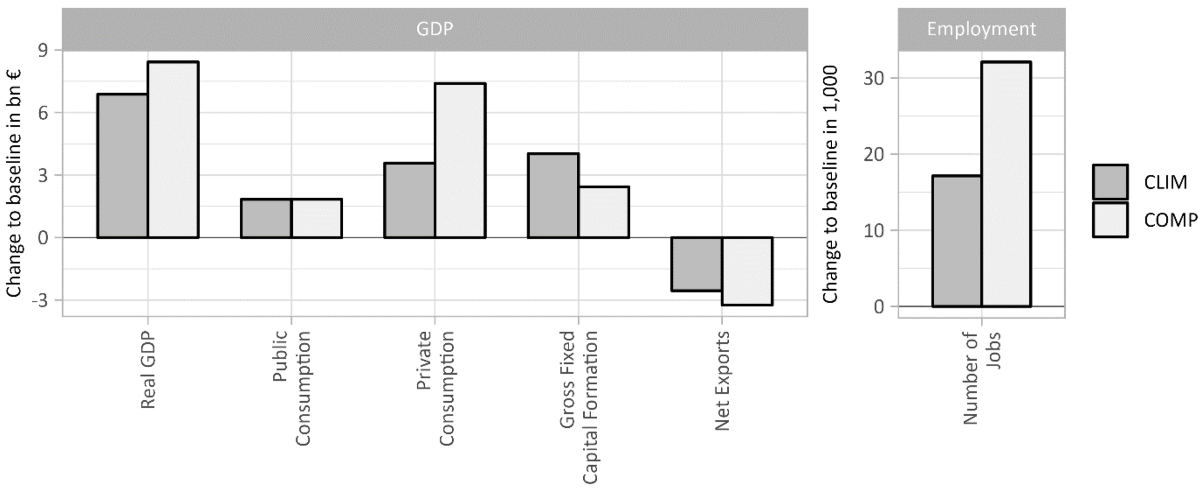


These emission reductions reflect the impact of policy measures on increasing energy efficiency and a shift towards renewable energy sources. Final energy consumption in residential buildings and passenger transport in 2040 is 26 TWh (28%) lower in CLIM than in the baseline scenario; in COMP final energy 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, which reflects both a shift towards public transport and the higher efficiency of electric drives. 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 10 illustrates changes in macroeconomic indicators under the CLIM and COMP policy scenarios compared to the reference scenario. The left panel focuses on real GDP changes, while the right panel shows employment impacts. In CLIM, real GDP on average increases by 6.8 bn € p.a. (1.5%) in the period 2024 to 2040 compared to the baseline, driven mainly by increases in gross fixed capital formation and private consumption (following from increasing household income). Reductions in net exports due to demand-related increasing imports and marginally decreasing exports mitigate the positive impact on GDP. COMP, by contrast, exhibits a more substantial growth in real GDP of 8.4 bn € p.a. (1.9%). With respect to the individual components, private consumption makes the largest contribution in this scenario. 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 compensation measures targeted at lower-income households who have a higher propensity to consume. On average over the period 2024 to 2040, CLIM delivers 17,200 additional jobs compared to the reference scenario, implying an increase of employment by 0.4%. In COMP, 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 10. Average annual macroeconomic effects (2024/40, in real terms)



In both scenarios, total tax revenues increase compared to the reference scenario. The increase is mainly driven by rising income tax revenues and CO_2

pricing revenues and levies related to mobility and to a lesser extent by an increase in goods tax revenues; fuel tax revenues, by contrast, decrease due to decarbonization. Subsidies also increase in both scenarios compared to the reference scenario. The net effect on government revenues (total tax revenues less total subsidies) is positive, amounting roughly to 2.1 bn € p.a. in CLIM and 1 bn € p.a. in COMP in the period 2024-2040.

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 11.

In CLIM, 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 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 below), since in the policy scenarios we implemented the same saving rates as in the reference scenario.

In CLIM, 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 that 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 11. Change in household consumption expenditure by income quintile (2024-40, in real terms)

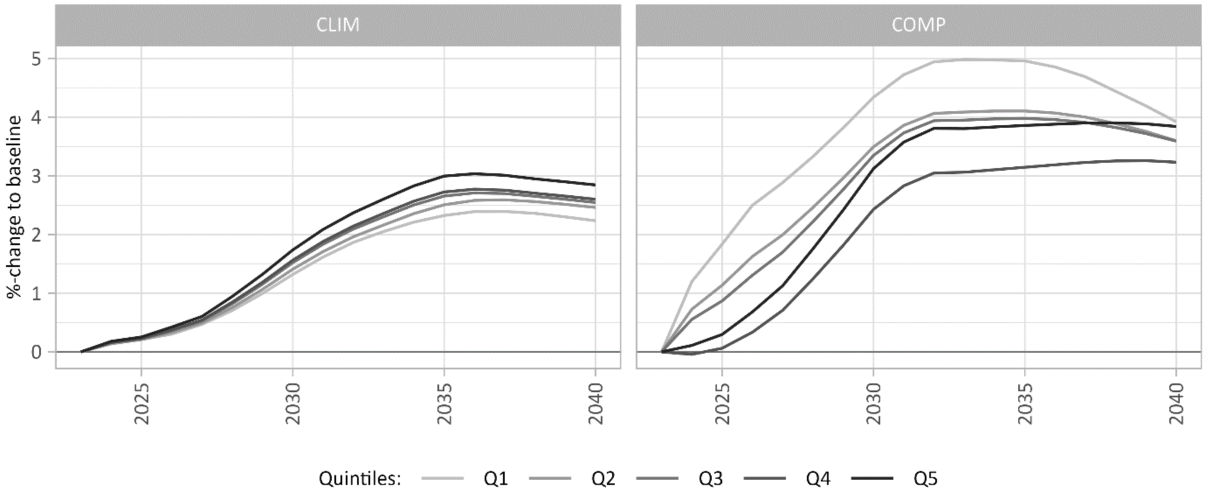
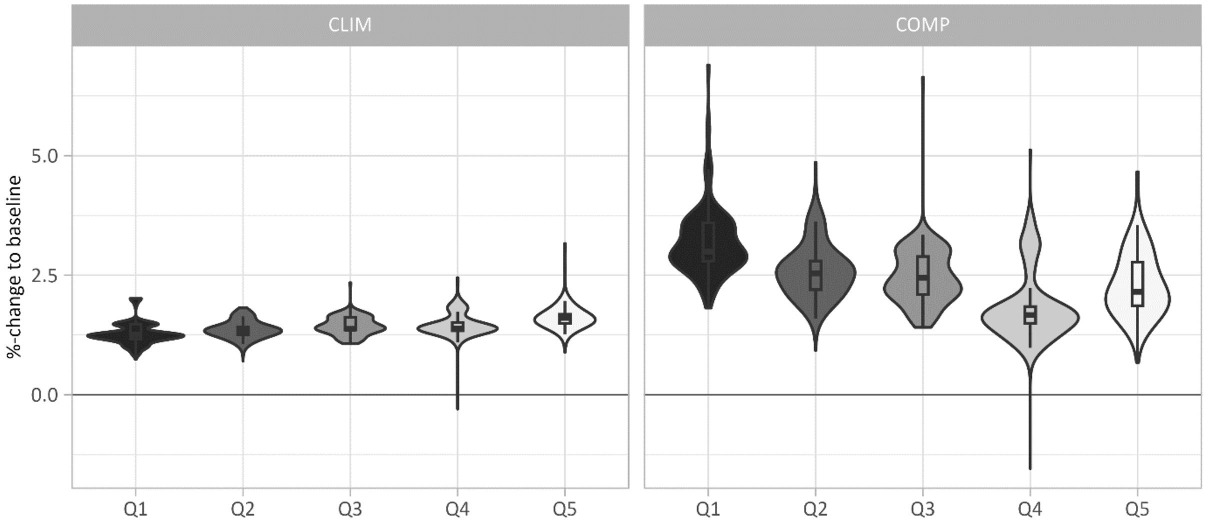


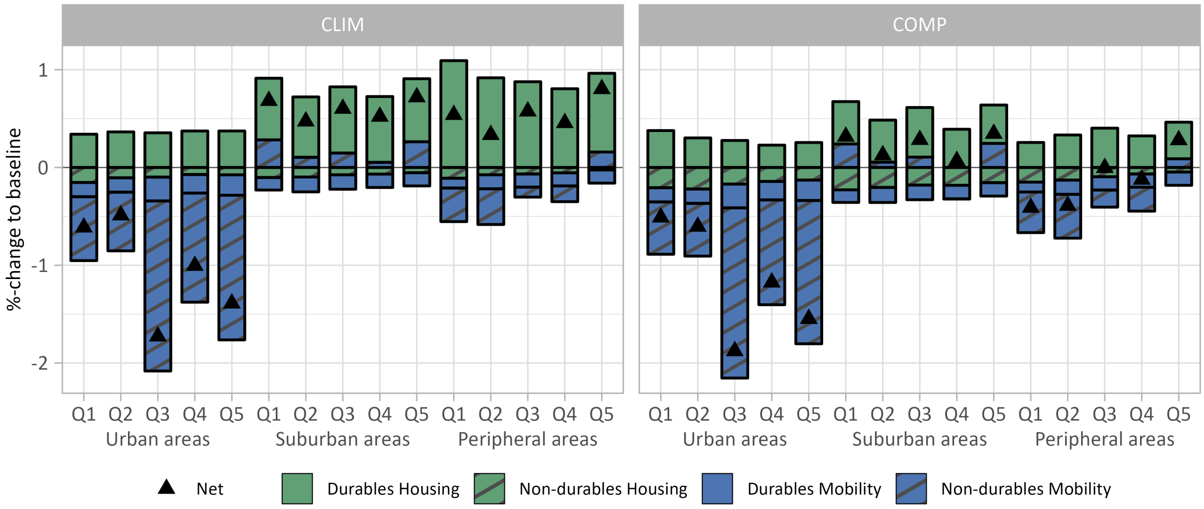
Figure 12 shows the distribution of average changes in real household incomes in the period 2024 to 2040 by income quintile. In CLIM, as shown above, the increase in real household consumption (including annuities for thermal refurbishment) grows with income. For instance, highest-income households (Q5) experience a weighted median increase of approximately 1.6% (with increases ranging between 0.9% and 3.2% depending on the household type), while 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, and implies growing income inequality. Conversely, in COMP 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 the compensatory measures directed to low- and middle-income households. 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.

Figure 12. Average annual change in household consumption by income quintile (2024/40, in real terms)



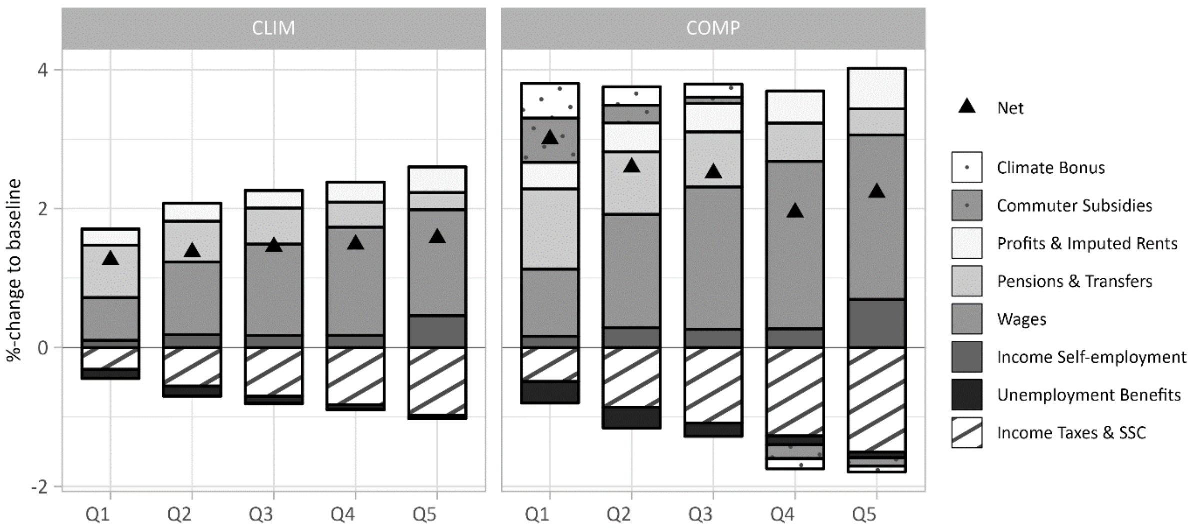
The regional dimension of the decarbonization is illustrated in Figure 13. With respect to the change in real consumption expenditures related to passenger transport and residential buildings, in CLIM we find reductions only in urban areas, and increases in suburban and peripheral regions. In COMP we see reduced expenditures on housing and mobility in urban areas, and – except for the highest-income households (Q5) – 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 implement the same saving rates as in the reference scenario. The most pronounced reductions in household consumption result 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 damped by the costs for the mileage-based road toll and to a lesser extent by additional expenditure on public transport. 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 CLIM, these reductions are, however, lower than in the COMP scenario since there is a shift towards district heating (see above), which is comparably more expensive. Consumption expenditure 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 13. 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 14 for the five income quintiles. In CLIM increases in household income are mainly based on rises in wages and pension payments and social transfers, 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.

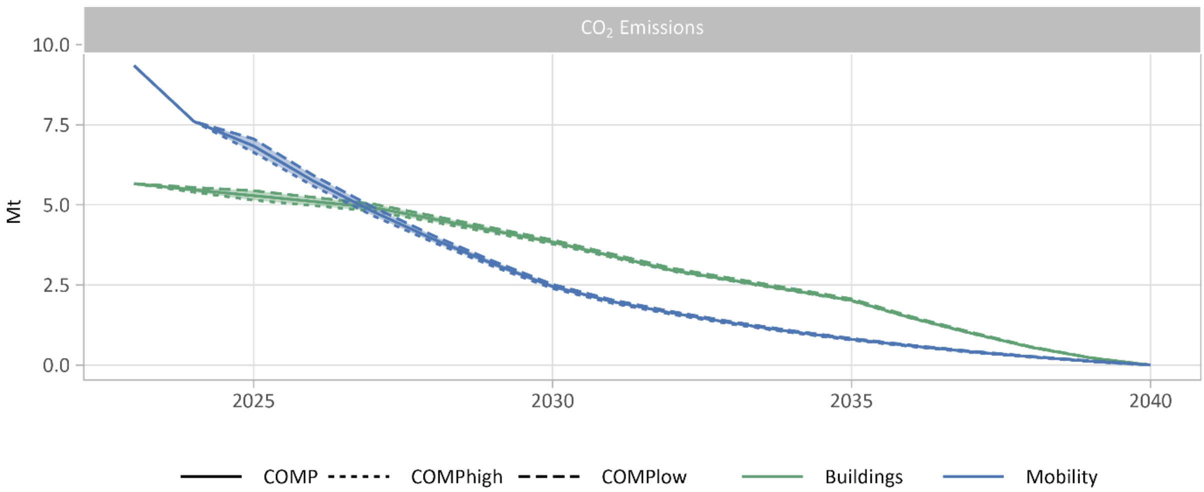
Figure 14. Average annual change in household income by income quintile and income component (2024/40)



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 15 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. This reflects that in the bottom-up models, the price is only one of many drivers relevant for adopting emission-friendly technologies and lifestyles.

Figure 15. Effects of changes in energy prices on CO_2 emissions



Impacts on macroeconomic indicators and household consumption are described in detail in Kettner et al. (2025). 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 (pp) higher compared to the baseline. GDP is particularly boosted by higher private and public consumption in this scenario. With respect to government revenues (which increase by 1.4 pp), 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 pp compared to the baseline). The deviations in real household consumption amount to 1 pp and mainly reflect changes in energy prices and 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 show a relatively large share of wages in their income composition, hence they benefit most from rising wages, while lower incomes benefit more strongly from increases in pensions and transfers. As a result, higher-income households show larger gains in a situation with lower energy prices (where real GDP and income increase) than lower-income households. For an increase in energy prices (COMPhigh) we find opposite effects in the same order of magnitude.

WP4. Synthesis and Policy Recommendations

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 integration of command-and-control measures and price-based instruments. While climate protection measures can yield positive macroeconomic effects, it is crucial to recognize that they may also exacerbate inequality among different income groups.

Therefore, a just transition pathway requires targeted compensation measures for low- and middle-income households and concerns regarding 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 for decarbonization measures can achieve positive distributional effects, yet (slightly) dampening macroeconomic performance and emission reductions. The literature shows, however, that subsidies that are not limited to lower-income households might even exacerbate distributional inequalities. Nevertheless, despite their potential drawbacks, public acceptance of subsidies is generally higher than for other price-based instruments or regulatory measures, which facilitates their implementability, making them also attractive options for policymakers (Segerson et al., 2024). Thus, a nuanced approach that combines various decarbonization measures with targeted compensation strategies will be essential to ensure that the benefits of decarbonization are equitably shared, thereby fostering broader acceptance and support for these necessary transitions.

Subsidies and recycling of carbon pricing revenues 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. In addition to supporting investments, e.g., in renovation or new heating systems, also the adaptation of legal framework conditions is called for. 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.

In the context of horizontal inequalities, also the question arises if or to which extent carbon pricing and other decarbonization measures affect women and men differently. This is influenced by socio-economic framework conditions for men and women as well as gender norms, preferences, and attitudes. Various aspects can be assumed to play a role in the development of gender-specific effects. These are general socio-economic, environmentally relevant framework conditions as well as gender differences. This regards foremost the distribution of income and wealth where a gender gap still exists. Thus, the risk of poverty is higher for women, and they are more often affected by energy poverty, including their inability to afford decarbonization investments. This also results from data on consumption expenditure on energy (disaggregated for female, male and mixed households with or without children) which shows a higher burden for female households. Furthermore, women and men differ in their consumption patterns and preferences (e.g., women tend to have stronger preferences for environmentally friendly products and sustainable consumption; Testa et al., 2021; Witek and Kuźniar, 2021). Due to the persistent traditional distribution of roles, women take on the majority of unpaid care work (De Lauretis et al., 2017; Smetschka et al., 2019). Their time use in relation to paid work and care work shapes for example their mobility patterns which are generally associated with relatively low emissions (Eggebø et al., 2023; Statistik Austria, 2023) but also with a higher number and complexity of journeys to be made compared to men (SORA, 2017). The empirical analysis of gender-differentiated impacts of carbon pricing and other decarbonization measures (especially in mixed households) is limited by data availability, as consumption expenditures are given at household level and do not allow a further disaggregation. In addition, one would need to take into account the relevant framework conditions regarding the distribution of income and work, social norms and preferences as well as the household context (decision making processes and individual affectedness, e.g., regarding the choice of a family car or the access to it).

WP5. Stakeholder Involvement and Dissemination

The two main objectives of this work package were:

1. Stakeholder Integration: Establish a dialogue with stakeholders to integrate their knowledge and feedback into the analysis.
2. Dissemination: Ensure continuous communication of project activities and findings.

This section provides a short summary of stakeholder integration results. For specific on knowledge integration methods, see section 6, for information on dissemination activities, see section 8.

We successfully incorporated several suggestions from the first stakeholder workshop, which took place on March 31st, 2022, and our stakeholder board. This included refining income thresholds for vulnerable household types, aligning household types with public transportation categories, and improving the presentation of results. Stakeholder input also highlighted challenges beyond our modelling approach, including detailed case studies for vulnerable households and barriers to policy implementation.

In addition, as shown in Table 1, we successfully simulated most of the measures proposed and endorsed during the first workshop, such as:

- Mobility Policies: Tax measures, non-motorized and public transport expansion, road tolls, fossil fuel vehicle bans, eco bonuses, cheaper public transport, and eco-social commuter allowance reforms.
- Housing Policies: Fossil fuel heating bans, infrastructure improvements, subsidies, tax incentives, renovation obligations, living space limits per person, financial transfers, and promotion of fossil fuel phase-out.

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 (Kirchner et al., 2019; Mayer et al., 2021; Kettner et al., 2024).

In the second and final workshop, stakeholders critically reviewed and largely validated the simulation outcomes, offering only minor suggestions for policy refinements. Stakeholders also discussed specific hardship case and measures to address them:

- Regarding *car dependency and persons with disabilities* stakeholders proposed to implement mobility planning in businesses, carpooling initiatives and targeted financial support for low-income households, linking refurbishment funding to living space per person (m^2/person), combining energy advice with social support to improve outreach, revising §18 MRG to ensure rent increases after renovation remain "warm rent neutral", reintroducing rent subsidies, and enhancing consumer protection for district heating.
- Regarding *the needs of older individuals living alone in single-family homes and car-dependent households at risk of poverty* stakeholders proposed to establish a "Transformation Agency" to support individuals in transitioning to sustainable living and mobility, promoting cultural changes in housing to increase flexibility, and correcting past spatial planning mistakes by improving public transport access to social housing.

While these discussions extended beyond the scope of our modelling approach, they provided valuable insights and expanded the range of policy options for reducing vulnerability.

Table 1. Stakeholder-Proposed Measures: Integration into Scenario Simulations

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

5 Conclusions and recommendations

In the following paragraphs three main findings of ***TransFair-AT*** are summarized. These relate to the definition of vulnerable households, the linking of sectoral bottom-up models with a macroeconomic model and the policy implications of different portfolios of decarbonization measures.

A first key finding of ***TransFair-AT*** was the identification of representative household types that fulfil certain criteria in terms of income, energy expenditure and mobility options. These households are regarded as vulnerable to climate policy interventions. The results are presented in the form of a composite index based on four dimensions that are considered relevant for mapping the vulnerability of households to rising costs of fossil fuels: income vulnerability, energy vulnerability, housing vulnerability, and mobility vulnerability. A total of six indicators were selected for the four categories to be considered in the structuring of vulnerable households and ultimately to construct the index (for details see Kettner and Bock-Schappelwein, 2024).

Vulnerable households are characterized by being affected by both income vulnerability (I) and energy vulnerability (E), following the definition used by Matzinger et al. (2018) that only those at risk of income poverty can also be energy poor. In addition, vulnerability can arise from housing vulnerability (H) or from mobility vulnerability (M), or from both. Four additional groups of households can be classified as potentially at risk because, although they are currently not at risk of income vulnerability, they are at high risk of energy vulnerability because they use fossil heating systems. These households may also be at risk of housing vulnerability or mobility vulnerability, or from both.

Almost one quarter (24%) of all households in Austria can be regarded as vulnerable, which means that they are particularly affected by rising fossil fuel prices. The largest group (12% of all households) is characterized not only by income and energy vulnerability but also by housing vulnerability reflecting the comparatively high prevalence of fossil fuel heating systems in Austrian households. 6% of households are characterized by income vulnerability, energy vulnerability and mobility vulnerability, 4% are vulnerable with respect to all four dimensions, and 3% of all households are characterized by income and energy poverty. A further 9% of households can be classified as potentially vulnerable to rising energy and carbon prices.

In addition, data from a combined mobility and consumer expenditure survey have been used to analyze the characteristics of mobility and energy poor households in Austria. According to the results of this analysis about 7% and 12% of the Austrian households can be classified as mobility respectively energy poor in terms of affordability.

Key findings concerning socio demography are that both, mobility, and energy poor households are smaller, have less children, predominantly female and have lower educational levels and employment rates. In addition, mobility behavior of mobility and energy poor households differs significantly. Mobility poor households have lower shares of walking, cycling and public transport trips and a higher share of car trips. Energy poor households, on the contrary, have higher shares of walking and public transport, a lower share of car trips and about the same share of cycling trips (Pfaffenbichler et al., 2023).

A second key finding follows from the model linkage in ***TransFair-AT***. The literature review shows that linking top-down CGE models with bottom-up models covering different aspects of the energy sector is a well-established practice. Nevertheless, no application explicitly linking bottom-up models of passenger transport and residential buildings with a top-down macro-economic model has been found. It can therefore be concluded that the modelling approach developed and implemented in ***TransFair-AT*** goes beyond the state of the art.

Due to major structural differences between the sector models and some technical obstacles a soft-linking approach was chosen in ***TransFair-AT***. A detailed analysis of the convergence of the top-down model DYNK and the bottom-up models MARS/SERAPIS and Invert/EE-Lab is provided in Gühnemann et al. (2024).

The main conclusion from the exchange of DYNK with INVERT/EE-Lab and MARS/SERAPIS is that the changes in demand from the bottom-up models did not cause economic disturbances to change disposable income significantly. As a result, the perturbation is only marginally reflected in the next iteration. A key reason for this is the relative robustness of the DYNK demand system. Consumption of non-durable goods is structured in such a way that changes in energy consumption are accompanied by opposite changes in other non-durable goods consumption. This is simply because available surplus income is spent under the assumption of stable saving rates. In other words, if a household has a surplus of money due to lower energy expenditure, the money is spent on other non-durable goods and the overall change in disposable income remains small. Therefore, in bottom-up models, changes in energy demand have a fairly small effect on disposable income and hence on its use in the next round. This leads to rapid convergence.

The third key finding concerns policy recommendations. The modelling of climate policy scenarios in ***TransFair-AT*** shows that a decarbonization of households and mobility in Austria by 2040 is achievable but requires a comprehensive mix of policy instruments and their rapid implementation. A successful transformation hinges on the integration of command-and-control measures and price-based instruments. While climate protection measures can yield positive macroeconomic effects, it is crucial to recognize that they may also exacerbate inequality among different income groups.

Therefore, a just transition pathway requires targeted compensation measures for low- and middle-income households and concerns regarding 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 for decarbonization measures can achieve positive distributional effects, yet (slightly) dampening macroeconomic performance and emission reductions. The literature shows, however, that subsidies that are not limited to lower income-households might even exacerbate distributional inequalities. Nevertheless, despite their potential drawbacks, public acceptance of subsidies is generally higher than for other price-based instruments or regulatory measures, which facilitates their implementability, making them also attractive options for policymakers (Segerson et al., 2024). Thus, a nuanced approach that combines various decarbonization measures with targeted compensation strategies will be essential to ensure that the benefits of decarbonization are equitably shared, thereby fostering broader acceptance and support for these necessary transitions. Although fully capturing nation-wide representative stakeholder perspectives remains a significant challenge, our approach successfully facilitated the integration of diverse stakeholder inputs into the research process. This inclusivity contributed to the development and simulation of transformation pathways that are not only more robust but also more likely to resonate with decision-makers and gain broader public acceptance.

Subsidies and recycling of carbon pricing revenues 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 can't afford on their own. In addition to supporting investments e.g. in renovation or new heating systems also the adaptation of legal framework conditions is called for. 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.

C) Project details

6 Method

In this chapter, first the models used in the ***TransFair-AT*** project and the approach for linking are described. Then, information on the stakeholder integration process is provided.

Overview TransFair-AT models

Top-down model DYNK

The top-down model DYNK (Dynamic New Keynesian) is a hybrid econometric Input-Output (IO) and computable general equilibrium (CGE) model. The model represents the linkages between 74 NACE industries[2] and deals with the Austrian economy. Households are divided into 15 different categories (income quintiles times regional structure). These are characterized by their specific consumption patterns in 47 consumption categories (COICOP[3]) and their sources of disposable income. Consumption of consumer durables, consumer non-durables and energy goods is modelled individually. Parts of the model resemble a CGE model in the long run. The term "New Keynesian" indicates the existence of a long-run full-employment equilibrium, which – starting from an unemployment equilibrium – cannot be reached in the short run due to institutional inflexibilities. DYNK has been used widely for policy analysis and is linked to energy statistics and can link sectoral activities to final energy demand, process CO_2 emissions and energy related CO_2 emissions. Figure 16 illustrates the basic structure of the model DYNK. A detailed description of the DYNK model is provided e.g. in (Kirchner et al., 2019; Kettner et al., 2024).

For ***TransFair-AT***, the result of several equations in the model were replaced by the exogenous inputs from the bottom-up models. This concerns the affected parts of private consumption. More precisely, it is energy demand (module 'final energy'), demand for public transport and the investment in cars and heating systems ('private consumption').

Furthermore, public consumption in the module 'government budget' was exogenously set to a trend path and was not restricted to budget constraints. Thereby, it was possible to see the isolated impact of the measures on public revenues and expenditures.

The structure in the household modules 'final energy' and 'private consumption' were expanded to 238 types. Due to the data structure and lack of time series of

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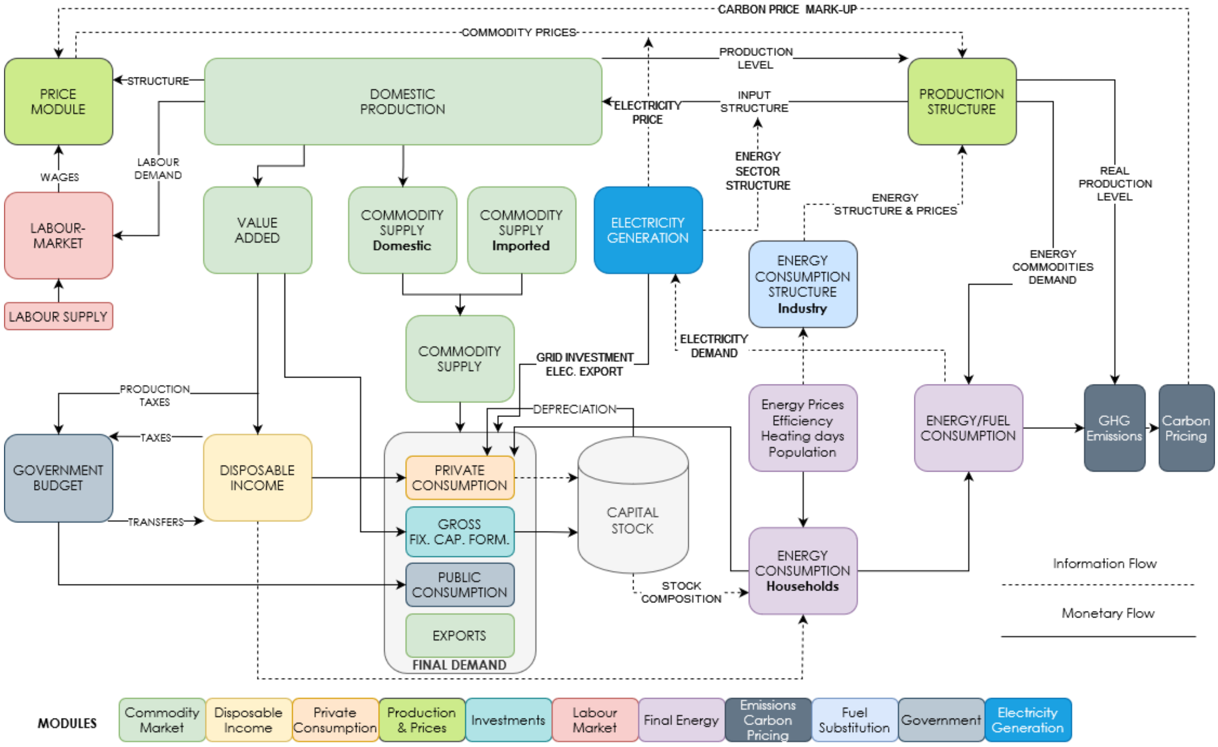
[2] Nomenclature statistique des activités économiques dans la Communauté européenne, https://ec.europa.eu/eurostat/web/nace/; accessed: 3/10/2024

[3] Classification of individual consumption by purpose, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Classification_of_individual_consumption_by_purpose_(COICOP), accessed; 3/10/2024

the consumer survey and SILC data sets in ***TransFair-AT*** it was not possible to apply econometric methods to extract differentiating price and income elasticities of demand per type. Hence, average elasticities and parameters were set for all households. Therefore, the structure of income and expenditure determine how a household is affected by economic changes, transfers, and consumer prices. The results regarding households' emissions were derived from the bottom-up model results instead of the DYNK module.

Figure 16. Basic structure of the model DYNK



Bottom-up mobility models MARS and SERAPIS

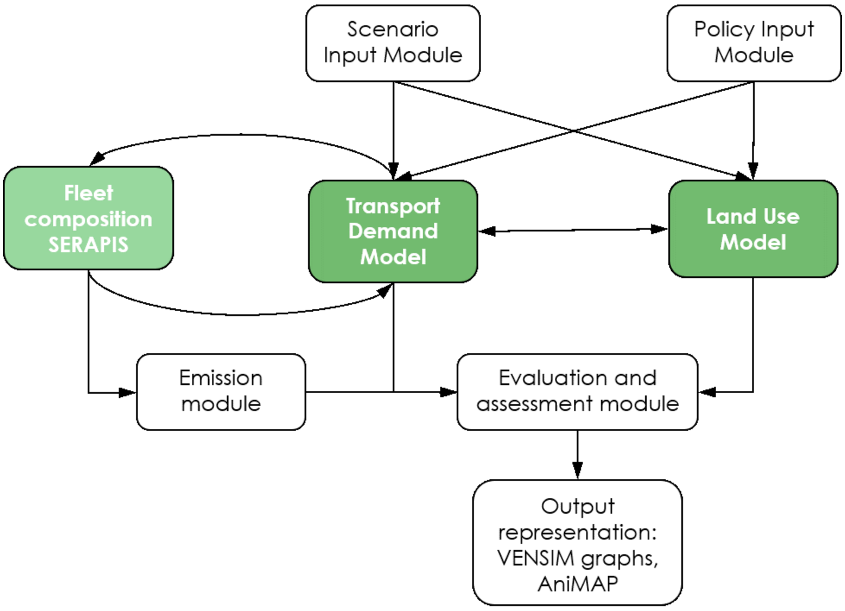
The mobility sector is represented through the use of two different models. The first is MARS (Metropolitan Activity Relocation Simulator). MARS represents a strategic and dynamic Land-Use and Transport Interaction (LUTI) model. The second is SERAPIS (Simulating the Emergence of Relevant Alternative Propulsion technologies in the car and motorcycle fleet Including energy Supply). SERAPIS represents a dynamic car fleet and propulsion technology model. The two models are founded on the principles of system thinking and systems dynamics and have been implemented in VENSIM®, which is a system dynamics software environment.

MARS consists of two sub-models for transport demand and land use and a set of sub modules, e.g. for the representation of the composition of the car fleet and the calculation of emissions. Given its inherently dynamic nature, MARS is designed to simulate the evolution of the transport and land use system in discrete time steps, from its base year up to a predefined time horizon. Given the strategic nature of MARS, the level of spatial aggregation is relatively high. The territory of Austria is subdivided into 116 zones, representing the Austrian political districts (Statistik Austria, 2021). The intra-zonal traffic is further classified into five distinct distance bands. The transportation demand model of MARS is capable of calculating the generation of trips, the distribution of trips, and the choice of modes in each discrete time step. The choice of options is dependent upon the application of a multinominal logit model, which employs a generalized cost structure comprising a weighted sum of both time and cost components of a given trip.

The SERAPIS model is designed to simulate the development of a fleet of vehicles across three propulsion technology categories (internal combustion engine, plug-in electric and battery electric), three vehicle size categories (compact, family and luxury) and for both first and second cars in a household. The selection of propulsion technologies is predicated upon a multinominal logit model. The utility of a propulsion technology is determined by a number of factors, including the initial investment costs, the operating costs, the variety of available makes and models, the density of service stations, the range of the technology, and the time saved by users due to exemptions from traffic regulations. Accordingly, the model is responsive to policy instruments such as tax exemptions and subsidies. The output of SERAPIS is a representation of the evolution of the passenger car fleet, disaggregated by propulsion technology. The resulting fuel and energy consumption and costs are incorporated as inputs into the transport demand model of MARS. Conversely, the car operation costs per year are included as inputs into the utility function of the multinominal logit model of SERAPIS. The principal outputs of MARS and SERAPIS are the number of trips by origin-destination pair by mode, the monetary costs associated with each trip, fuel and energy consumption, and CO_2 and other emissions.

Figure 17 illustrates the basic structure of the mobility sector modelling framework consisting of the models MARS and SERAPIS. A more detailed description of MARS and SERAPIS is provided e.g. in Soteropoulus (2021), Emberger and Pfaffenbichler (2020) and Pfaffenbichler et al. (2024).

Figure 17. Basic structure of the mobility sector modelling framework



Bottom-up building stock model Invert/EE-Lab

Invert/EE-Lab is a bottom-up model for analyzing space heating, hot water and cooling in existing buildings (TransFair-AT, 2022). It aims to quantify the impact of different frameworks on overall energy demand, fuel and technology mix, CO_2 emissions and costs. These include price scenarios for energy sources, cost scenarios for technologies and efficiency measures, different settings of economic and regulatory incentives, consumer behavior, climate change and resource constraints. Invert/EE-Lab relies on a highly disaggregated description of building stock in each analysis region. These include building type, age, state of renovation, existing heating systems, occupancy patterns and regional aspects such as the availability of gas or district heating infrastructure. Both residential and tertiary buildings are usually included in the analyses. In addition, different structures of housing provision and household income classes are represented in the model. The model uses an extended technology and efficiency database with technical and economic characteristics. On the one hand, it integrates current and potential future technologies for space heating, hot water and space cooling, including on-site solar thermal and photovoltaic generation, as well as the heat distribution systems in the building. On the other hand, a wide range of options for the renovation of the building envelope and heat recovery systems are considered to reduce the energy demand of the buildings.

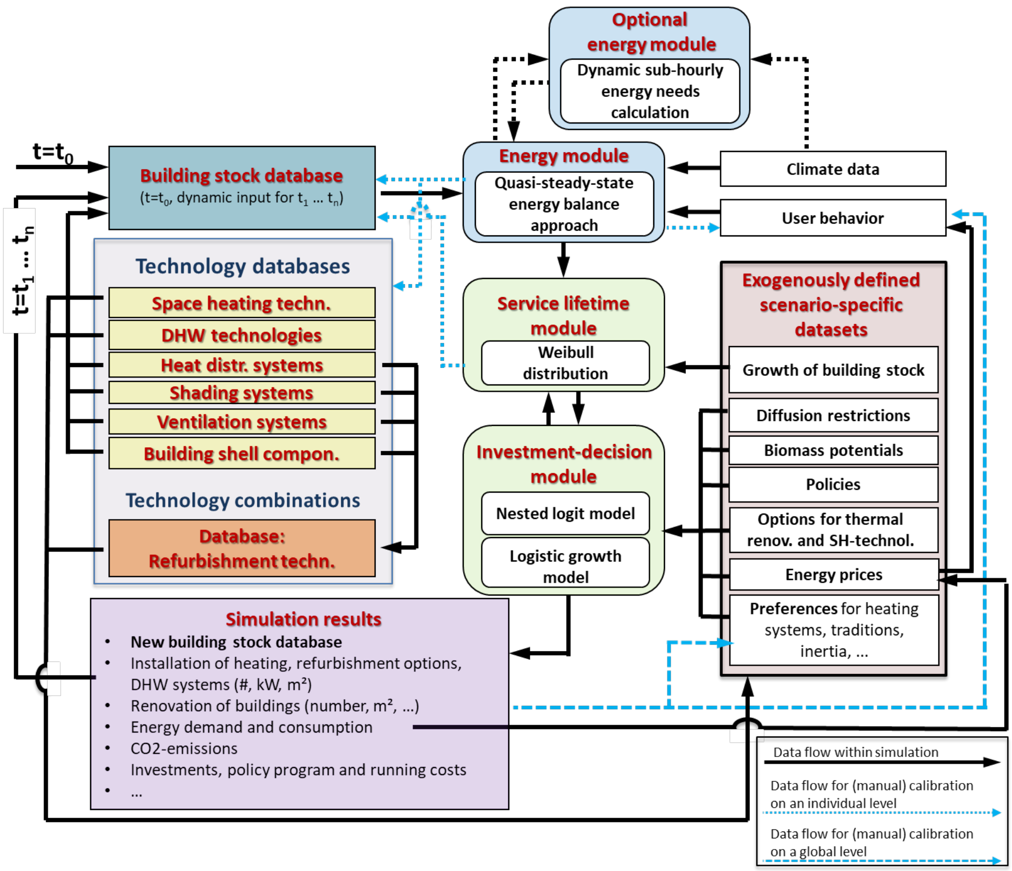
Invert simulates energy related investment decisions in the building stock and is used in particular to study the impact of economic and regulatory incentives on the decisions of different agents (i.e. owner types) when an investment decision has to be made for a specific building segment. This takes into account the inhomogeneous structure of decision-makers in the building sector. A myopic multinomial logit approach, which optimizes agents' objectives under imperfect information, is at the core of the EE-Lab version. The market shares of heating systems and energy efficiency measures are calculated by building and investor type using a nested logit approach. A detailed description of the decision algorithm can be found in (Müller, 2015) and (Steinbach, 2016).

The model allows different owner types to be defined as instances of predefined investor classes: owner-occupiers, private landlords, shared owners and housing associations. The different perspectives on building-related investment motivate this structure. For example, saving on energy costs is only relevant to those who own and occupy the building. Refinancing energy saving measures through additional rental income (investor-tenant dilemma) is the relevant variable for landlords.

Owner types are distinguished by their investment decision behavior and their environmental perceptions, the former being captured by investor-specific weights of economic and non-economic attributes of alternatives (Kranzl et al., 2019 p. 229). Perception-relevant variables – environmental awareness, energy price expectations or risk aversion – influence the attribute values.

The basic structure of Invert using the EE-Lab version of the tool is shown in Figure 18.

Figure 18. Basic structure of the Invert/EE-Lab model



Model Linkage

All three models, DYNK, MARS and Invert/EE-Lab, were or are used in the biannual reports on emission projections for 2030 und 2050, which analyze sectoral energy consumption and greenhouse gas emissions in Austria (Krutzler et al., 2017, 2023a). In these reports typically two scenarios are analyzed, one focusing on already implemented or passed measures (WEM – with existing measures) and the other on additional measures currently discussed and likely to be implemented (WAM – with additional measures). Usually the models DYNK, MARS and Invert/EE-Lab were applied independently in these reports. Although occasionally the models have been linked in a very simple unidirectional manner. That means no feedback mechanisms and iterations have been implemented in the past. In addition, variables such as operation costs were not exchanged between the models and especially the financial implications of different policy measures on different household groups have not been assessed.

Process of linking the models

Prior to linking the models each of the three modelling groups revised their models and updated them with the most recent data available. Selected exogenous parameters and scenario assumptions were harmonized in this process. Additionally, modifications necessary to tackle the topic of the project were implemented. E.g. the composition of household types in the models was adjusted to fit the requirements of the project, i.e. household types have been aligned. Subsequently, a coordination group with one representative of each modelling team has been set up. The members of the coordination group were Paul Pfaffenbichler (BOKU), Mark Sommer (WIFO) and Andreas Müller (e-think). Due to the major structural differences between the sector models and technical obstacles, hard-linking or integration of the models was no viable option within the resources of the project. Therefore, a soft-linking approach was selected for model linkage in ***TransFair-AT***. This approach has also some significant advantages. Linking rather than integrating models allows to retain models separate and also retain the consistency of their database. Coupling bottom-up and top-down models by soft-linking is seen by some references as the best option to exploit the strength of each of the two modelling approaches.

As a first step of the soft-linking approach the coordination group defined a list of relevant data, the "interface variables" for model linkage, and revised the basic structure from the project proposal (Figure 19).

Figure 19. Basic structure TransFair-AT model linkage

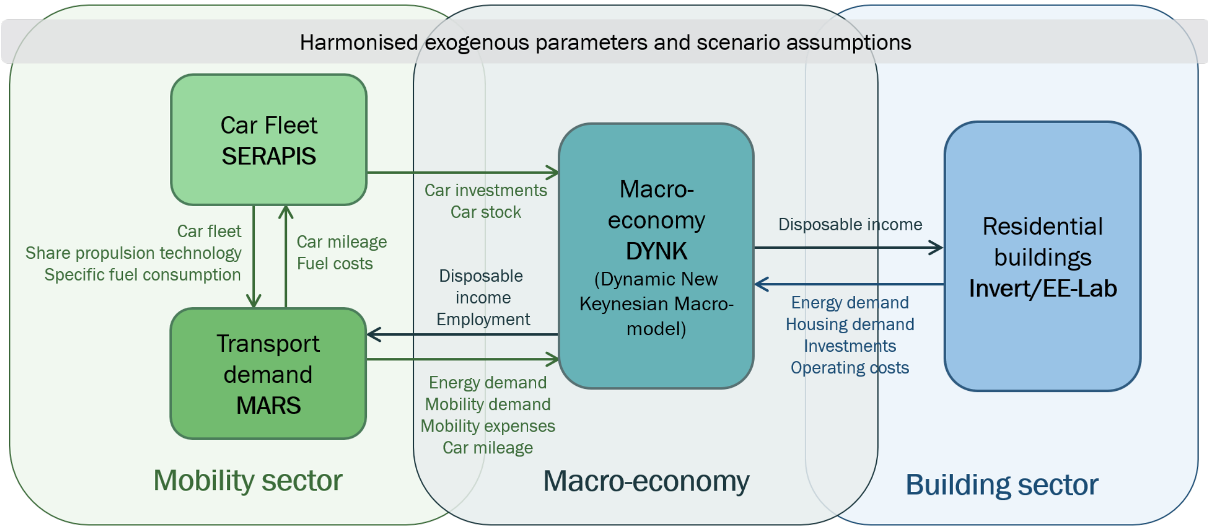
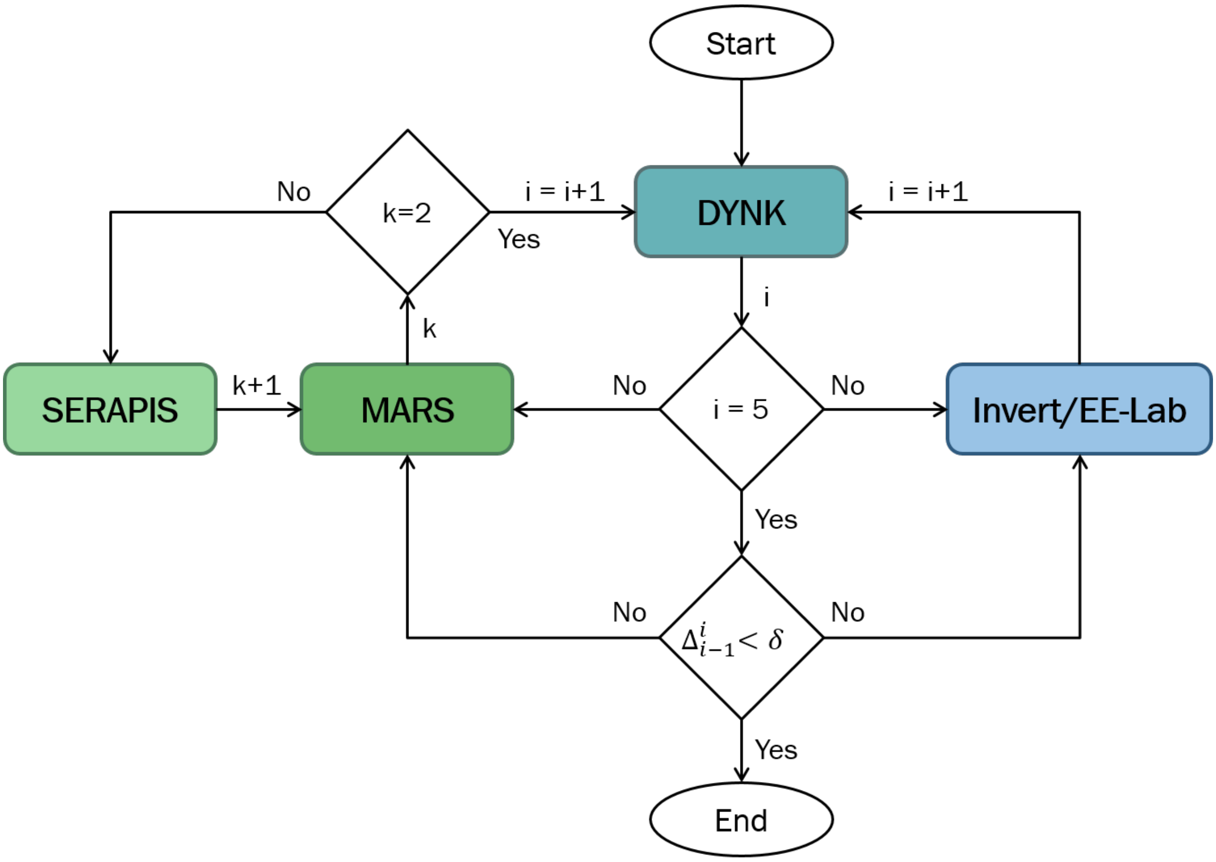


Figure 20 illustrates the iterative soft-linking approach. Each iteration starts with a simulation of the top-down model DYNK. The resulting interface variables are exported to the building sector bottom-up model Invert/EE-Lab and the mobility sector bottom-up model MARS. Both sector bottom-up models run their simulations in parallel, as there is no direct interaction between the sectors. While Invert/EE-Lab directly exports the interface variables back to DYNK, MARS first has to iterate with the car fleet model SERAPIS. First tests have shown that one feedback loop is sufficient to stop this process. Once the iteration MARS-SERAPIS-MARS is complete, the interface variables from the mobility sector are exported back to DYNK. A new iteration is started with a DYNK simulation using the new interface variable values from both bottom-up models. The iterations were stopped after a set of five iterations to analyze potential convergence. Based on the results of this analysis it was decided whether another set of five iterations had to be started. If the difference in the interface variables between the last iterations Δ^{i}_{i-1} is below the target threshold value δ, the process is stopped. If not, a new set of five iterations is started. The process was finally stopped after 20 iterations.

Figure 20. TransFair-AT model iterations



Model-specific Excel spreadsheets containing the interface variable have been defined. The exchange of these interface files was organized via a git repository.

TransFair-AT Stakeholder Process

Stakeholder integration was a central aspect of the project, particularly at the beginning and end of the project. 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:

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

To facilitate this, we established a **Stakeholder Board (SB)**, comprising six key stakeholders from administration (Federal Ministry for Climate Action, Federal Ministry for Social Affairs, Environment Agency Austria), NGOs (Caritas, VCÖ), and interest groups (Chamber of Labor). The SB provided valuable feedback at three critical stages:

- Project Proposal Review (February 1st, 2022)
- Vulnerable Household Analysis: Feedback on proposed household types, initial vulnerability results, and potential case studies (April 26th, 2023)
- Preliminary Model Results and Policies: Review of simulated policy measures (May 14th, 2024)

In addition to the SB, stakeholder integration included **two interactive workshops** held at the start and conclusion of the project.

The first workshop (March 31st, 2022), held online due to COVID-19 restrictions, involved 18 stakeholders and focused on two objectives: (1) identifying characteristics of vulnerable households, and (2) proposing effective climate policies and accompanying compensation measures.

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:

- 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.
- Ranking: Evaluating and prioritizing measures based on their perceived importance, effectiveness, and fairness.
- 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 (see section 4).

The second interactive workshop took place at the end of the project (20/06/2024) and served two primary purposes:

1. Validation of Model Results.
2. Identification of Measures for Hardship Cases: Two working groups addressed specific challenges.

The first task was conducted in a plenum, where stakeholders were able to discuss the findings presented by the research team.

In the second task, stakeholders were divided into two groups, one focusing on car dependency and persons with disabilities, and the other focusing on the needs of older individuals living alone in single-family homes and car-dependent households at risk of poverty. The discussion was moderated by selected members of the research team, and a final summary of the group discussion and findings was then presented in the plenum.

The stakeholder integration process has been instrumental in ensuring the relevance, robustness, and practicality of our project outcomes. By engaging stakeholders throughout the project, we incorporated critical feedback, simulated stakeholder-endorsed policies, and explored broader solutions to address hardship cases and reduce vulnerability effectively.

7 Work and time plan

Work Package	2021		2022												2023												2024									
	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
1 Foundations																																				
Construction of a common household database			M1.1																																	
Identification of Representative Household Types					M1.2								D1.1																							
Development of Decarbonisation Policy Scenarios														M1.3																						
Development of Scenarios for Compensation Measures														M1.4																						
Scenario finalisation and validation																												M1.5								
2 Model Preparations and Linkage																																				
Model adjustments and identification of the relevant data for linking																			M2.1																	
Data exchange between models; adjustment of data gaps and inconsistencies																			M2.2																	
Linking of DYNK and the mobility models (MARS and car fleet model)																									M2.3											D2.1
Linking of DYNK and Invert-EE-Lab																																				
Validation of model framework results																																			M2.4	
3 Model-based Analysis of Decarbonisation Scenarios																																				
Simulation of decarbonisation policy scenarios																											M3.1									
Simulation of combined policy scenarios																															M3.2	M3.3				
Sensitivity analyses																																M3.4				
4 Synthesis and Policy Recommendations																																				
Discussion of the role of policy instruments																																				
Discussion of distributional impacts																																				D4.1
Development of policy recommendations																																			M4.1	D4.2
5 Stakeholder Involvement and Dissemination																																				
Project website		D5.1																																		
Expert workshops, stakeholder and dissemination workshop				M5.1		M5.2												M5.3														M5.4				
Report on stakeholder and expert integration														D5.2																						D5.3
Policy brief on social impacts of climate policy instruments – based on WP3																																				D5.4
Policy brief on policy recommendations for Austria – based on WP4																																				D5.5
6 Project Management																																				
Project management and coordination																																				
Coordination and management of the SAB																																				
Kick-off Meeting	M6.1																																			
Reporting												D6.1											D6.2													D6.3

Milestones:

M1.1 Construction of common household database completed
M1.2 Cluster analysis completed
M1.3 Concerted list of input parameters for decarbonisation policy scenarios
M1.4 Concerted list of input parameters for compensation policy scenarios completed
M1.5 Concerted list of input parameters for compensation policy scenarios completed
M2.1 All models updated and adjustments completed
M2.2 List of interface data defined
M2.3 The linked modelling framework is operational
M2.4 The validated linked modelling framework is operational
M3.1 First set of model simulations of mitigation policies completed
M3.2 First set of model simulations including compensation policies completed
M3.3 Final set of simulations completed
M3.4 Sensitivity analyses have been conducted
M4.1 Development of policy recommendations for Austria
M5.1 Establishment of a core Stakeholder Board
M5.2 Stakeholder workshop on policy options and household types
M5.3 Expert workshop on modelling issues
M5.4 Stakeholder workshop on policy recommendations
M6.1 Kick-off meeting

Deliverables:

D1.1 Fact sheet on household types
D2.1 Working Paper on Methodological Issues related to Model Linkage
D4.1 Working Paper Investigating the Social Impacts of Climate Policies
D4.2 Report on policy recommendations for Austria
D5.1 Project webpage
D5.2 Intermediate report on stakeholder and expert integration
D5.3 Report on stakeholder and expert integration
D5.4 Policy brief on social impacts of climate policy instruments
D5.5 Policy brief on recommendations that ensure an inclusive decarbonisation
D6.1 First interim report
D6.2 Second interim report
D6.3 Final report

8 Publications and dissemination activities

Publications	
Peer-reviewed publications	
	Households' vulnerability to carbon pricing: a case study for Austria, in Critical Issues in Environmental Taxation Biodiversity and Climate Tackling Global Footprints 2024 (by Julia Bock-Schappelwein and Claudia Kettner). https://www.elgaronline.com/edcollchap/book/9781035340521/book-part-9781035340521-23.xml
Working papers	
	Exploring effects of climate policies and mitigation strategies for vulnerable households in Austria – Methodological issues related to model linkage. TransFair-AT Working Paper #1 (by Paul Pfaffenbichler, Astrid Gühnemann, Andreas Müller, Mark Sommer). https://zenodo.org/records/14760100
	Socially Fair Decarbonization Pathways for Housing and Mobility – Insights from a multi-model analysis for Austria. TransFair-AT Working Paper #2 (by Claudia Kettner, Julia Bock-Schappelwein, Daniela Kletzan-Slamanig, Mark Sommer, Paul Pfaffenbichler, Olivia Gold, Mathias Kirchner, Eva Wretschitsch, Nathalie Spittler, Lukas Kranzl, Andreas Müller). https://www.wifo.ac.at/publication/421257/
	Integrating stakeholder knowledge to design fair and acceptable climate mitigation and compensation measures in the buildings and mobility sectors in Austria. TransFair-AT Working Paper #3 (by Mathias Kirchner, Nathalie Spittler, Julia Bock-Schappelwein, Daniela Kletzan-Slamanig, Mark Sommer, Paul Pfaffenbichler, Andreas Müller, Eva Wretschitsch, Claudia Kettner), https://zenodo.org/records/14763244
Other publications	
	Households Vulnerable to Rising Energy Prices. TransFair-AT Research Brief #1 (by Julia Bock-Schappelwein and Claudia Kettner) https://www.wifo.ac.at/publication/48502/
	Exploring the characteristics of mobility and energy poor households in Austria. TransFair-AT Research Brief #2 (by Paul Pfaffenbichler, Lukas Hartwig, Olivia Gold, Astrid Gühnemann) https://zenodo.org/records/8273233
	Wohnen und Mobilität – Optionen für eine klimaneutrale Transformation. TransFair-AT Policy Brief (by Claudia Kettner, Julia Bock-Schappelwein, Daniela Kletzan-Slamanig, Mark Sommer, Astrid Gühnemann, Paul Pfaffenbichler, Olivia Gold, Mathias Kirchner, Nathalie Spittler, Eva Wretschitsch, Lukas Kranzl, Andreas Müller) https://www.wifo.ac.at/publication/421210/
Project workshops	
	Stakeholder Workshop (March 31st, 2022)
	Expert Workshop (April 17th, 2023)
	Dissemination Workshop at WIFO (June 20th, 2024)
Presentations at external conferences	
IEWT, Vienna, February 26-28th, 2025	
	Kettner, C., Sozial gerechte Optionen für eine klimaneutrale Transformation von Wohnen und Mobilität in Österreich (submission accepted)
NOeG2024, Vienna, September 3rd, 2024	
	Kirchner, M. Socially Fair Options for Effective Climate Policy
NOeG2024, Vienna, September 3rd, 2024	
	Kettner, C., Assessing Households' Vulnerability to Carbon Pricing

Österreichischer Klimatag, Vienna, April 4th, 2024	
	Pfaffenbichler, P., Soziale Auswirkungen der Dekarbonisierung des österreichischen Personenverkehrs
European Transport Conference 2023, Milan, September 6th-8th, 2023	
	Pfaffenbichler, P. Social impacts of decarbonising the Austrian passenger transport system
23. Österreichischer Klimatag, Leoben, April 13th, 2023	
	Kettner, C., Socially Fair Options for a Climate Neutral Transformation of Housing and Mobility in Austria
5th ESPAnet Austria Conference, Vienna, September 14th, 2022	
	Schappelwein, J., Steigende Preise für fossile Brennstoffe: Was zeichnet betroffene Haushalte aus?
Other dissemination activities	
Project webpage	
	https://transfair.wifo.ac.at/
WIFO-Newsletter	
	TransFair-AT at the 23rd Austrian Climate Day, April 2023
	TransFair-AT: Expert workshop model linkage, May 2023
	TransFair-AT at the 24th Austrian Climate Day, April 2024
	TransFair-AT Dissemination Workshop, June 2024
	TransFair-AT: Special Session at the NOeG, September 2024
ACRP Poster Session, 23. Österreichischer Klimatag, Leoben	
	Socially Fair Options for a Climate Neutral Transformation of Housing and Mobility in Austria https://transfair.wifo.ac.at/ppts/TransFair-AT_20230413-Klimatag-Poster.pdf

References

Bock-Schappelwein, J., and Kettner, C. (2023). *Households Vulnerable to Rising Energy Prices. TransFair-AT Research Brief #1*. Vienna: WIFO - University of Natural Resources and Applied Life Sciences, Vienna - e-think - Zentrum für Energiewirtschaft und Umwelt - Vienna University of Technology. Available at: http://www.wifo.ac.at/wwa/pubid/70682

Bock-Schappelwein, J., and Kettner, C. (2024). "Households' vulnerability to carbon pricing: a case study for Austria," in *Biodiversity and Climate Tackling Global Footprints*.

Böhringer, C., and Rutherford, T. F. (2008). Combining bottom-up and top-down. *Energy Economics* 30, 574–596. doi: 10.1016/j.eneco.2007.03.004

De Lauretis, S., Ghersi, F., and Cayla, J.-M. (2017). Energy consumption and activity patterns: An analysis extended to total time and energy use for French households. *Applied Energy* 206, 634–648. doi: 10.1016/j.apenergy.2017.08.180

Eggebø, H., Lundberg, A. K., and Teigen, M. (2023). Gaps and Silences: Gender and Climate Policies in the Global North. *Social Politics: International Studies in Gender, State & Society* 30, 164–187. doi: 10.1093/sp/jxac032

Emberger, G., and Pfaffenbichler, P. (2020). A quantitative analysis of potential impacts of automated vehicles in Austria using a dynamic integrated land use and transport interaction model. *Transport Policy* 98, 57–67. doi: https://doi.org/10.1016/j.tranpol.2020.06.014

Gühnemann, A., Pfaffenbichler, P., Müller, A., and Sommer, M. (2024). Exploring effects of climate policies and mitigation strategies for mobility poor households in Austria - D2.1 Working Paper on Methodological Issues related to Model Linkage. Zenodo. doi: 10.5281/zenodo.13986820

Kettner, C., Bock-Schappelwein, J., Kletzan-Slamanig, D., Sommer, M., Pfaffenbichler, P., Gold, O., et al. (2025). Socially Fair Decarbonization Pathways for Housing and Mobility – Insights from a multi-model analysis for Austria. TransFair-AT Working Paper #2.

Kettner, C., Leoni, T., Köberl, J., Kortschak, D., Kirchner, M., Sommer, M., et al. (2024). Modelling the Economy-wide Effects of Unilateral CO_2 Pricing Under Different Revenue Recycling Schemes in Austria – Searching for a Triple Dividend. *Energy Economics*, 107783. doi: 10.1016/j.eneco.2024.107783

Kirchner, M., Sommer, M., Kratena, K., Kletzan-Slamanig, D., and Kettner-Marx, C. (2019). CO2 taxes, equity and the double dividend – Macroeconomic model simulations for Austria. *Energy Policy* 126, 295–314. doi: 10.1016/j.enpol.2018.11.030

Kranzl, L., Aichinger, E., Büchele, R., Forthuber, S., Hartner, M., Müller, A., et al. (2019). Are scenarios of energy demand in the building stock in line with Paris targets? *Energy Efficiency* 12, 225–243. doi: 10.1007/s12053-018-9701-1

Krutzler, T., Wasserbauer, R., and Schindler, I. (2023a). *Energie- und Treibhausgasszenarien 2023 - WEM, WAM, Transition mit Zeitreihen von 2020 bis 2050*. REP-0882. Wien: Umweltbundesamt GmbH.

Krutzler, T., Wasserbaur, R., and Schindler, I. (2023b). Energie- und Treibhausgasszenarien 2023. Available at: https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0882.pdf (Accessed June 14, 2024).

Krutzler, T., Zechmeister, A., Stranner, G., Wiesenberger, H., Gallauner, T., Gössl, M., et al. (2017). *Energie- und Treibhausgas-Szenarien im Hinblick auf 2030 und 2050*. Wien: Umweltbundesamt.

Matzinger, S., Heitzmann, K., and Dawid, E. (2018). Studie zur Eruierung einer Definition von Energiearmut in Österreich aus Sicht der sozialwirtschaftlichen und energiewirtschaftlichen Praxis. Wien: BMASGK (Austrian Federal Ministry for Social Affairs, Health, Care and Consumer Protection).

Mayer, J., Dugan, A., Bachner, G., and Steininger, K. W. (2021). Is carbon pricing regressive? Insights from a recursive-dynamic CGE analysis with heterogeneous households for Austria. *Energy Economics* 104, 105661. doi: 10.1016/j.eneco.2021.105661

Müller, A. (2015). Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock. TU Wien.

Pfaffenbichler, P., Emberger, G., Figenbaum, E., and Fearnley, N. (2024). Simulating the effects of tax exemptions for plug-in electric vehicles in Norway. *European Transport Research Review* 16, 1–15. doi: 10.1186/s12544-024-00648-y

Pfaffenbichler, P., Gühnemann, A., Gold, O., and Hartwig, L. (2023). TransFair-AT Research Brief #2: Exploring the characteristics of mobility and energy poor households in Austria. Zenodo. doi: 10.5281/zenodo.8273233

Savard, L. (2003). Poverty and Income Distribution in a Cge-Household Micro-Simulation Model: Top-Down/Bottom Up Approach. doi: 10.2139/ssrn.485665

Segerson, K., Polasky, S., Scheffer, M., Sumaila, U. R., Cárdenas, J. C., Nyborg, K., et al. (2024). A cautious approach to subsidies for environmental sustainability. *Science* 386, 28–30. doi: 10.1126/science.ado2615

Smetschka, B., Wiedenhofer, D., Egger, C., Haselsteiner, E., Moran, D., and Gaube, V. (2019). Time Matters: The Carbon Footprint of Everyday Activities in Austria. *Ecol Econ* 164, 106357. doi: 10.1016/j.ecolecon.2019.106357

SORA (2017). Mobilitätsverhalten von Frauen und Männern in unterschiedlichen Lebenslagen - Auswertungen der österreichweiten Mobilitätserhebung „Österreich unterwegs 2013/2014“ nach Haushaltstyp, Geschlecht und räumlicher Lage. Wien: SORA.

Soteropoulos, A., Pfaffenbichler, P., Berger, M., Emberger, G., Stickler, A., and Dangschat, J. S. (2021). Scenarios of Automated Mobility in Austria: Implications for Future Transport Policy. *Future Transportation* 1, 747–764. doi: https://doi.org/10.3390/futuretransp1030041

Statistik Austria (2021). *Gemeindeverzeichnis, Stand 1.1.2021*. Wien.

Statistik Austria (2023). Zeitverwendung 2021/2022 - Ergebnisse der Zeitverwendungserhebung. Wien: Statistics Austria.

Steinbach, J. (2016). *Modellbasierte Untersuchung von Politikinstrumenten zur Förderung erneuerbarer Energien und Energieeffizienz im Gebäudebereich*. Fraunhofer Verlag.

Testa, F., Pretner, G., Iovino, R., Bianchi, G., Tessitore, S., and Iraldo, F. (2021). Drivers to green consumption: a systematic review. *Environ Dev Sustain* 23, 4826–4880. doi: 10.1007/s10668-020-00844-5

TransFair-AT (2022). Socially Fair Options for a Climate Neutral Transformation of Housing and Mobility in Austria - Invert-EE/Lab. Available at: https://transfair.wifo.ac.at/models/inverteelab.htm (Accessed October 31, 2024).

Umweltbundesamt (2017). Energiewirtschaftliche Szenarien im Hinblick auf Klimaziele 2030 und 2050. Wien.

Witek, L., and Kuźniar, W. (2021). Green Purchase Behavior: The Effectiveness of Sociodemographic Variables for Explaining Green Purchases in Emerging Market. *Sustainability* 13, 209. doi: 10.3390/su13010209

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