Application of the Concept of "Functionalities" in Macroeconomic Modelling Frameworks – Insights for Austria and Methodological Lessons Learned

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Table of contents

1. Introduction

This working paper is the last one in the series of the EconTrans Working Papers (WPs). EconTrans WP#1 (Schinko et al., 2021) discusses the required transformation to a climate neutral socio-economic system in the context of well-being and human needs as well as disruptive technological change and argues that a change of perspective and a re-thinking of how we can meaningfully measure well-being and the potential effects of the transformation on well-being is needed. One approach towards a new perspective, is the use and operationalisation of the concept of energy services – also called "functionalities" (Köppl and Schleicher, 2018) – in economy-wide modelling. We describe functionalities as the interaction between stocks and flows, which in combination provide a service that satisfy broad categories of basic human needs, such as Shelter or Access (to persons, goods, services and locations). For more details on the concept of functionalities we refer to EconTrans WP#1 (Schinko et al., 2021) and WP#3 with respect to the implementation of functionalities in a new I-O-model (Sommer et al., 2021).

Based on the theoretical underpinning (Schinko et al., 2021) and having set up the data structures to describe the status quo of functionality satisfaction consistently with Austria's national accounts (in WP#3), this paper focuses on the application of the concept of functionalities for Austria in different macroeconomic modelling frameworks, typically used for analysing transformation pathways.

The aim of this exercise is twofold: First, we demonstrate first steps towards an operationalisation of this new concept and derive quantitative results and insights for Austria. Second, we reveal important (data) gaps and potential limitations when it comes to operationalising specifically the functionalities approach in macroeconomic models. Doing so, this analysis connects to the report of the 'Commission on the measurement of economic performance and social progress' (Stiglitz et al., 2009, p. 4), which emphasizes that "*advances both in our conceptual understanding of [economic, environmental and social] issues and [increasing] data availability mean that it is now possible to construct better indicators.*"

Specifically, we set up scenarios for the two functionalities Shelter and Access until 2050 and analyse them from a functionality perspective. These two functionalities as analysed here cover changes in residential building structures for the functionality Shelter, and changes in private transport patterns in the case of the functionality Access. This means that not all aspects of Shelter and Access are covered, as for example freight transport or non-residential buildings. Furthermore, the functionality "Other Life Support" (which includes nutrition, public services etc.) is at this stage not explicitly modelled but captured as with conventional macroeconomic modelling.

For the scenario analysis we use two models. First, the EconTrans "Core Model" evolving from an I-O model, which assigns emissions as well as other resource to functionalities (see also WP#3) in its basic structure and allows to analyse how these changes, when policies/system interventions like new technologies are implemented. Second, we present results obtained with the EconTrans "Extended Model", based on a CGE model structure, showing the socio-economic impacts of a climate-neutral fulfilment of the functionalities Shelter and Access. These results include effects on standard macroeconomic indicators (such as GDP and Welfare) but contrasts these standard indicators with – in our view – more relevant indicators for assessing the transformation towards climate neutrality. These are distributional effects which emerge via the interplay of changes in income and expenditure patterns, effects on wages and capital rents as well as a more accurate quantitative measure for human wellbeing, which combines changes in material consumption with co-benefits and a valuation of a potential leisure-consumption trade-off.

2. Scenario development

2.1 General scenario framework

For the assessment of changes for the functionalities Shelter and Access we make use of a scenario approach. Specifically, we compare two scenarios: First, an "Autonomous Transformation" scenario (AUTO) in which expected technological trends are implemented (e.g. an electricity sector mainly based on renewable energy sources by 2030, generic energy efficiency increases, moderate penetration of e-mobility, moderate improvements of the residential building stock). Note that the AUTO scenario should not be interpreted as a business-as-usual scenario, but already includes changes in terms of climate change mitigation, which however are not sufficient to reach climate neutrality in Austria by 2050.

Second, a "Targeted Transformation" scenario (TARGET), which aims at climate neutrality by 2050. Compared to AUTO this requires stronger interventions. As mentioned, we analyse the share of the functionalities Shelter and Access that concern private households, whereas for the rest of the economy no changes compared to the AUTO scenario are assumed. Nevertheless, we take account of all intermediate inputs for these two functionalities. By comparing TARGET to AUTO we can deduce deviations in the trend given by AUTO and thus isolate the socio-economic effects of switching to the TARGET trajectory.

For achieving climate-neutral Shelter and Access, we structure the assumed measures according to the Avoid-Shift-Improve (ASI) framework (Creutzig et al., 2018), which aligns well with the demand perspective of the functionalities approach. The logic of the ASI framework suggests to start climate change mitigation measures by avoidance of greenhouse gas emission intensive activities (e.g. avoiding physical transport needs by means of telework). This is followed by technological shifts towards more climate friendly activities for those fractions that cannot be avoided (e.g. shifting from motorized individual transport to public transport). Finally, some aspects can neither be avoided nor shifted and are thus subject to improvement (e.g. use electric cars instead of fossil fuelled cars).

Table 1 summarizes the modelled measures for Access and Shelter, according to the ASI structure. For Access we focus on the avoidance of commuting trips by increasing the share of telework and by work-time reduction. The category Shift includes modal split changes towards more public transport as well as active mobility and Improve includes the increase of e-car penetration in the privately owned car fleet. For Shelter a more efficient usage of living space leads to avoidance of emissions, changes in heating systems and building technologies are regarded as technological shifts, whereas the refurbishment of the existing building stock and the setup of so-called "Superblocks" (see Frey et al., 2020) and a focus on quarters (e.g. Suurstoffi in Switzerland) improve (i.e. lower) the emission intensity of the functionality Shelter. The basic idea of Superblocks/quarters is the transformation of single-use into multi-use space, hence it is an example where both investigated functionalities are affected. More details regarding these measures and how they relate to the scenario framework is described in sections 2.2 (for Shelter) and 2.3 (for Access).

Table 1: The modelled changes for the functionalities Shelter and Access

	Shelter	Access
Avoid	- More efficient usage of living space	- More Telework - Work-time reduction
Shift	- Change in heating systems (replace oil heating) - Change in building technologies of new houses	- Modal shift towards more public and shared transport as well as active mobility
Improve	- Refurbishment of existing building stock	- Increasing the penetration of electric cars in motorized individual transport
	Superblocks/Focus on quarters	

In general, low-carbon transition pathways, as analysed here, are due to their long-term character of several decades subject to high uncertainty which limits any attempt of forecasting. Such long time horizons can nevertheless be assessed using scenario techniques refraining from *probability* assignments but reflecting on selected and/or extreme cases, from which *plausible* developments can be derived. Even in that case, a quantification of scenarios may be deemed too uncertain leaving qualitative tools the adequate choice. Yet, as quantified implications are of interest in many cases, the technique of scenario comparison can be applied where scenarios are compared to each other (in this case AUTO and TARGET) with one scenario usually denoted as baseline or reference development. This approach has the advantage that the focus on the uncertainty surrounding the baseline (but not denying it) is shifted towards deviations from the baseline. Such results can be derived more reliably from any (set of) chosen reference development(s).

2.2 Scenario assumptions for the functionality Shelter

This chapter presents assumptions, inputs and parameters for the AUTO and the TARGET scenario regarding the functionality Shelter. This set of input assumptions is applied for simulations in the Core Model as well as the Extended Model.

2.2.1 Expected autonomous transformation scenario for Shelter (AUTO)

Floor space of dwellings has increased 21% from 2004 to 2020, while the population has grown by 9% over the same period. Additional to the population growth, a decreasing occupancy rate (-6 %) and an increasing area per household (+4 %) are driving the total demand for floor area in dwellings. For the period until 2050, the demographic forecast by Statistic Austria assumes that the population increases by 8% and the occupancy rate decreases further to 2.15 persons per dwelling until 2050.[1] The total Austrian floor area for housing in 2050, i.e., the housing area that needs to be heated and cooled, will be a result of the already existing building stock and its evolution as well as newly built dwellings. The heating systems in the survey of 2013/14 reveal that 17% of installed primary heating systems in main residences are based on fossil oil or LPG[2] and 24% are operated with natural gas.[3] Due to the government program on the withdrawal of oil heating systems it is expected that the use of oil for domestic heating is phased out until 2050 (Bundeskanzleramt, 2020).

Based on the information available, detailed scenarios (AUTO and TARGET) until 2050 are derived for Shelter. Details are explained in Appendix A.

The total Austrian living space, the thermal quality of buildings and the applied heating systems determine the energy and fuels needed for the provision of hot water and heating for shelter in Austria. Figure 1 shows the decreasing energy demand and the fuel mix in the AUTO scenario. Here a phase-out of the oil based heating systems is assumed, which are replaced by systems reflecting the composition of 2018, the latest available structure (Statistik Austria, 2021c). Figure 1 illustrates the development of energy demand by energy source for the functionality Shelter between 2014 and 2050, illustrating the phase-out of oil and coal, and the remaining relevance of gas for heating and warm water.

[1] Statistik Austria (2021a) and Statistik Austria (2021b)

[2] Liquified Petroleum Gas

[3] Statistik Austria, Energieeinsatz der Haushalte (2021c)

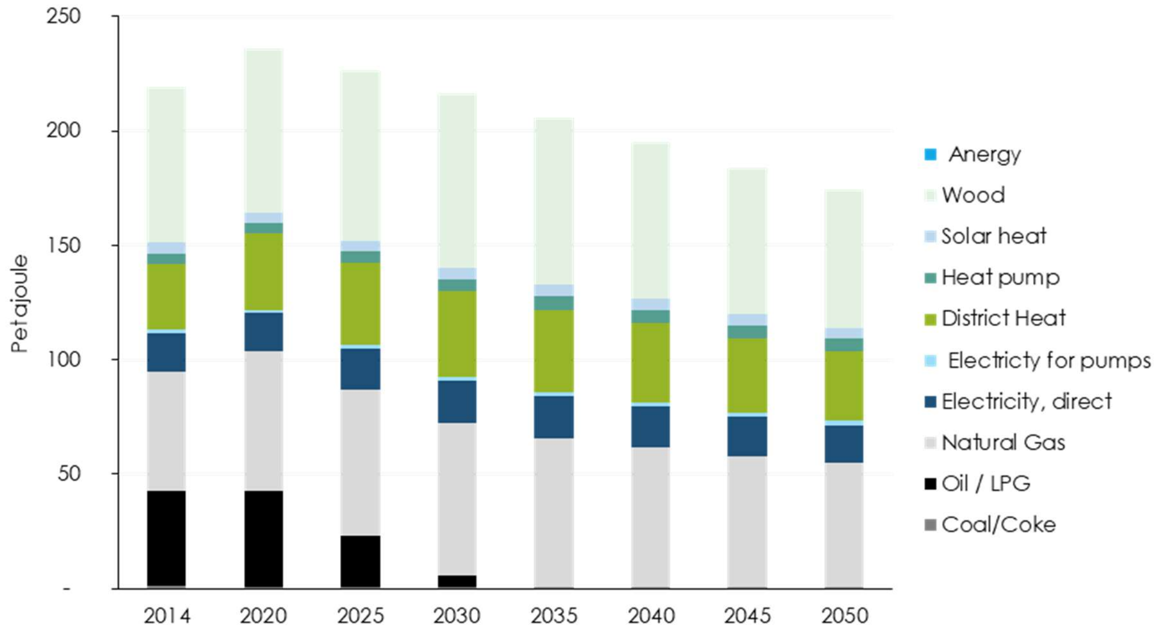

Figure 1: Fuel demand for room heating and hot water in AUTO
S: Own calculations and (Statistik Austria, 2021d)

2.2.2 Targeted low carbon transformation scenario for Shelter (TARGET)

Three sub-scenarios are defined that frame the transformation process for the functionality Shelter. As stated above an avoid-shift-improve approach in designing the scenario assumptions is applied. This approach was originally developed for policies that aim at minimizing the negative impact of the transport sector on the environment (Creutzig et al., 2018). However, it can be applied for Shelter as well. For the sub-scenario **Avoid** we assume a reduction of the total floor area and of construction material which translates to a reduction in energy demand. The rationale for a smaller total floor space for housing is based on the assumption that, over time, there will be a higher share of multi-family houses at the expense of single-family houses, and that, e.g. shared office space in a multi-family house could reduce the amount of space required per apartment. In the sub-scenario **Shift**, we assume a shift towards renewable energy for heating and additionally a shift in the material composition and material use of buildings. Here we rely on the one hand on research results with regard to material efficiency and on the other hand on examples of innovative building concepts, such as those implemented at "Suurstoffi"[4] in Switzerland, as well as examples realised within the Austrian research programs "Stadt der Zukunft". The assumptions for the sub-scenario **Improve** comprises an improvement of the thermal quality of buildings through refurbishment and an improved standard for new

[4] https://www.suurstoffi.ch/home

buildings as demonstrated e.g. by research of the Buildings Performance Institute Europe[5] or NEST.[6]

Furthermore, a sub-scenario includes an increased application of the “superblock” or quarters concept in urban areas, that aim at an integrated perspective on whole neighborhoods. Such concepts are of interest from the perspective of energy systems for buildings on the one hand and for avoiding physical mobility needs, on the other hand, by providing functionalities relevant for well-being in close distance or allowing their accessibility with public transport. With respect to the functionality Shelter this could support the rising dwelling area for shared spaces, but at the same time the focus on quarters allows an integration of buildings into the energy system (as storage facilities for heat and electricity and as load balance (Loeffler et al., 2020; Mair am Tinkhof et al., 2017; Märzinger and Österreicher, 2020).

The effect of the combination of the assumptions for the three sub-scenarios on energy demand by fuel is summarized in Figure 2. Energy demand for heating and hot water – in comparison to the AUTO scenario – decreases (29% or 50PJ) due to a smaller total floor area and a higher quality of the residential building stock. The shift in fuels shows a strong reduction in fossil fuel use which directly means a reduction in GHG emissions. An indirect reduction in emissions occurs due to less material demand, especially steel and concrete. This effect can be seen in the overall results on GHG emissions (section 3.2).

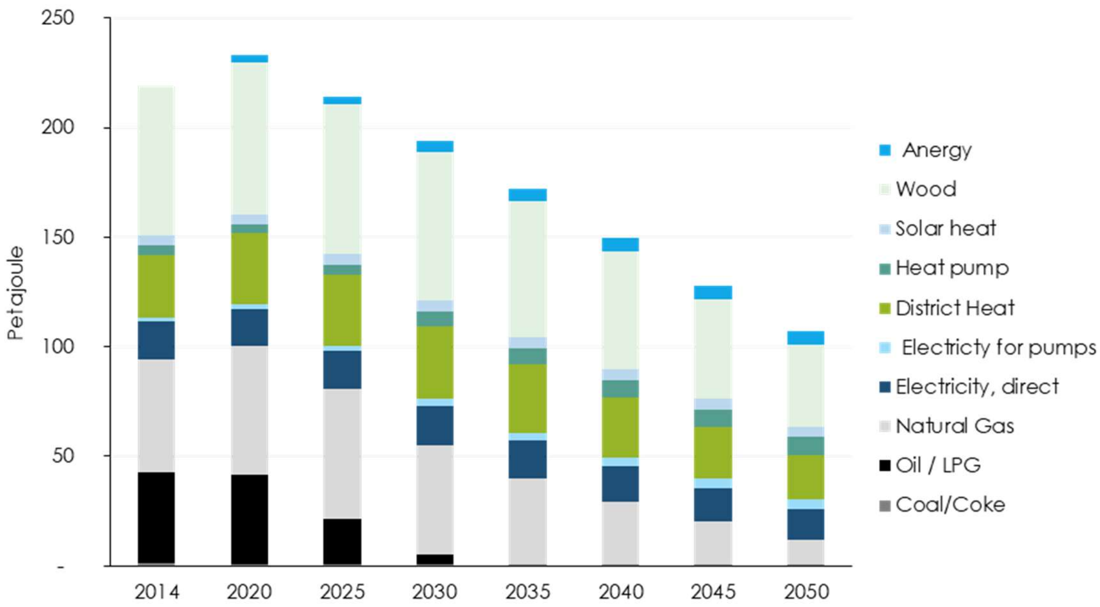

Figure 2: Fuel demand for room heating and hot water in TARGET

[5] https://www.bpie.eu/

[6] https://www.empa.ch/de/web/nest

The difference between the two scenarios AUTO and TARGET per fuel is given in Figure 3. Since natural gas has a large share in AUTO and the total demand decreases in TARGET, the majority of the decrease is accounted to this fuel. For the same reason the demand for wood is going down while the use of ambient heat increases in absolute terms.

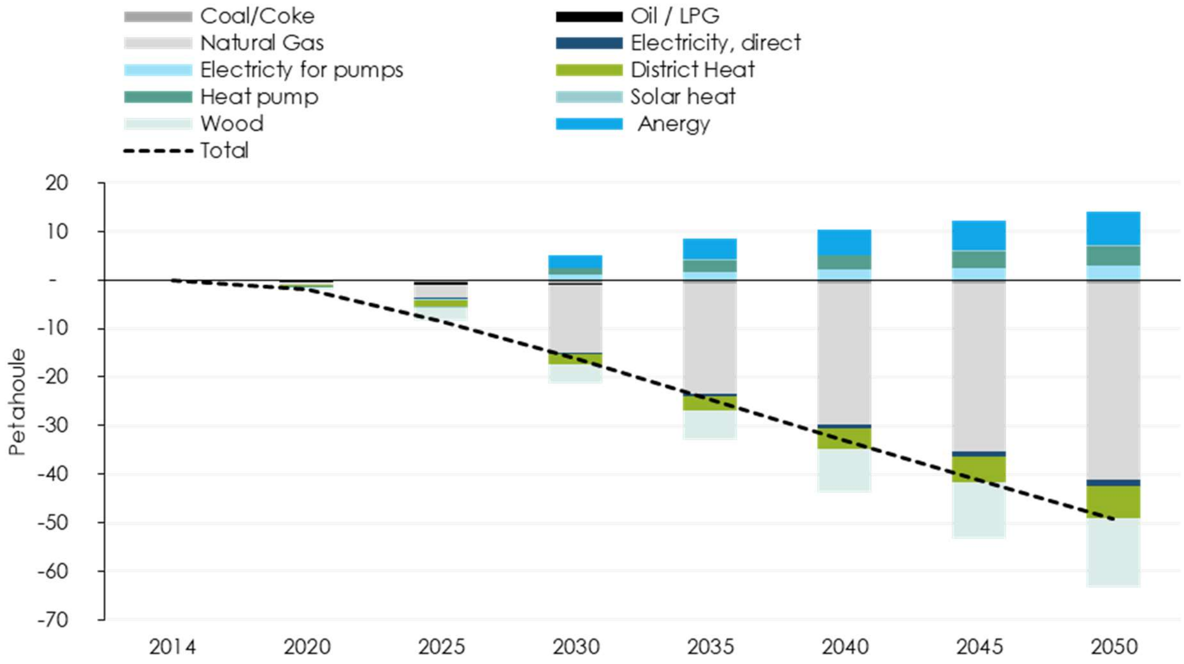

Figure 3: Difference in fuel demand in total between TARGET and AUTO scenario

2.2.3 *Linking to the national input-output table*

The starting point for connecting to the national input-output table is to define a scenario on a physical level as outlined in 2.2.1. In the case of Shelter this refers to development of heated floor area, thermal quality of new buildings and area that undergoes thermal refurbishment.

Based on information from (Schleicher et al., 2018) on costs for stricter building standards in new buildings and refurbishment these additional costs are derived for the TARGET scenario. For AUTO the current technologies and refurbishment rates are assumed and therefore no additional costs are incurred in this scenario. These additional costs for TARGET are transferred to the hybrid structure of the Core Model and the monetary structure of the Extended Model. In TARGET the usage and expenditure for concrete and steel is reduced because of an assumed increase in wood-based structures. The commodity shares that relate to these products change respectively (see Appendix A for details).

Next we connect the changes in heating systems to the national input-output table. As before a physical development is defined as an initial step, namely the development of the composition of heating systems in Austria's households (details in Appendix A). This defines the fuel demand, i.e. energy flows determined by the underlying stocks, needed for the satisfaction of heating and hot water demand in physical units (Terajoule). The resulting fuel demand structure is displayed above in Figure 1 and Figure 2. Based on these physical flows, changes in the expenditure structures of final demand (fuel mix) is derived. The energy demand for cooking and electric appliances is related to population size and changes in energy efficiency. The resulting energy demand is handled similar as energy for heat.

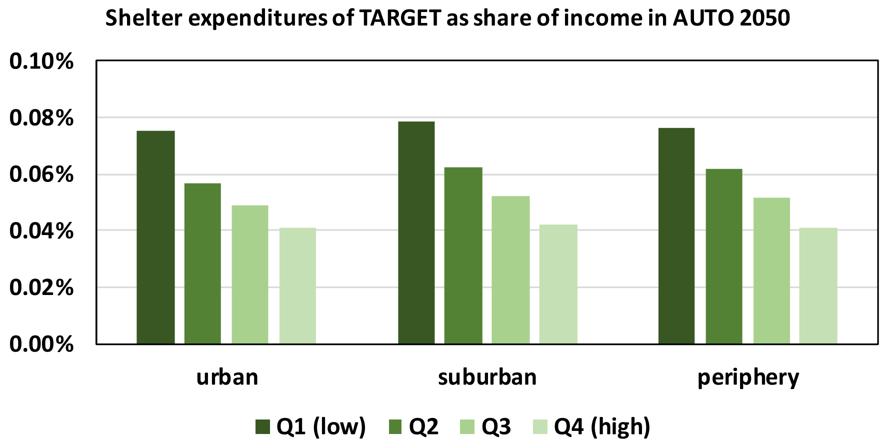

Figure 4: Higher expenditure requirements of Shelter fulfilment in TARGET as share of income in AUTO 2050 across groups of private households.

As shown in Figure 4, the expenditures for fulfilling Shelter in the TARGET scenario are slightly higher compared to AUTO in 2050. This is because the corresponding monetized energy savings are lower than the higher expenses on (actual and imputed) rents for dwellings that are caused by the additional cost for refurbishment and higher costs for new buildings. Relative to income of households in AUTO 2050, low(er) income groups of households bear a greater burden with the structural changes of the TARGET scenario. We do not see differences across location of residence, though.

2.3 Scenario assumptions for the functionality Access

Between 2000 and 2017 domestic passenger transport (measured in person-km [pkm]) has increased by 23%, while the population has grown by only 10% over the same period. The demand for (physical) mobility has thus increased in absolute but also in per capita terms and if the development remains unchanged, passenger transport performance could rise to 150 billion pkm p.a. by 2050 according to (Umweltbundesamt, 2019a). This would correspond to an increase of about 33% (in 2014: 112 billion pkm). The majority of the pkm are travelled by car.

In 2014, around 71% of the transport performance was covered by this mobility mode (Umweltbundesamt, 2016a). Additionally, the segment of pkm travelled by car has risen stronger than other segments, such as public transport or active mobility in recent years.

In order to set up the AUTO and TARGET scenarios for Access a stepwise approach is followed. In the first step a fictional business as usual (BAU) scenario is set up without further changes such as the implementation of policy measures. Note, that the BAU only forms the starting point for the second step, where we develop and implement the assumptions for the AUTO and TARGET scenarios, by systematically changing the BAU trajectory. The details for the BAU scenario (which is finally not used for the analysis, but which is needed for the derivation of AUTO and TARGET) are given in the Appendix. For the AUTO and TARGET scenarios "physical" satisfiers of Access are forms of active mobility (walking, bicycling), motorized individual transport with conventional (cMIT) and electric cars (eMIT), long-distance public transportation on rail (RailPT) and road (RoadPT), short-distance public transport in (sub)urban areas (CityPT) and other means of transport (e.g. micro public, shared commuting, taxis). The mix of these satisfiers determines the structure of passenger-kilometres by mode. "Non-physical" satisfiers such as home-schooling, tele-work and spatial planning (including superblocks/quarters) determine the required level of passenger-kilometres.

2.3.1 Expected autonomous transformation scenario for Access (AUTO)

Due to the outbreak of the COVID-19 pandemic, traffic patterns have changed (Pase et al., 2020) in terms of reduced travelling. In addition, existing framework conditions (such as subsidy schemes and falling costs for batteries) promote e-mobility to some extent. These expected autonomous structural changes are implemented in the AUTO scenario. The AUTO scenario thus applies the same modal split as in the BAU (with increasing shares of e-cars), but total pkm per capita are assumed to flatten from 2020 onwards. The corresponding population development in Austria is taken from Fricko et al. (2017, SSP2) and is consistent with the assumptions made for Shelter. Figure 5 shows the resulting development of passenger kilometres for the different modes from 2014 to 2050 for the AUTO scenario. The total transport performance in 2050 amounts to 128 billion passenger kilometres, which is an increase of 13.6% compared to 2014. Apart from a flattening in demand of pkm in total and the increasing share of e-cars (21% in 2050), no fundamental changes are assumed.

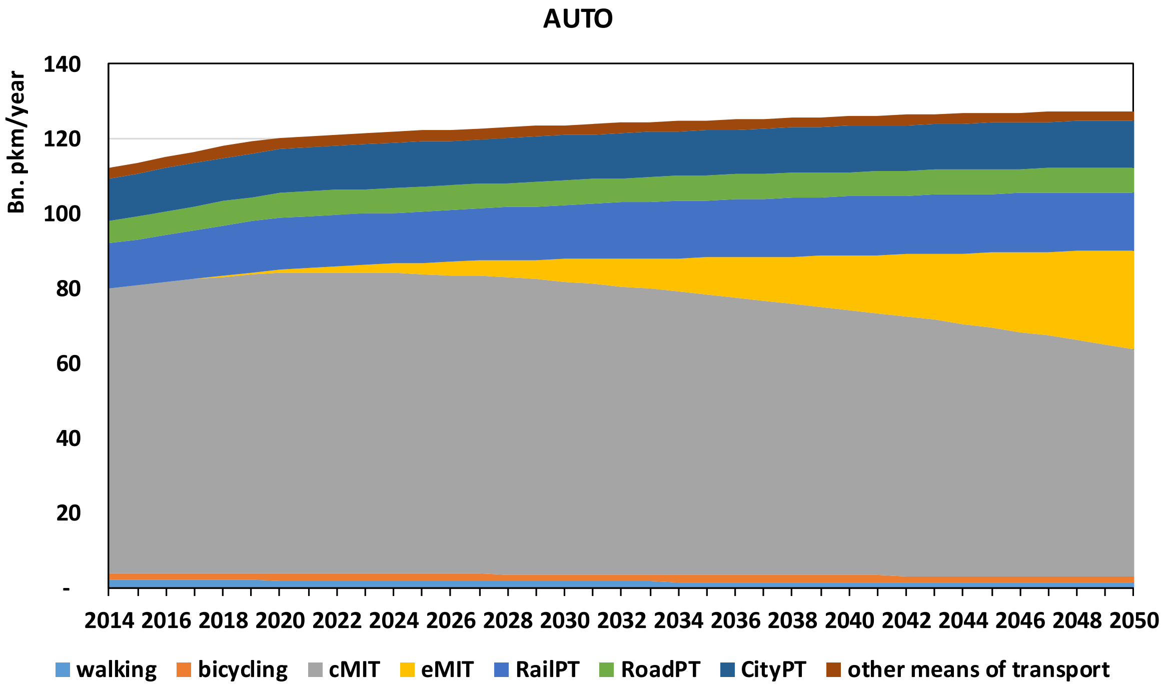

Figure 5: Development of passenger kilometres in the AUTO scenario.

2.3.2 Targeted low carbon transformation scenario for Access (TARGET)

For the transformation scenario that aims to reduce demand-side emissions from private transport, five sub-scenarios were created: A single scenario for each of the three categories of the ASI framework, a scenario that is driven by the structural changes in the functionality Shelter, as well as a combination of the four sub-scenarios, which represents the final TARGET scenario for Access.

More precisely, the sub-scenario **Avoid** shows a reduction of the need for travel, due to increasing home-office practices and work-time reduction. In the sub-scenario **Shift**, the more environmentally friendly modes of transport are expanded and thus pkm shifted. This refers to an increase in public and shared transport and active mobility, while MIT is being reduced. In the sub-scenario **Improve**, the energy efficiency of transport facilities and vehicle technologies are enhanced. This is done by increase the share of electric cars in the car fleet. The fourth scenario assumes a reduction in traffic due to a change in the settlement structure (i.e. in functionality Shelter less transport demand due to changes such as the implementation of superblocks and a focus on quarters). Note that the chronology in the scenario construction is as follows: First the avoidance of pkm demand by home office and working time reduction is calculated, and then the remainder of pkm is shifted to public/shared transport and active mobility, and finally e-mobility is used to cover a fraction of pkm that can neither be avoided nor shifted but at least improved in terms of emission intensity. For further details about the scenario construction and underlying assumptions please see Appendix A.

To summarize, the TARGET scenario combines assumptions on measures along all the ASI categories and assumes an effective structural shift in spatial planning. Figure 6 shows the TARGET scenario in pkm and by mode until 2050. Compared to 2014 we derive based on our assumptions that total pkm are reduced by -16%. Figure 7 compares the scenarios and shows the absolute differences in pkm between TARGET and AUTO by transport mode and in total.

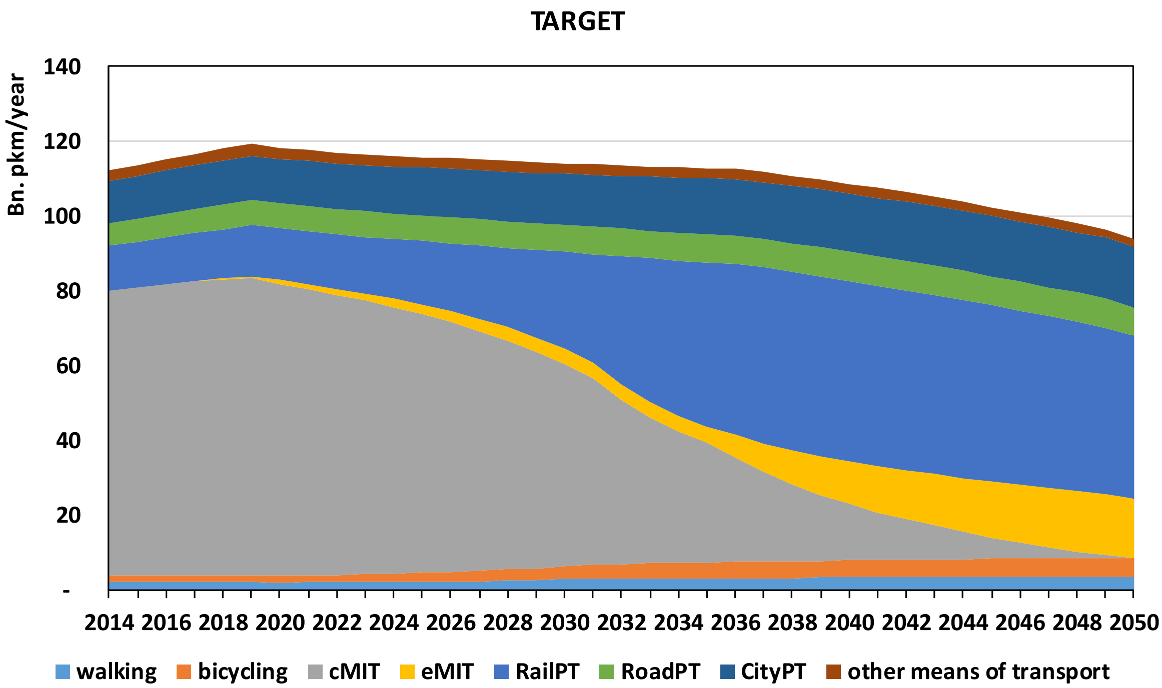

Figure 6: Development of passenger kilometres in the TARGET scenario.

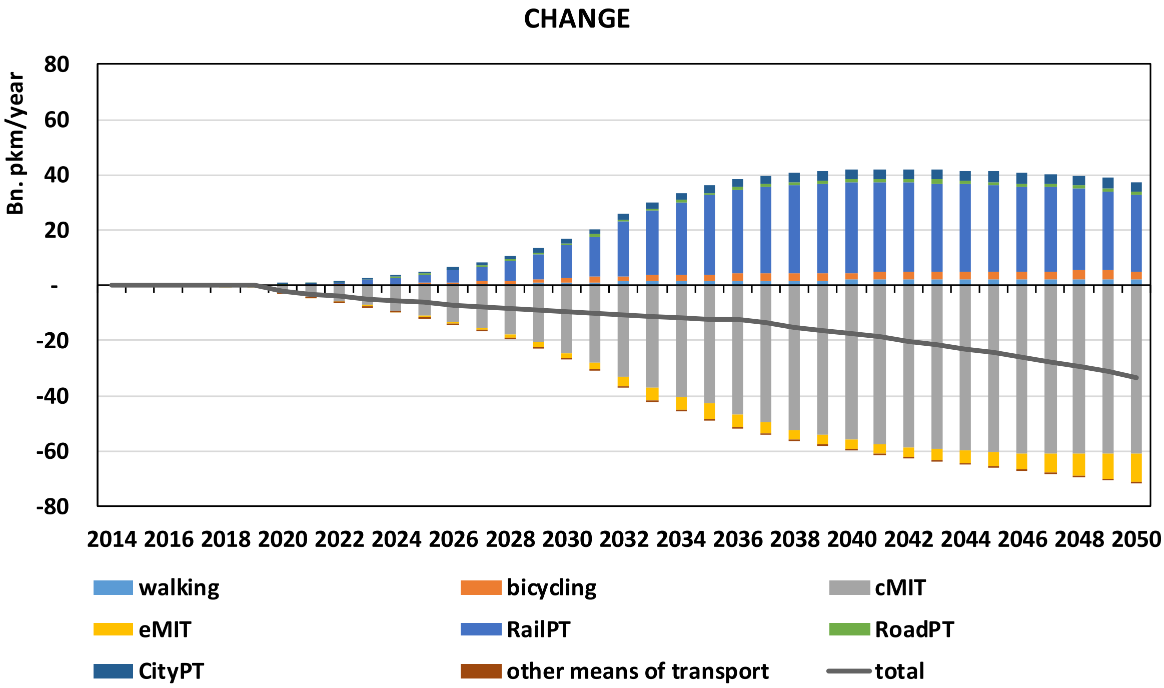

Figure 7: Difference in pkm per mode and in total between TARGET and AUTO scenario.

2.3.3 Linking to the national input-output table

For linking the changes in physical dimensions of the satisfiers of Access – as described above in the AUTO and TARGET scenarios – with the Core and Extended Models, we need to accomplish the following tasks. First, within the existing national input-output table (IOT) the currently existing structure of functionality satisfaction needs to be identified. For example, private MIT is embedded in the consumption vector of a representative household in the IOT. For modelling a reduction and replacement of private MIT, its structure needs to be isolated from the rest of consumption. A conceptual description of this process is given in Section 4.1.

In Figure 8, we report the current satisfaction of the functionality Access based on monetary flows in the socio-economic system, differentiated by income groups of private households. The monetary flows relate to the expenses for different satisfiers of Access. In this status quo structure, the share of cMIT rises with income level and declines with the degree of urbanization. Note that active mobility (walking, bicycling) does not show up here since no significant monetary flows are linked to it.

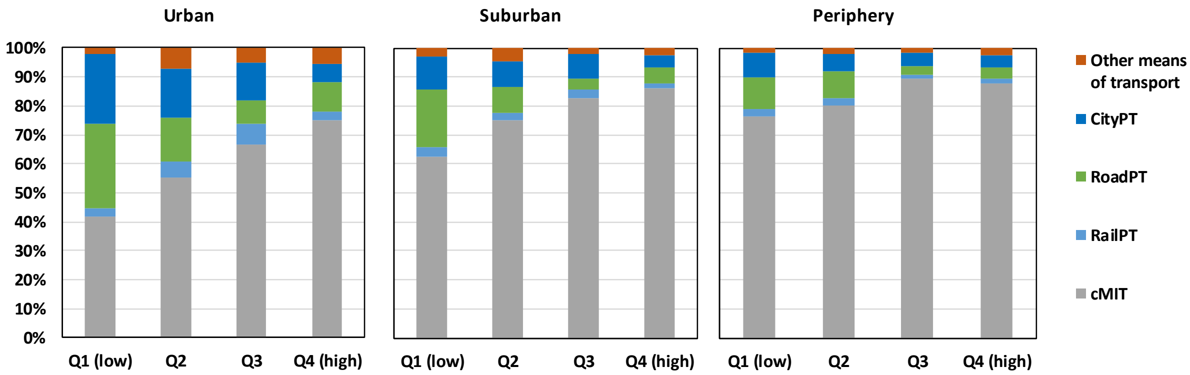

Figure 8: Status quo (2014) expenditure shares of satisfiers of Access across household groups.

The second task concerns the translation of the changes in the physical quantities (pkm-changes) of each satisfier into monetized annual units. In this step, we distinguish the operating phase and the investment phase. For the *operating phase*, the unit costs of public/shared mobility are kept at the benchmark level, which are based on EUROSTAT (2021a) and are directly linked to the respective pkm-development. For MIT, the unit cost and structure (i.e. more eMIT means more electricity, less cMIT means less gasoline and diesel) are expected to change substantially. We account for the changing MIT-fleet by modelling operating and capital expenditures of cMIT and eMIT separately based on assumptions regarding economic lifetime of 15 years, an interest rate of 1%, and expected development of acquisition costs (based on (Kreyenberg, 2016; Lutsey and Nicholas, 2019), reported in Figure A 8 in the Appendix). The resulting picture for total private household consumption expenditure for fulfilling the functionality Access in the AUTO (left) and TARGET (right) scenarios is given in Figure 9. The satisfaction of Access in the TARGET scenario requires -64% (-54%) lower operating expenses compared to AUTO (benchmark 2014). These expenses for satisfying the functionality Access are used as inputs for the macroeconomic scenario evaluation.

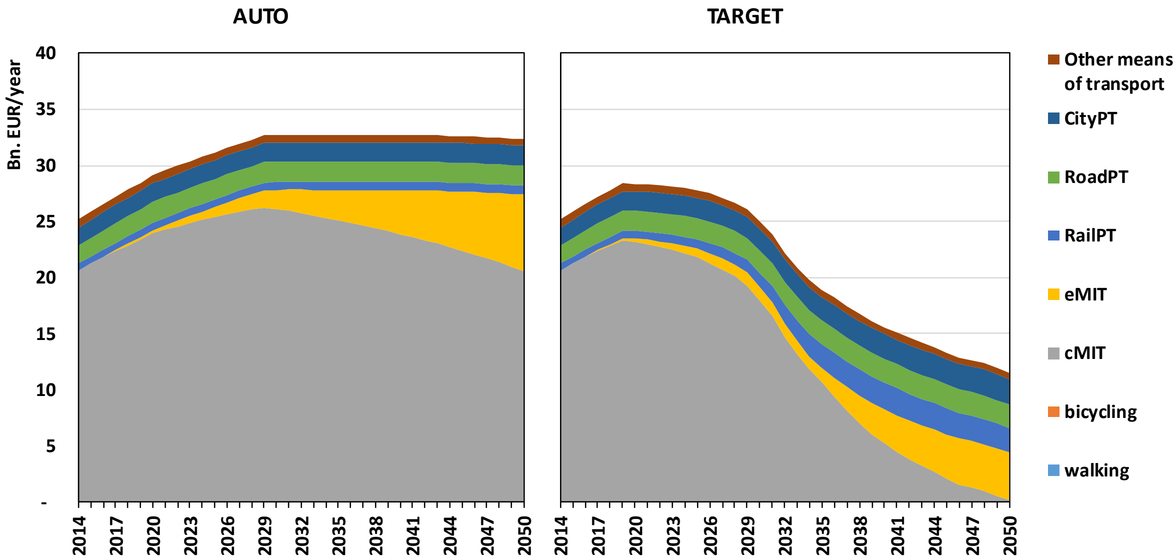

Figure 9: Monetized scenario parameters of fulfilment of Access in the operating phase for AUTO and TARGET.

For the *investment phase*, we include additional infrastructure in monetary terms which is needed for the provision of the functionality and report these in Figure 10. For road transportation (both public/shared), no substantial changes beyond annual reinvestments are needed and the benchmark investments are maintained. As the share of rail transport increases, also additional investments are necessary, which increase from an annual amount of around 2 billion EUR in 2014 to 3 billion. EUR in 2050. This is assumed for both, the AUTO and TARGET scenarios, even though the pkm-share of rail is substantially larger in TARGET. This assumption is motivated (and confirmed by sector representatives) with qualitative (e.g. organisational) improvements of the built capital stock allowing for significant service gains achieved by similar investment amounts (e.g. digital services, smoothing of rush hours capacity utilization due to flexible work schedules, *et cetera*). For MIT, which is not an investment category in a national accounts definition but is recorded in the consumption category of durable goods, our scenarios derive a substantial drop in operating and capital expenses for private vehicles in the TARGET scenario, -84% or -23 billion EUR compared to the 2050 level in the AUTO scenario or -78% or -16 billion EUR compared to 2014.

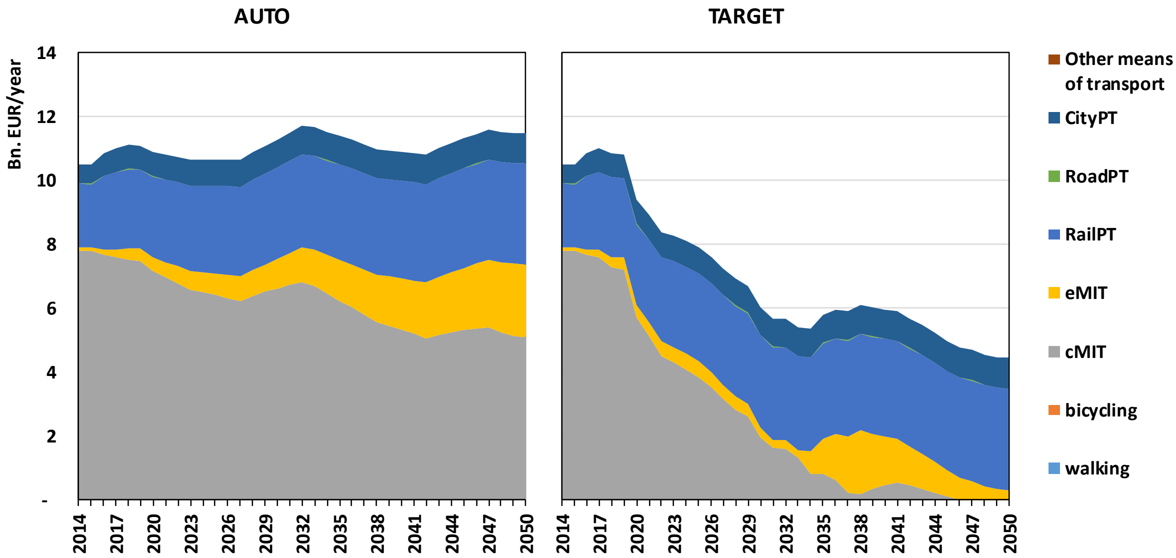

Figure 10: Monetized scenario parameters for the functionality Access for the investment/acquisition phase for AUTO and TARGET.

The radical changes assumed in the required quantity and quality of stocks allow for keeping the same level of Access (or utility out of it), but lead to substantial savings in terms of the monetary flows for the provision of the functionality. Based on these top-down changes in functionality fulfilment, we assume that the structural changes happen uniformly across household groups, nevertheless taking into account their starting point as shown in Figure 8. Since the largest changes accrue to MIT, it is the higher-income households and households living in the periphery benefitting more than others from the assumed structural change in mobility (Figure 11).

In a standard evaluation of such savings, we expect increased consumption in other areas (welfare in the mainstream economic sense) i.e. the savings do not translate into lower material consumption. However, an increasing number of scholars in a plural field of (economic) research discusses leisure as an increasingly relevant option for compensation of such savings in the context of climate change mitigation (e.g. Antal (2018); Cieplinski et al., (2021); Gerold and Nocker (2018); Schor, (2008)). We will come back to this issue in section 4.

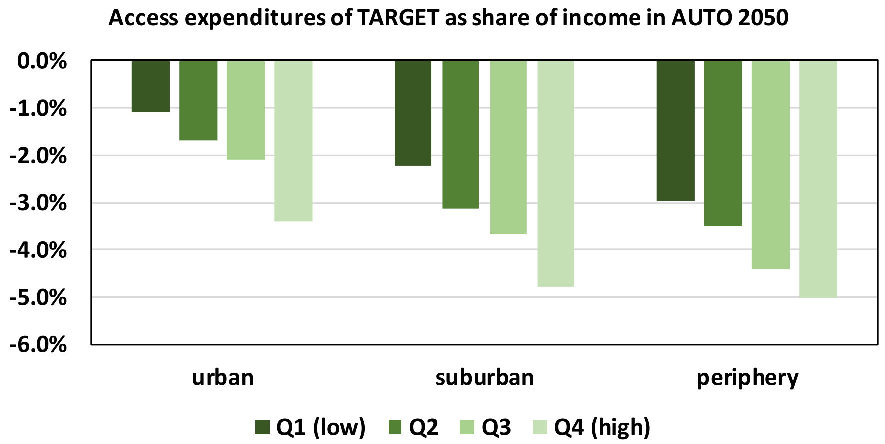

Figure 11: Lower expenditure requirements of Access fulfilment in TARGET as share of income in AUTO 2050 across groups of private households.

2.3.4 Co-Benefits

For a more comprehensive perspective, we also quantify the co-benefits that result from the described changes in the supply of the functionality Access. This serves as a first step towards a more comprehensive and accurate measurement of effects on wellbeing (see also Econ-Trans WP#1; Schinko et al.; 2021).

As the modal split in the transport sector shifts towards public, electric and active transport various co-benefits arise. In our analysis co-benefits stemming from reduced levels of congestion, noise as well as health and non-health benefits connected with a better air quality are examined. Physical health benefits from increased levels of active mobility are also considered. To monetize the co-benefits, values on the external average cost per pkm for Austria from the "European Handbook on external costs of transport" are applied (van Essen et al., 2019). For the evaluation of co-benefits from increased physical activity the HEAT tool is used (WHO, 2017). Co-benefits are calculated as the difference between external costs of transport in the AUTO and the TARGET scenario. For details regarding the method of the quantification of the co-benefits, see Appendix B.

Figure 12 shows the co-benefits in 5-year steps until 2050. Since differences between AUTO and TARGET scenario are only realized from 2018 onwards, co-benefits appear from 2020 onwards. The co-benefit-development essentially follow a S-shaped growth pattern with increasing growth rates in the beginning and a slow-down in growth approximately around 2030 for physical health, around 2035 for congestion and around 2040 for air pollution and total co-benefits. An exception to the pattern is the co-benefit from noise reduction, which rises to 46 million EUR in 2030 but then declines to 25 million EUR in 2036 before increasing again and reaching 154 million EUR by the end of the modelled period in 2050. This can be explained by the fact that also public transport emits noise as an externality, which is found to be stronger than noise from individual car traffic. Co-benefits from reduced congestion are significantly higher than the ones from reduced noise, reaching a maximum of 387 million EUR by 2050. Co-benefits connected to decreased air pollution reach approximately 684 million EUR by 2050 and those arising from increased physical health reach 877 million EUR in 2050. This amounts to total co-benefits of 2.1 billion EUR for the year 2050. The detailed results for the co-benefit-calculations can be found in Appendix B. Note that these quantifications are an attempt to capture at least the lower bound of co-benefits associated with the investigated structural changes.

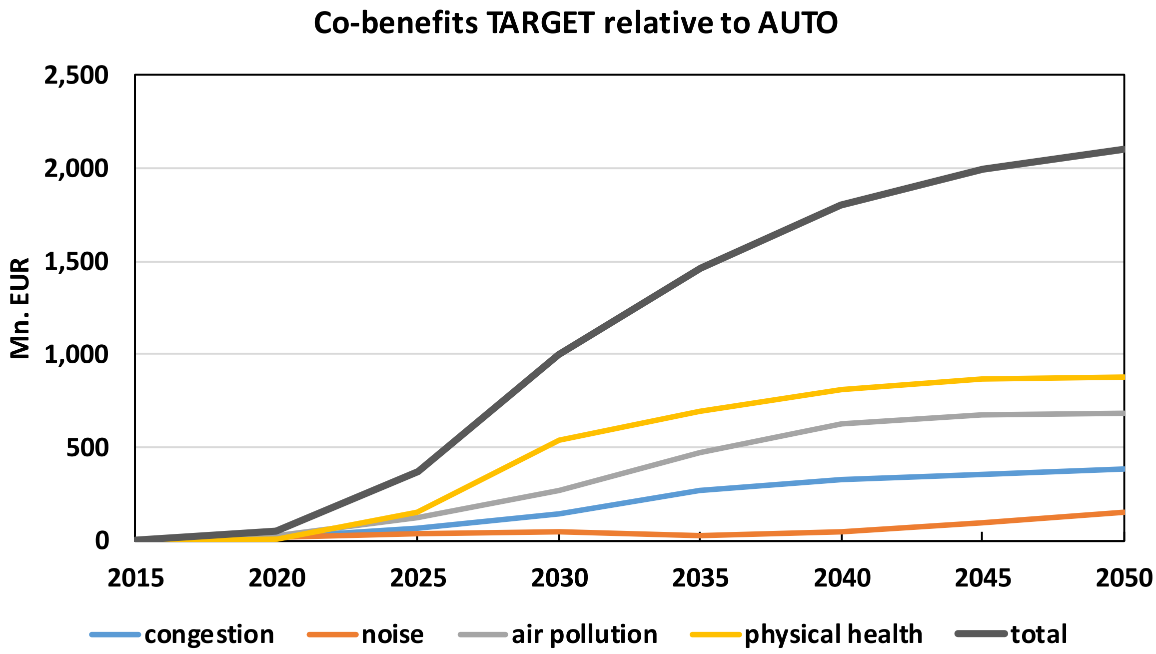

Figure 12: Co-benefits from 2015 to 2050

3. Analysis with the Core Model

3.1 The Core Model

3.1.1 General model description of the Core Model

The Core Model is based on the approach of the well-established input-output analysis. This method is based on a set of matrices, the Input-Output-Tables (IOT), that represent the monetary interconnections between a range of economic sectors and between the sectors and domestic and foreign consumers. The available IOT's for Austria comprise 74 sectors and commodity groups. The typical focus of an Input-Output analysis is the final demand – that comprises private and public consumption, investment and exports – and the link thereof to value added, trade, production and employment.

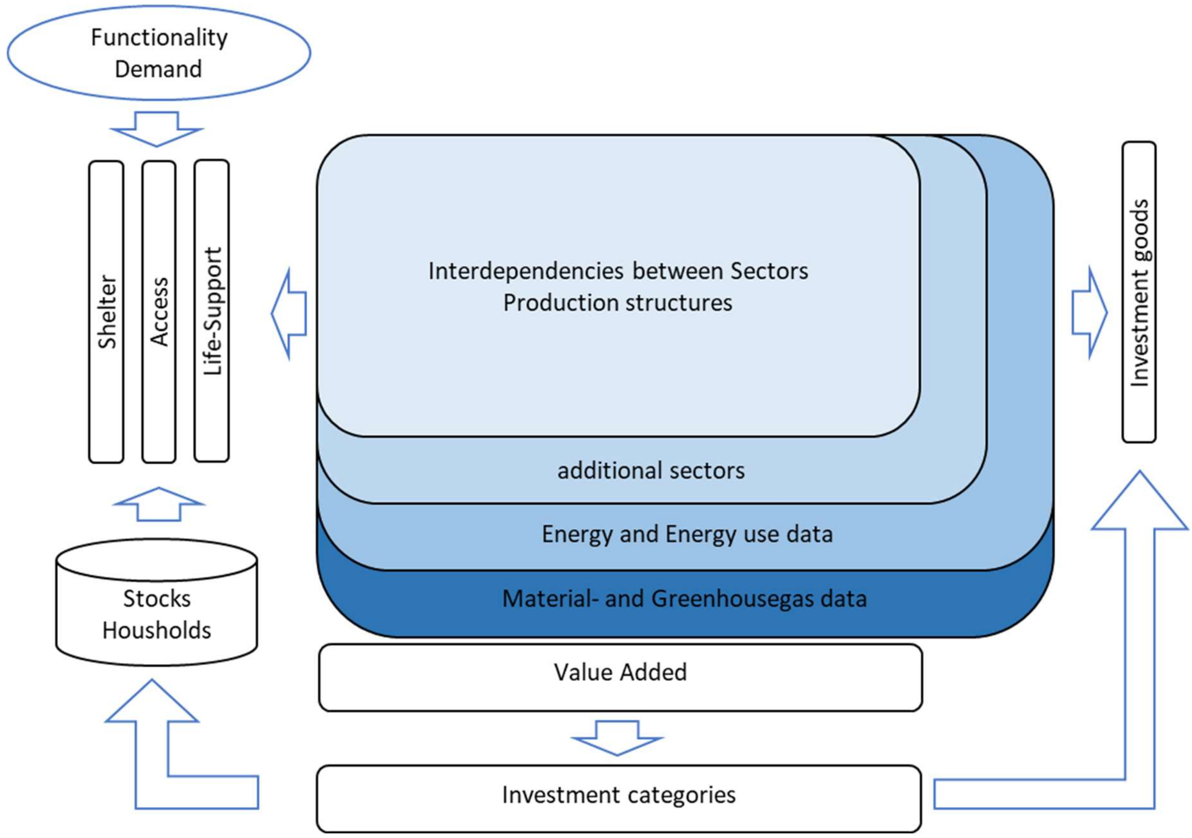

Figure 13: Main Structure of the Core Model

For EconTrans the original IOT for Austria for the year 2014 has been rearranged and expanded (Figure 13). The aim of the rearrangement was to put the focus on three functionalities (Shelter, Access and Other Life Support) and the commodities, services, investments and energy needed to satisfy a certain level of the functionalities. Investments of companies are linked to their economic activity and interpreted as necessity to maintain the capital stock to produce the demanded goods and services. This rearrangement is complemented by the expansion of the economic structure that allows to allocate physical data on energy demand, GHG emissions and material consumption to economic sectors. Using the Input-Output-Analysis approach and this modified IOT allows us to reveal the underlying emissions and material consumption linked to the satisfaction of functionalities.

In the Core Model the amount and structure of commodities and services needed to serve a certain level of functionality are not constant. On the one hand it depends on the behavior of companies and households. Examples are support for home office by companies and legal frameworks, the choice of where to live or the choice of the transport mode, e.g. the use of public transportation. Assumptions about such behavioral changes are important for significant emissions reductions. Assumptions on changes in behavior can be implemented in in the Core Model exogenously, which then illustrates how these changes unfold in the IOT structure.

On the other hand, the inputs needed to serve a certain level of functionality is dependent on the existing capital stock and its quality in terms of energy efficiency (i.e. past investment decisions). The composition of the stock defines the flow and structure of commodities, energy and services needed to satisfy a functionality. Hence, a different stock or higher quality stock that serves the same functionality might use less materials and/or energy. Therefore, in EconTrans the IOT is complemented with the composition of household stocks, comprising buildings, heating systems and vehicles. These stocks define the energy inputs required for the satisfaction of functionalities, here with the focus on fractions of Shelter and Access. This means, that in the Core Model, investment decisions over time in new specific technologies or improvements are exogenously set. These investment activities change the existing stock over time which then also changes the flow of materials and energy. This modelling approach represents the implementation of a stock-flow relation and also represents the trade-off between the quality of the capital stock and the energy/material consumption determined by this stock.

3.1.2 Implementation of scenarios in the Core Model

The Core Model developed in EconTrans can be used for scenario analysis, showing how the structure of the commodities needed for providing a certain level of a functionality and the related direct and indirect GHG emissions change with different scenario assumptions. For our focus on the two functionalities Shelter and Access we define detailed scenarios for their respective underlying structures (see Appendix A). The information of these scenarios, derived from literature and expert judgements, is translated into inputs for the Core Model in form of direct energy demand and changes in consumption and investment expenditures. Note that the third remaining functionality Other Life Support is not in the focus of the current analysis. Therefore, no specific scenario and scenario inputs are constructed. The level of the provision of this functionality, and the resulting commodities and services demand, are changing according to population growth.

3.2 Results from the Core Model

Based on the described inputs direct, indirect and investment related emissions are revealed for each of the functionalities in the time span until 2050. The direct emissions relate to emissions that are directly emitted for the satisfaction of the functionality; i.e. from fuel combustion in heating systems of dwellings and in fossil engines for traction in cars. Indirect emissions are emissions that are emitted along the value added-chain in the production of a specific commodity, service, electricity or district heat. Investment related emissions are related to commodities needed for the investment activities in the economy. This covers for instance emissions caused by the need for concrete or steel to construct a manufacturing site or road.

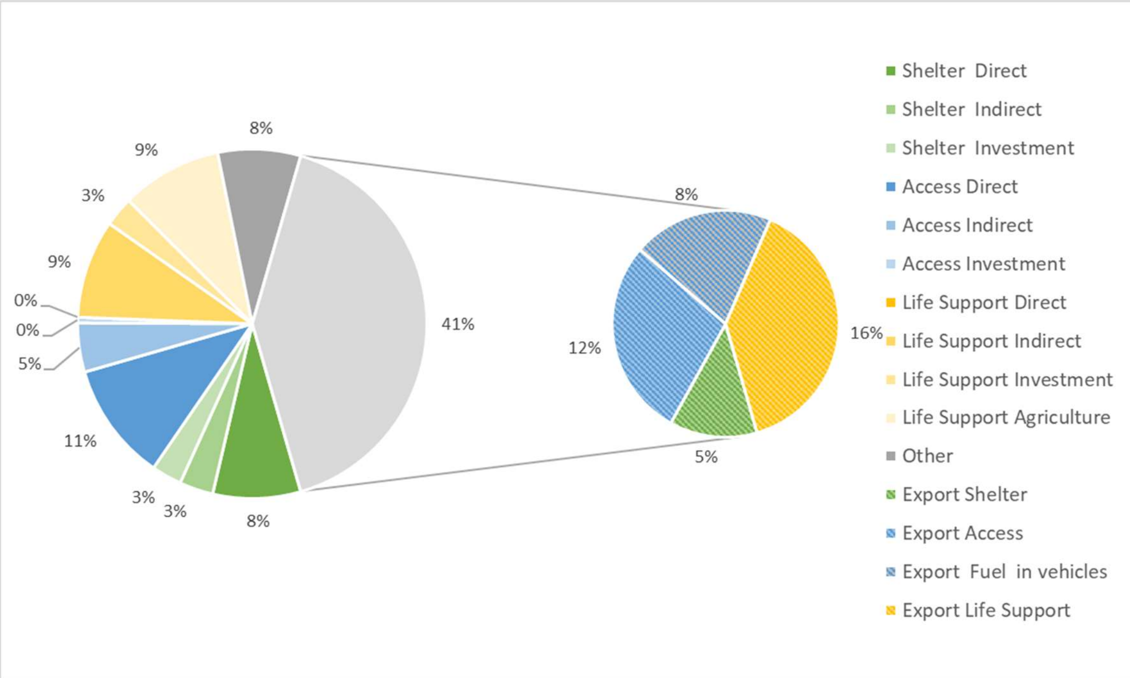

Figure 14: Allocation of emissions per functionality in 2014 (Direct, Indirect, Investment related)

The method to derive the emissions per functionality and satisfier is outlined in detail in Econ-Trans WP#3 (Sommer et al. 2021). Here we examine emissions determined by the provision of functionalities for scenarios until 2050. The starting point for the simulations is the base year 2014. Figure 14 shows the allocation of GHG emissions in 2014 with respect to the functionalities and shows which emissions are covered by the scenario assumptions.

This figure clarifies the importance of the international development for Austria as a small open economy and Austria's emissions. Over 40% of the 76 Mio.t GHG emissions in 2014 are related to export activities and fuel export in fuel tanks of cars and trucks which account for 8% or 6 Mio.t CO_2e in 2014.[7] Because of the single-country perspective of the Core Model, it is not possible to detail the use of the exported commodities in the importing countries, i.e. for which functionality they serve abroad. This is beyond the scope of this project. Therefore, a simplified assumption has been made, namely that exported commodities are used for the satisfaction of the same functionality as in Austria to allow the estimation of a probable distribution of emissions. Nevertheless, one has to keep in mind, that this allocation of emissions from export is rather uncertain. This results in 12% of Austria's emissions that are linked to the satisfaction of the functionality Access in other countries, 5% for Shelter and 16% for Other Life Support. This seemingly high proportion of emissions related to the export of commodities for the functionality Life Support stems from two main sources. First the export of steel for buildings and structures.[8] In other words, the exported steel that might be used for the satisfaction of Other Life Support causes emissions in Austria. The second source is surprisingly road transport. According to the

[7] This number is based on (Umweltbundesamt, 2016b) and integrated in the Core Model.

[8] Such Non-building structures are for instance wind power towers, electricity or telecommunication infrastructure, metal silos etc.

calculations with the Core Model, about 1.6 Mio.t CO_2e emitted are caused by the export of commodities that are used for Other life support in other countries. In other words, in its upstream production of export commodities, transport services from producer to manufacturing and to wholesale are necessary. These transport services, necessary to produce and transport the products to the border contributes to the functionality related emissions.[9] Details on the attribution of emissions to the respective functionalities can be found in EconTrans WP#3 (Sommer et al., 2021).

Of the remaining emissions about 8% (grey in area Figure 14) could not be allocated[10] to a functionality and are kept constant for the period until 2050. 51% are related to the domestic satisfaction of functionalities, directly, indirectly and via the investments necessary. The two functionalities, Shelter and Access, and their direct emissions are the main focus of this analysis. Both sum up to 30% of Austria's GHG emissions in 2014, or about 23 Mio.t. CO_2e. Other emissions are either kept constant or change according to the population or export growth as explained in the following chapter.

3.2.1 General developments

The scenarios for Shelter, Access and their direct emissions are outlined in detail in Appendix A. Besides the specific scenario assumptions six identical developments are assumed in both scenario simulations (AUTO and TARGET) within the Core Model.

1. Autonomous energy efficiency
2. Autonomous material efficiency
3. 100% renewable electricity generation in 2030
4. Phase out of heating-oil based heating systems
5. Export grow at rate of 1.5%
6. Export of gasoline and diesel in vehicle tank is connected to domestic use

First, an autonomous energy efficiency improvement is set for all producing sectors. I.e. energy demand per unit of output decreases by 1% p.a.. Second, the same efficiency gain is applied for material efficiency of metals[11] and minerals.[12] Third, the achievement of 100% renewable electricity in 2030. I.e. in 2030 no fossil fuels are used in powerplants to produce electricity. It is assumed that electricity is provided by wind power and PV. Electricity supply as a by-product in steel production (which stays coal based) does not change. The fourth assumption implemented is to the exit from oil-based heating systems until 2035, as announced by the Austrian

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[9] As described in EconTrans WP#3 (Sommer et al., 2021), the functionality Access describes the access to persons, goods, services and locations. This does not cover the entire volume of transport services. For instance, the transport of fruits from farmers to a wholesaler or retailer, is at this stage part of Other Life Support whereas the mobility required by a person to get to the store is part of Access.

[10] Mainly Non-CO2 Emissions except emissions from agriculture. Largest contributing categories are "Product Uses as Substitutes for ODS" with 1.6 Mio.t CO2e and "Solid Waste disposal" with 1.4 Mio.t. CO2

[11] Inputs of commodity CPA 24 "metals"

[12] Inputs of commodities CPA 23 "glass an minerals"

government. The fifth development assumption is that exports are growing faster than the domestic population and is set to 1.5% in real terms. The last assumption concerns export of transport fuels in the tank of vehicles. Here we assume that, if domestic consumption of gasoline and diesel decreases due to an increase of electric driven vehicles, this development can also be assumed for our neighbour countries. Hence the fuel export decreases in line with reduced fuel demand in Austria.

3.2.2 Emissions relating to Shelter

GHG emissions related to Shelter in 2014 amount to over 14 Mio.t. CO_2e. About half of these emissions are emitted directly by fuel combustion for room heating and hot water. About half of the 2.3 Mio.t. indirect emission are related to the energy demand of district heating and electricity. Emissions from power plants and heat plants that provide district heat or electricity for housholds are reflected in these indirect effects. The other half of indirect emissions comprise emissions that stem from the production of commodities that are needed for the functionality Shelter. These are commodities and services for maintenance or equipment of buildings (tiles, glass, furniture, cement for renovation). About 4 Mio.t. CO_2e of domestic emissions are related to exported commodities that might be used for satisfying the functionality Shelter. Since export grows and no assumptions on Austria's production technologies are set, but energy efficiency improvements are assumed, these emissions stay stable. The development of emissions until 2050 related to Shelter in the scenario TARGET are displayed on Figure 15. The dotted line represents the level in the AUTO scenario.

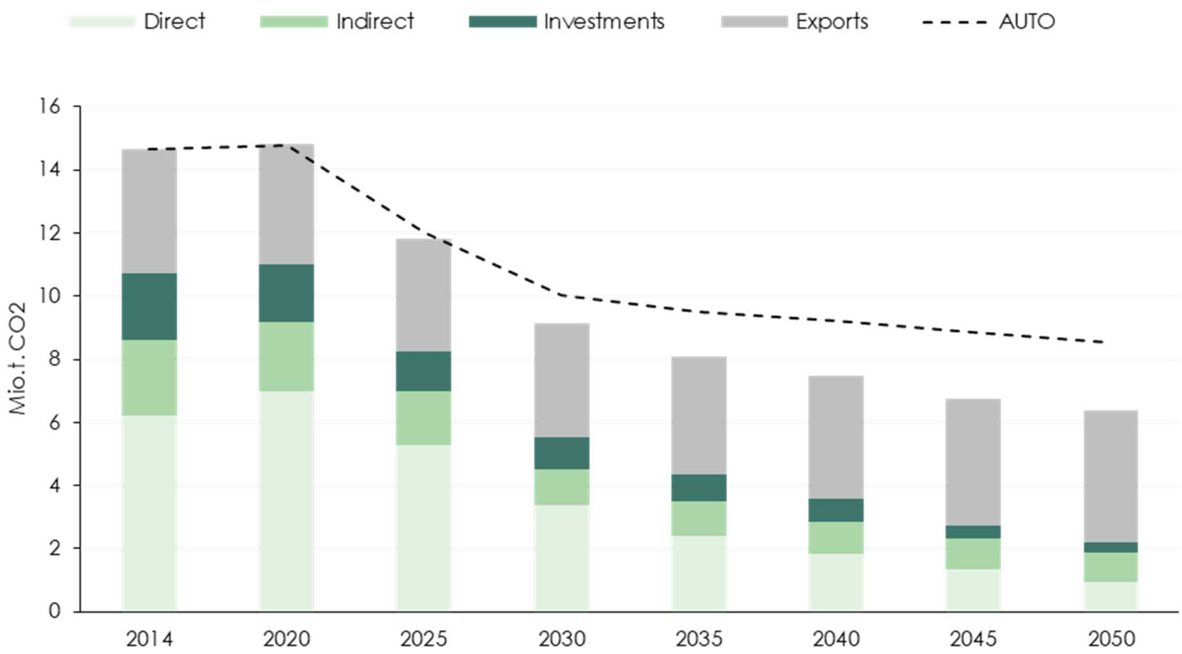

Figure 15: CO_2 Emissions 2014-2050 realted to Shelter (Core Model)

Based on the scenario definitions the direct emissions of Shelter (light green in Figure 15) decrease sharply. This is due to three developments in both scenarios, AUTO and TARGET. First the depreciation of the old building stock and replacement by energy efficient buildings. Second, the phase-out of fossil-oil based heating systems. Indirect emissions decrease due to the assumption of 100% renewable electricity. The remaining indirect emissions are caused by heating plants for which the same fuel mix as in 2014 is maintained. The share of export related emissions from the functionality Shelter stays constant. Emissions in TARGET decrease stronger compared to AUTO due to the assumption that less space per capita is needed to be built, a higher energy standard for new buildings is realized, higher refurbishment rates for the existing stock and less concrete due to more wood-based structures are achieved. All these developments and measures lead to a decrease in direct and indirect emissions for Shelter from almost 11 Mio.t. CO_2e in 2014 to about 2 Mio.t. CO_2e in 2050.

3.2.3 Emissions relating to Access

Emissions to satisfy the functionality Access amount to over 27 Mio.t. CO_2e in 2014. Direct emissions from the combustion in fossil fuel powered engines in private vehicles contribute 6 Mio.t. CO_2e. Indirect emissions of almost 3.5 Mio.t. CO_2e comprise emissions from public transport and emissions in the oil refinery industry that produces gasoline and Diesel. The emissions from car manufacturing would be also attributed to indirect emissions, but since cars purchased in Austria are mainly imported, these emissions do not appear in the Austrian emissions inventory. Emissions caused by investment activities related to Access are relatively small (0.4 Mio.t.CO_2e). Export related emissions with 15 Mio.t. CO_2e make up the bulk of the Access-related emissions and stem from two main sources. On the one hand export of fuels in the tank of vehicles (6

Mio.t. CO_2e). On the other hand, export of steel for the construction of transport infrastructure such as rails. According to the Input-Output-Tables for Austria for 2014, the majority of the domestic use of products "CPA 24 – basic metals", which comprises steel, is used as investment of the sectors NACE49 to 52 which are related to transport services. In this analysis we assume that exported metals are used for the same functionality. Hence a substantial amount of emissions from steel production is allocated to exports for Access. The development of emissions related to Access in the scenario TARGET are displayed on Figure 16. The dotted line represents the level in the AUTO scenario.

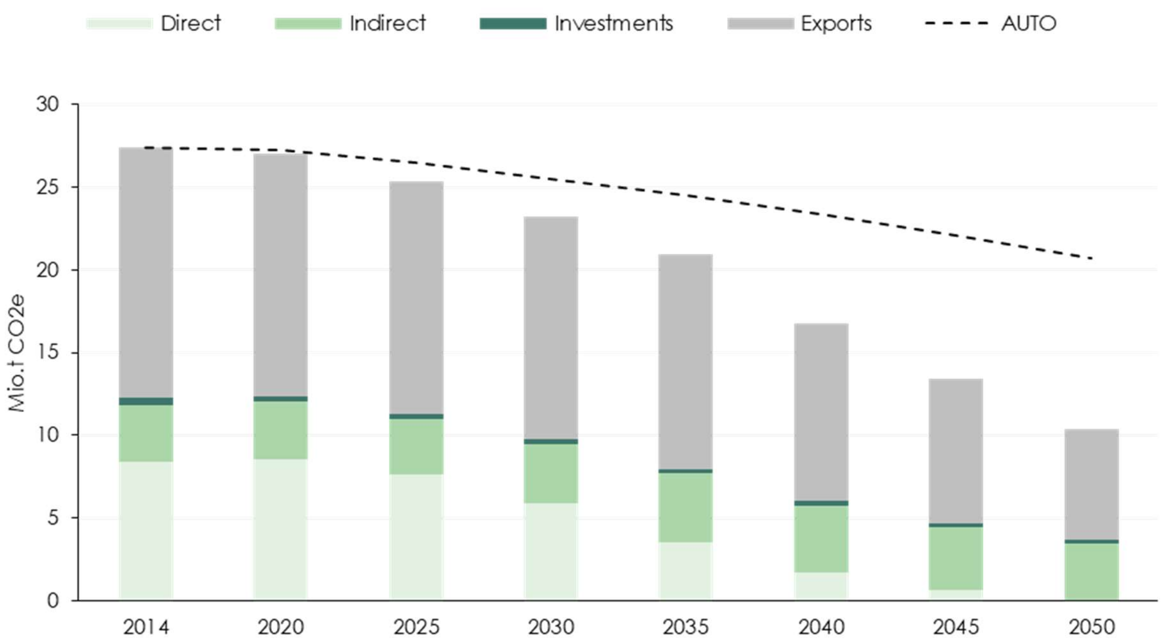

Figure 16: CO_2 Emissions 2014-2050 realted to Access (Core Model)

Since in TARGET the breakthrough of electro-mobility is assumed and also much of MIT can be avoided, the direct emissions decrease to zero by 2050. Indirect emissions increase because in TARGET a strong shift towards public transport is assumed (see Appendix A for details), but no low-emission-technology assumptions are made for vehicles for public transport. This means that public transport is still fuelled with Diesel which is translates into an increase of indirect emissions. Export related emission decrease according to the assumption that the diffusion of e-mobility in foreign countries is similar to Austria, hence fuel export in vehicle tanks decreases. For other export related emissions no scenario assumptions are made. They thus stay relatively constant until 2050.

In the AUTO scenario fossil fuel driven vehicles are not phased out, and consequently emissions decrease less than in TARGET.

3.2.4 Emissions from the functionality Other Life support

Emissions apart from Access and Shelter are summarized in Other Life Support and amount to over 28 Mio.t. CO_2e. This comprises emissions from the production and provision of food, education, health, and recreation as well as the linked infrastructure. No fuels are directly combusted to satisfy this functionality, therefore the direct emissions are zero. Indirect emissions amount up to 7 Mio.t. CO_2e and reflect the energy and material needed to provide the services, products and the infrastructure. In 2014 over 7 Mio.t. CO_2e are cause by the sector agriculture which is allocated to the functionality Other Life Support. Over 12 Mio.t. CO_2e emission are linked to exports that satisfy Other Life Support abroad. As mentioned above, this mainly comprises emissions from steel production and up-stream transport services for the exported commodities. The development of emissions related to the functionality Other Life Support in the scenario TARGET are displayed on Figure 17. The dotted line represents the level in the AUTO scenario. One has to keep in mind, that at this stage of research this functionality is a very aggregated residual category for which no specific scenario assumptions have been made. Thus, the results do not express a potential contribution to long term emission reductions.

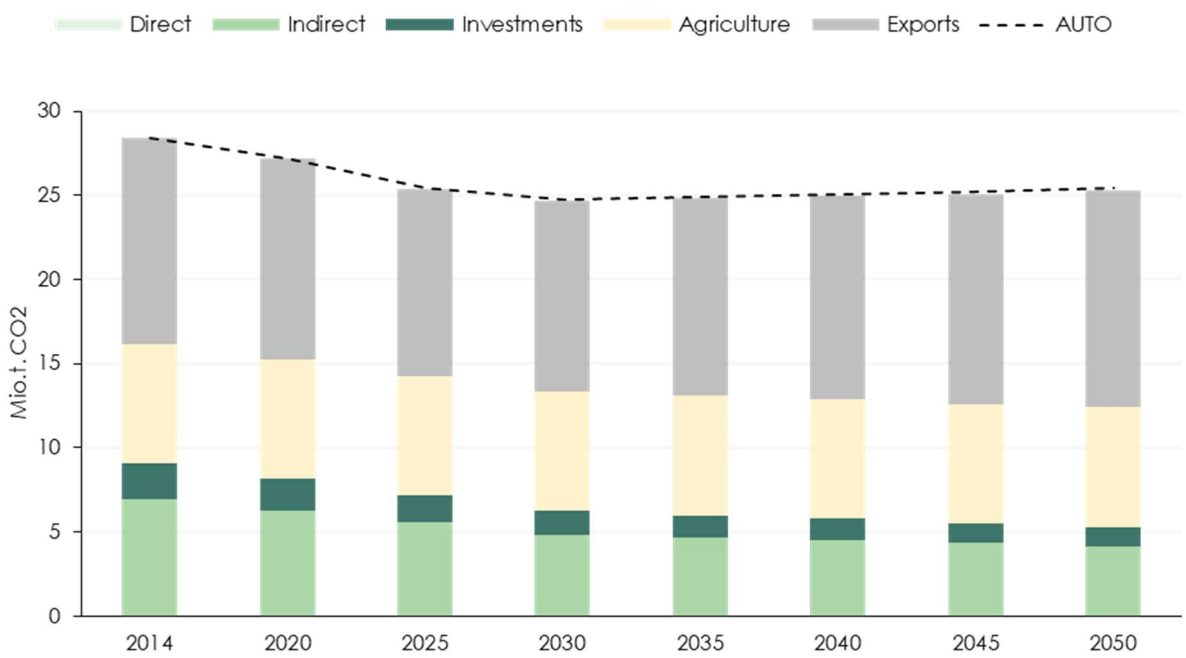

Figure 17: CO_2 Emissions 2014-2050 realted to Other Life Support (Core Model)

3.2.5 Total GHG Emissions

The analysis of the two scenarios, AUTO and TARGET, focuses on the direct and indirect emissions of the functionalities Shelter and Access. These two sub-categories of the entire economy and emission inventory cover 23 Mio.t. CO_2e (excluding fuel export) in 2014. Figure 18 illustrates this in form of the green and blue areas at the bottom of the bars. The implementation of the scenarios in the Core Model shows that the direct and indirect emissions of these two functionalities decrease by 75% to less than 6 Mio.t.CO_2e. The remaining emissions in 2050 stem mainly from public transport and natural gas-based heating systems. In the AUTO scenario the emission from Shelter and Access decrease also substantially by 40% to 14 Mio.t.CO_2e in 2014.

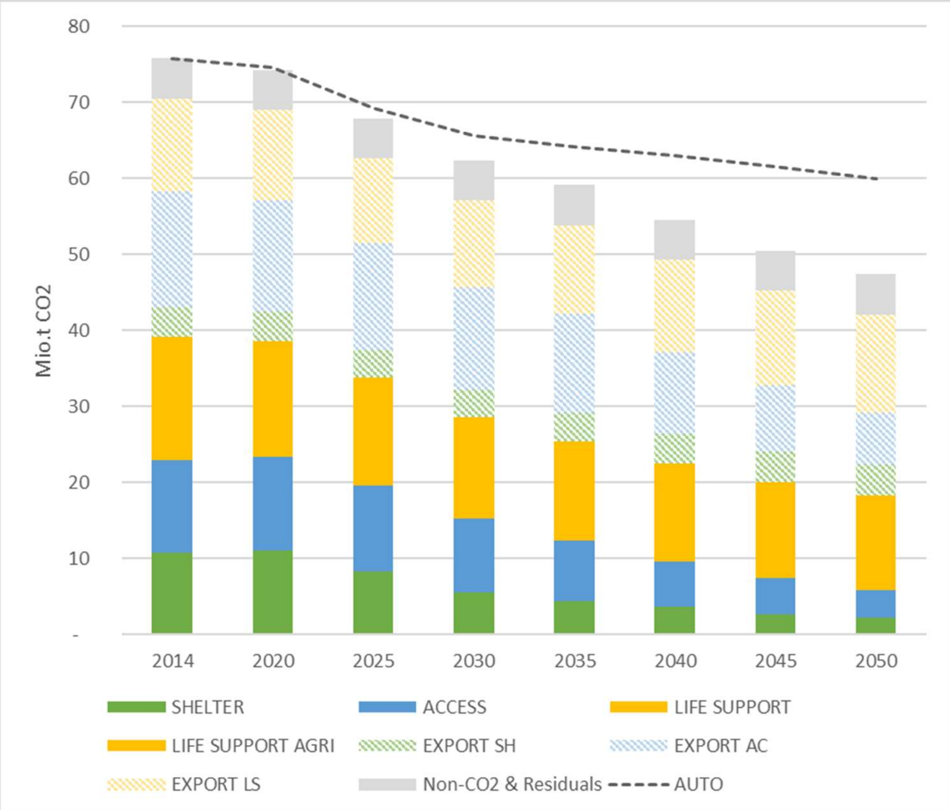

Figure 18: Total GHG Emissions by functionality from 2014 to 2050 (note that only for Access and Shelter assumptions for a climate neutral transformation have been implemented)

Figure 18 illustrates that the changes assumed in the structure (stocks, flows) of providing the functionalities has a substantial effect on Austria's GHG emissions. Nevertheless, one must keep in mind that for a small open economy as Austria, a considerable part of emissions is linked to international trade and thus is not attributable to emissions from satisfying domestic functionalities. Emissions from imports that contribute to the provision of domestic functionalities on the other hand are not accounted for in the Austrian emissions inventory. Attributing emissions to functionalities, however, is useful as it illustrates the relevance of an integrated view on stocks and flows for emission outcomes.

4. Analysis with the Extended Model

4.1 The Extended Model

4.1.1 General model description

The Extended Model refines certain features of the Core Model by adding restrictions and changing assumptions with respect to the behaviour of economic agents, i.e. transforms the model into a computable general equilibrium (CGE) model. The objective is deriving economy-wide feedback effects from changes in the provision of respective functionalities. To this end, the Extended Model adds two key features: First, restrictions in factor supply are set by endowing the model agents with scarce production factors capital and labour, which in turn mirrors income restrictions. This restriction in the availability of production factors is crucial, since it implies that the model is closed and that neither value nor product can appear out of nowhere (Sue Wing, 2004). This feature is especially important when it comes to the modelling of investments as it means that additional investment either replaces other investment or is financed by higher savings (i.e. lower consumption). Second, relative price mechanisms on goods/services and factor markets are added, i.e. prices are flexible and driven by supply-demand interaction. On top, the Extended Model allows exploring distributional impacts. For this purpose, we build on the small open economy CGE model for Austria (see Mayer et al. (2021)) and improve the model's structure to account for an explicit representation of the functionalities 'Shelter' and 'Access' and its stock-flow interactions.

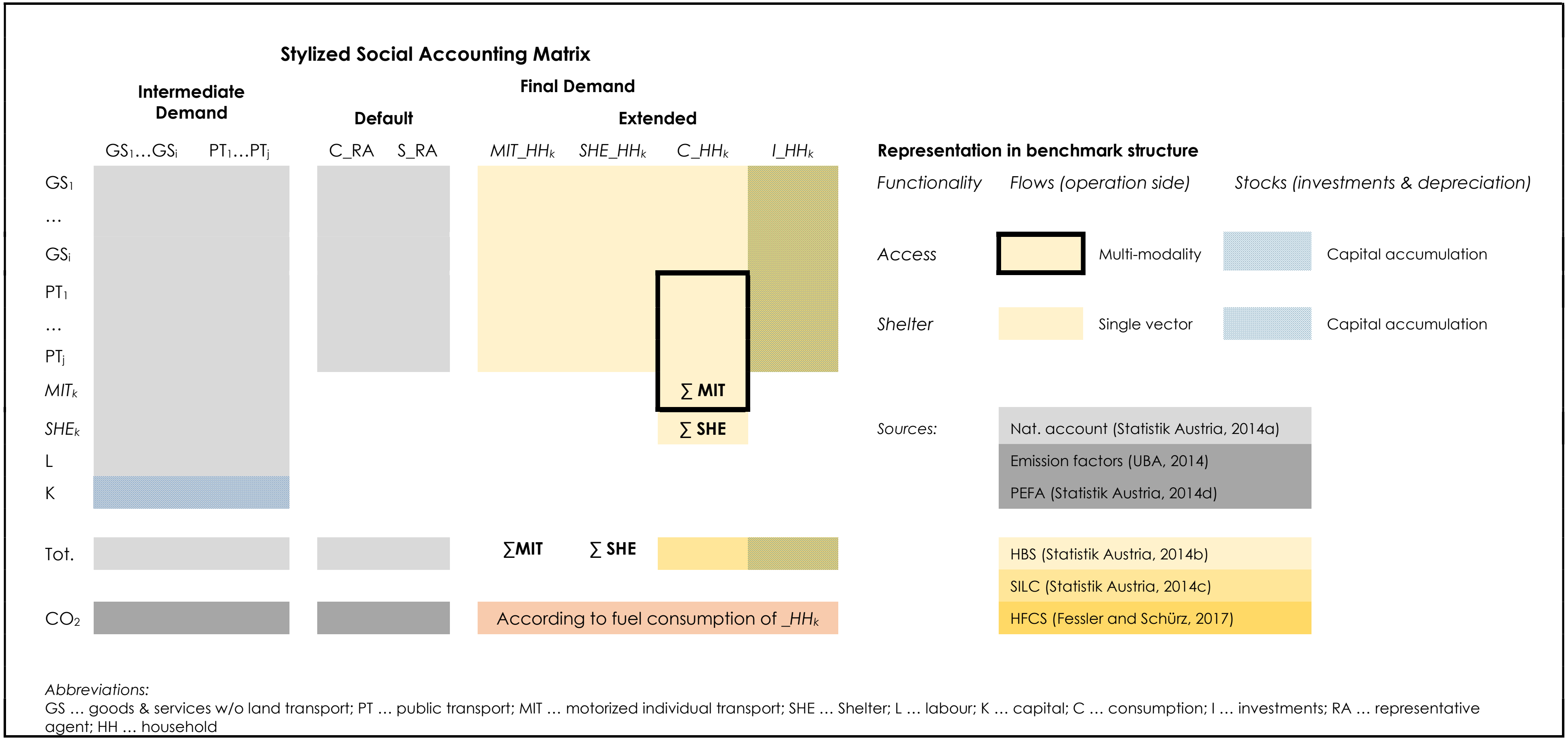

Figure 19: Stylized SAM with extended final demand and its explicit representation of the flows and stocks of 'Shelter' and 'Access'.

Final demand of the default social accounting matrix (SAM) of the CGE model comprises two columns for the domestic private representative agent as shown in Figure 19. These vectors represent the expenditures for bundles of goods and services GS_i for consumption of the representative agents (*C_RA*) and investments (*I_RA*) taken from national accounts statistics provided by Statistics Austria (2014a). Total expenditures match with total income, implicitly showing a top-down savings rate for the whole economy. Combining carbon dioxide emission factors of UBA (2014) and the physical energy flow analysis of Statistik Austria (2014d) links emission intensities with demand, hence emissions that occur directly at the stage of producing and consuming goods and services.

The extended SAM is a core development, which disaggregates (i) the representative agent into twelve groups of households HH_k (k=1,…,12) and (ii) the expenditures satisfying the functionalities Access and Shelter into the structure of the benchmark year. Households are differentiated by four income quartiles and three locations of residence (urban, suburban, rural). This disaggregation is done by matching distributional data by income source (Statistik Austria, 2014c) with fine-grained data of the consumer survey (Statistik Austria, 2014b) and savings (Fessler and Schürz, 2017). Based on household-specific vectors of consumption C_HH_k and investments I_HH_k, we extract from the former household expenditure for motorized individual transport *MIT* (which covers car purchase and operating expenditures) and Shelter *SHE* using also the consumer survey of Statistik Austria (2014b). While a single vector represents the explicit monetary flows of Shelter, the benchmark functionality of Access covers multi-modality flows i.e. the status quo satisfiers. Next to *MIT*, it is public transport *PT* that is relevant in the benchmark structure. Details of extracting passenger-related public transport (rail, road and city) from OENACE sector 49 (land transport) and sectors H52-53 (warehousing and support for transportation) of the national accounts statistics are given in Dugan et al. (2020) and Bachner (2017), which is complemented by data from EUROSTAT (2021a) as well as data from annual reports of transport companies in Austria. Finally, carbon dioxide emissions of the default SAM are allocated to the columns of the extended SAM according to the fuel consumption of household expenditure.

Due to data limitations, other satisfiers of Access such as active mobility (i.e. cycling, walking) do not show up in the extended SAM explicitly.[13] We nevertheless account for them from a physical (i.e. distance measured in person-km) perspective affecting the input parameters of the Extended Model as well as output variables such as household's welfare through non-market based evaluation techniques (see Section 2.3.4 on co-benefits). Further relevant satisfiers for Access are, for instance, information and telecommunication technologies ('avoidance'), shared/micro mobility ('shift') and e-mobility ('improve'), which we take into account in our scenarios but omit in its representation in Figure 19 for ease of exposition.

[13] Representing expenses for shoes for modal split walking and purchase of bicycles could be included in future extensions, but are a relative minor cost component compared to other satisfiers of Access in our scenarios.

Hence, the Extended Model takes up radical structural changes for satisfying the functionalities Access and Shelter and explores the impact on emissions and socio-economic implications including macroeconomic feedbacks. This is achieved by enforced structural changes steering fixed-coefficient (Leontief) functions representing the individual satisfiers of functionalities. Hence, the structural changes of Access and Shelter at the final demand side is not induced by a relative-price or equilibrium mechanism. These are only implemented for the remaining intermediate and foreign supply-demand relations to fulfil the outlined objective for the Extended Model, which is complementing the features of the Core Model.

Another crucial methodological development compared to "conventional" macroeconomic models is the linking of flows to respective stocks. The EconTrans framework not only looks at the quantitative evolution of stocks (and its effects on future flows via annual investments and depreciation) but also puts emphasis on the (particularly environmental) quality of stocks (and thus future flows). Using spreadsheet tools, we connect time-series of capital stocks (vehicles such as e-cars or buildings), with the respective flows of satisfiers (investments and depreciation over respective life-times as well as operating expenditure).

Note that the AUTO scenario in the Extended Model is calibrated to 1.5% annual GDP growth, which is composed by (working age) population growth, 1% annual labour productivity growth, 1.5% annual autonomous energy efficiency improvements, as well as total factor productivity growth (which is determined endogenously in the model calibration such that target GDP growth of 1.5% is met). Capital stock depreciation is set to 5% annually. In addition, we assume a modest CO_2 pricing of 20 EUR/tCO_2 in 2020 rising linearly to 50 EUR/tCO_2 by 2050 (on top of existing excise duties on fossil fuel use)[14].

4.1.2 Implementation of scenarios in the Extended Model

The general aim of the analysis is to replace certain satisfiers for functionality fulfilment by climate neutral ones, while at the same time holding the level of the functionality constant. In terms of the presented scenarios this means that in the TARGET scenario the structures for the provision of the functionalities Shelter and Access are explicitly changed, however functionalities are implicitly served at the same level than in the AUTO scenario.

[14] Note that this applies for EU ETS and non-ETS CO_2 prices in the Extended Model. The reasons for implementing such moderate CO_2 pricing, and not a different e.g. steeper development over time, are threefold. First, our focus is on functionality fulfilment and not on the effectiveness of market-based instruments. Second, the evolution of CO_2 prices depends on many aspects, which are not in the scope of this analysis. For instance, CO_2 prices for EU ETS sectors depend *inter alia* on the reduction factor of the overall cap, adjustments via the EU Market Stability Reserve and the speed of abatement in EU ETS sectors outside Austria. We are however aware that the current EU ETS price already reached a level of about 50 EUR/tCO_2. For Austrian non-ETS sectors, a tax reform is discussed in the policy sphere, but details are pending. This leaves chosen CO_2 price paths arbitrary. However, and the most relevant third reason for its explicit incorporation, that producers and consumer will face some CO_2 price signal in the future is more plausible than otherwise. Although arbitrary, we report here our assumption for transparency. For the scenario comparison between AUTO and TARGET, the assumed prices are less relevant, because they are kept at the same level.

Based on the developed scenario inputs for Shelter and Access, four different system interventions are implemented in the Extended Model. Each intervention can be interpreted as a separate policy shock that exogenously imposes the respective change into the economic system. Taken together, the following four policy shocks represent the full transformation of functionality fulfilment in terms of macroeconomic modelling:

(i) electrification of MIT ('improve') and lower MIT demand compared to AUTO ('avoid'), but without a switch to public/shared transportation,

(ii) switch from MIT to public/shared transportation and active mobility ('shift') and a lower overall transport demand ('avoid'), but no electrification of MIT

(iii) electrification ('shift') of overall lower heating demand due to accelerated refurbishments, stricter buildings standards ('avoid') and 'Superblocks/quarters' ('improve'), and

(iv) forced additional investments associated with the changes in functionality fulfilment at the expense of private consumption (increased savings).

For the interpretation of results, it is useful to think about the expected effects of each of these aspects in isolation. We expect the following isolated macroeconomic effects of these policy shocks. For policy shock (i), electric vehicles are advantageous compared to internal combustion engine cars particularly with high utilization rates due to their higher round-trip efficiency and thus lower required operating expenses. However, the 'avoid' component in the TARGET scenario is so strong, that eventually the expenditure share for e-mobility in consumption is below the AUTO level, which in turn lowers overall system productivity. Thus, GDP is affected negatively. For policy shock (ii), no direct productivity changes are implemented as only the composition of final demand is changed, which would result in a neutral effect on GDP. However, due to indirect effects GDP can be affected either positively or negatively. With policy shock (iii), GDP is eventually affected negatively because lower energy expenses for overall lower heating demand are dominated by higher (actual and imputed) rents on housing. Finally, policy shock (iv) is expected to be GDP-neutral when only direct (within-year) effects are taken into account, as additional investments are financed at the expense of private consumption (higher savings). In the long-term, however, a higher level of investment leads to stronger capital accumulation, a larger capital stock and thus higher GDP.

4.2 Results from the Extended Model

4.2.1 Traditional evaluation perspective

As mentioned, GDP growth in the AUTO scenario is calibrated to 1.5% p.a. until 2050, reaching an absolute GDP level of around 570 billion EUR.[15] With the deep structural changes in functionalities Access and Shelter in the TARGET scenario, the average annual GDP growth rate rises slightly to 1.52% p.a.. Thus, in 2050 the level effect on GDP equals +0.9% or around +5 .billion EUR. This modest increase in GDP can be explained by stronger capital accumulation due to higher investment which is triggered when switching to the TARGET scenario. Taking stock of our prior expectations of effects originating from individually implemented policy shocks (i) to (iv), we trace back this economy-wide increase in GDP (economy-wide income) as follows. With radical shifts from MIT to public/shared transportation and active mobility (policy shock ii), capital rents are rising because the provision of public/shared transportation is more capital-intensive than for other goods and services, which is an indirect effect of the intervention. With higher expenses on (actual and imputed) rents for dwellings (policy shock iii), also here capital rents are higher as an indirect effect. On the contrary, policy shock (iv) enforces increased investments rendering capital less scarce and thus taking pressure from the capital market, while increasing relative scarcity of labour. In total, the indirect effects of this last policy shock (iv, increased investment) dominates, leading to stronger economic growth via stronger capital accumulation with more abundant capital and relatively scarce labour.

Figure 20 shows the modest difference in GDP between TARGET and AUTO, decomposed for the income side (left) as well as on the expenditure side (right). Wen looking at the income side effects (left panel in Figure 20), we see that overall, income from labour increases whereas income from capital decreases, which is due to rising wages relative to capital rents as the additional investments render capital more abundant (Figure A 1 in Appendix). Since labour is subject to higher taxes, tax income for the government rises slightly. Looking at the expenditure side of GDP (right panel in Figure 20), we see that higher investments are necessary in the TARGET scenario, particularly in the early phase of restructuring Access and Shelter. As increased investment is driven by higher savings, this leads to less consumption expenditures by private households. However, after around 2040 consumption expenditures of both, private and public households, are higher relative to AUTO. This is explained by the somewhat lower investment demand than in the decades before (but still higher than in AUTO) and at the same time still rising GDP due to stronger capital accumulation.

[15] For easier reproduction and comprehension of identified effects, we also report selected absolute developments of key indices. However, these absolute values should not be interpreted as forecasts but rather as a plausible scenario development.

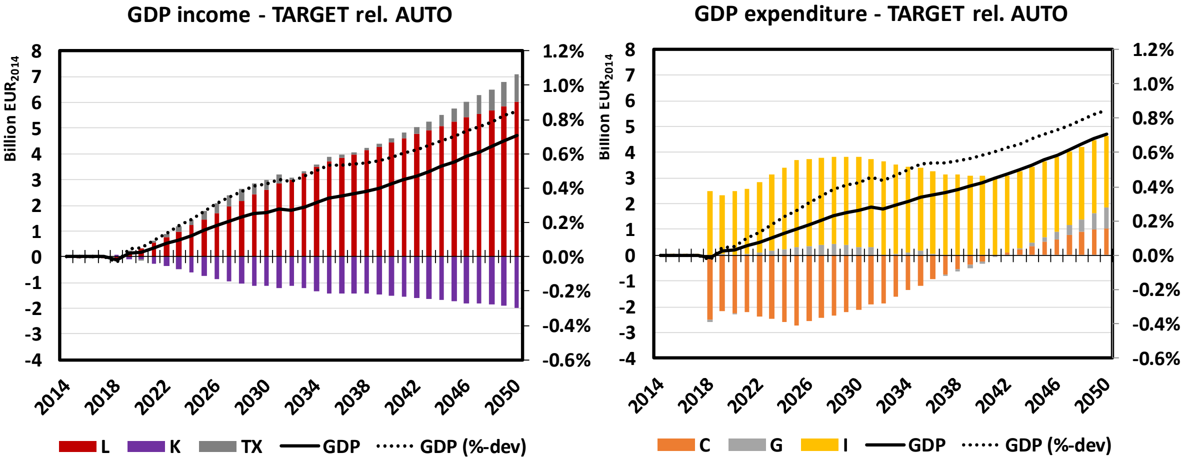

Figure 20: GDP effects in TARGET relative to AUTO. Left: by income, right: by expenditure (L … labour income, K … capital income, TX … tax income, C … private consumption, G … public consumption, I … investments).

Our results show that in the AUTO scenario the implemented abatement measures are insufficient to achieve absolute decoupling of GDP and CO_2 emissions (see Figure 21). In fact, CO_2 emissions further increase by 0.2% annually until 2050. The assumed autonomous e-mobility uptake and moderate mitigation measures in the buildings sector lead to small decreases in non-ETS CO_2 emissions, however, electrification and keeping material-intensive structures (steel, cement) shifts emissions to energy and basic material supply, leading to slightly higher ETS emissions there.[16]

Looking at the TARGET scenario, we show that absolute decoupling of CO_2 emissions and GDP is achievable. This is especially the case for the non-ETS sectors because, first, the TARGET measures 'Avoid', 'Shift' and 'Improve' apply to all relevant satisfiers of Access and Shelter. Second, we observe no substantial sectoral leakage, meaning that abatement in the non-ETS sector is not compensated by additional emissions in the ETS sector. This originates from the perspective on functionalities. For instance, the uptake of e-mobility in TARGET is much stronger in relative terms (100% shift away from conventional cars instead of only a 30% share in AUTO) but smaller in absolute terms because emission intensive physical transport is needed to a lesser extent due to the deep structural changes and a focus on avoidance. This underscores the relevance of the *integration* of the purpose of trips (leisure, school, working, shopping, etc. in "near"-distance environments) in scenario development. Along the whole energy chain starting from functionalities, no additional energy supply is needed for satisfying the functionality,

[16] Note that we deliberately do not assume any substantial additional policies in ETS sectors in order to highlight such shifts. Decarbonization and carbon management in energy and basic material supply is necessary for reaching long-term climate targets, though not the focus here.

which reduces pressure for mitigation efforts in other areas such as (domestic) renewables expansion or electrification of industry. Such structural changes would be additionally required for achieving the Austrian contribution to the target of the Paris Agreement. The levels of CO_2 emissions stemming from Access and Shelter of the TARGET scenario in 2050 are 4 Mt lower than 2014 and 8 Mt lower compared to the level in AUTO 2050.

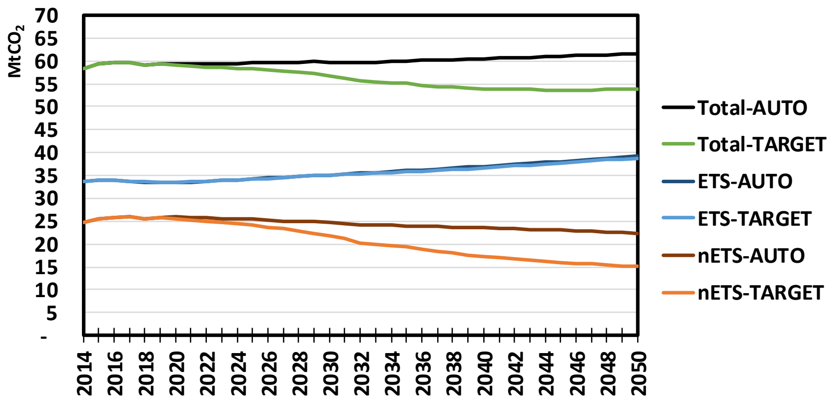

Figure 21: TARGET and AUTO 2014-2050 CO_2 emissions.

In the following we analyse welfare effects. Welfare effects, in the traditional economic perspective, measures the change in consumption possibilities of citizens.[17] We thus measure changes in consumption *quantities* of goods and services without real relative price changes (the product of quantity and price would give the consumption "C" and "G" as given in the decomposition of GDP in Figure 20). Note that we *implicitly* ensure that the same functionality level as in AUTO is achieved in TARGET, however by using different satisfiers, which are *explicitly* measured (e.g. pkm avoided, shifted, or improved). The necessary consumption expenditure to fulfil the functionalities Shelter and Access with this different set of satisfiers are lower in TARGET, and we assume that these savings are compensated by an increase of other generic (i.e. non-Access and non-Shelter) consumption. In isolation this would yield a neutral welfare effect, however there are indirect effects leading to changes in welfare, which we discuss next.

Figure 22 reports the welfare effects of the TARGET scenario relative to AUTO. For the analysis of welfare, we differentiate the impact of private and public consumption quantities, which in total give economy-wide welfare by definition in a CGE context. We see that until around 2030, welfare is lower compared to AUTO, which is mainly driven by lower consumption of the private households, since savings need to be increased in order to finance the higher investment demand of TARGET. Since these savings/investments are assumed to be made by the private sector, there are hardly any effects for government consumption. Starting around 2030 welfare

[17] Also known as Hicks'ian Equivalent Variation (HEV).

effects become positive. This is driven by rising income (GDP) due to stronger investment activity (capital accumulation), setting off the initial negative welfare impacts from increased savings over time.

We see that the total welfare effect follows the change in private consumption quantities (priv-cons-Q), however, there is a negative effect on government consumption. Despite an increase in tax income (see Figure 20), government consumption is below the AUTO level. This is because the price index for the public consumer basket (P-CPI) increases steadily, overcompensating the increase in tax income.[18] The higher P-CPI emerges for two reasons: First, because the wage rate is higher in TARGET and government consumption is relatively labour intensive. Second, because there is an interaction with the consumption demand of private household. Private households have higher income and since functionalities Shelter and Access are met, private households fully use up their higher income and shift consumption to other (non-Access and non-Shelter) goods and services. This leads to competition for similar goods and services between public and private agents. Consequentially, the P-CPI is higher and overall public consumption possibilities (quantities) lower than in AUTO. Note that the price index for the private consumer basket (CPI) keeps falling until 2030 due to lower consumption demand and then starts to rise again due to higher income and respective slowly rising demand for private consumption.

To summarize, after around 2030 the combined effect on private and public consumption possibilities (i.e. welfare) is higher in TARGET than in AUTO. Hence, absolute decoupling of *welfare* and emissions is possible as well with the deep structural changes in the TARGET scenario. Detailed sector turnover and sector emission impacts are shown in Figure A 5 and Figure A 6 in Appendix D.

After having explained the main economic effects from a traditional, rather neoclassical perspective, we now extend our evaluation perspective to a focus on wellbeing rather than GDP and consumption possibilities and explore if further (stronger) emission reductions are possible while not reducing wellbeing.

[18] We assume that transfers from public to private households are kept at the AUTO level, hence in isolation we would expect an increased public budget with higher public consumption.

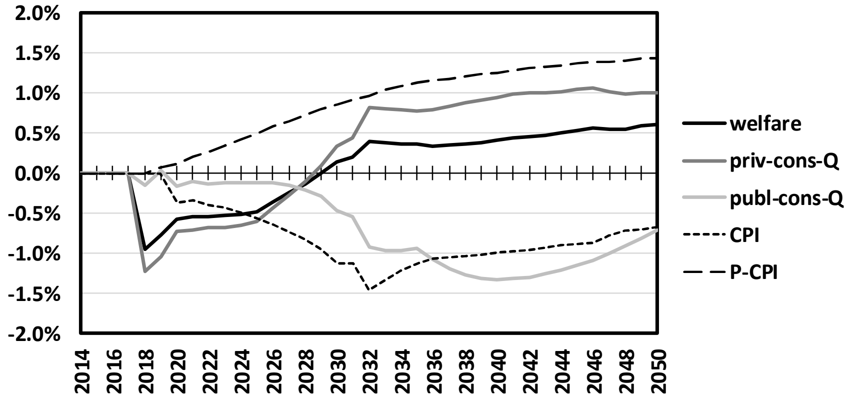

Figure 22: TARGET relative to AUTO 2014-2050 welfare, private and public consumption (priv-cons-Q and publ-cons-Q, respectively) and consumer price indices (CPI and P-CPI for private and public consumer basket, respectively).

4.2.2 Extended evaluation perspective

We build on the findings of WP#1 (Schinko et al., 2021) and define the effects on wellbeing as the sum of welfare effects (private and public consumption possibilities), co-benefits and changes in leisure. We do not claim an all-encompassing monetary measure here, since various amenities are either not convertible to monetary measures or doing so is connected to serious caveats (e.g. fatalities). However, we do offer an illustrative proxy for wellbeing that comes closer to wellbeing compared to what the traditional evaluation perspective (focusing on GDP and welfare) as presented in section 4.2.1 can offer.

The incorporation of co-benefits stems directly from the analysis given in 2.3.4. Note that the specific numbers should serve as indicative lower bound for the very broad concept of co-benefits.

Regarding the effects on leisure, the Extended Model features a labour-leisure trade-off of private households. It can be argued that the choice between leisure and labour (supply) is not exclusively a deliberate decision by Austrian employees but an upper bound for labour supply is given by institutionalized framework conditions imposed by legislation ("Arbeitszeitgesetz"). However, without a labour-leisure trade-off, the model mechanism is thus a traditional neoclassical one, where eventual productivity gains are always remunerated by increases in income, inducing more consumption. This in turn is connected to a carbon footprint and thus rebound effects in terms of CO_2 emissions can emerge. In the extended perspective, we explore an alternative remuneration option of potential increases in income, namely through increased leisure. We assume that private households acknowledge that wellbeing does not exclusively rely on their income and respective consumption and, hence – in the case of potential increases in income – they choose to reduce working hours to keep their utility from consumption constant instead of translating their potentially higher income into increasing consumption. By that, we model the avoidance of potential emission rebounds.[19]

Specifically, the labour-leisure trade-off of each modelled household category is incorporated in the Extended Model as a constraint that guarantees the same level of private consumption as in the AUTO scenario, which is further adjusted for the lower income requirements for functionality fulfilment (slightly higher expenses for Shelter (Figure 4) and strongly lower expenses for Access (Figure 11)), which are induced by the investigated structural changes. This implies an equal experienced utility from consumption in AUTO and TARGET, however at lower monetary consumption expenditures. Representative households, thus, choose to stay fully employed if they were worse off in terms of utility from consumption (but cannot choose to increase labour supply due to institutional constraints) or will decrease working hours if they were able to increase utility from consumption. As we observe positive consumption effects in the conventional evaluation for the year 2050 for all households as well as overall reduced income requirements due to the structural change in Access and Shelter fulfilment, we expect that all households decrease their labour supply. We denote this scenario variant TRGT-LEIS.[20]

Figure 23 gives an overview on aggregate effects in 2050, again for the traditional indicators GDP and welfare, but in addition also effects on wellbeing. The top row gives absolute levels, the bottom row relative effects, for both scenarios TARGET and TRGT-LEIS relative to AUTO. In 2050, GDP in TARGET is +0.8%, welfare is +0.6% and wellbeing is +1.0% higher than in AUTO (dark blue bars in bottom left panel of Figure 23) with national CO_2 emissions lower by -12.6% (bottom right panel). As indicated as a methodological note on uncertainties regarding scenario techniques in Section 2.1, we report not only trend deviations but also absolute values to facilitate the discussion of results. Absolute future levels of GDP, welfare and wellbeing are increasing strongly compared to 2014, irrespective of the scenario, while CO_2 emissions decline resembling absolute decoupling of emissions from economic activity. This absolute decoupling means that the social cost of reducing emissions actually turn into social benefits of around 625 EUR per ton of CO_2 emission reduction in the TARGET scenario (derived by dividing the increase in wellbeing of around 5 billion EUR by 8 $MtCO_2$ emission reduction).

The relative changes in the scenario TRGT-LEIS look different (light blue bars in bottom panels of Figure 23). Here we achieve a larger national emission reduction of additional 3.6%-points compared to TARGET (in total -16.3% compared to AUTO) but at the expense of strongly reduced GDP (-3.8%) and welfare (-5.5%). Hence, further emission reductions based on working

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[19] Note that this rests on the assumption that leisure in itself is not connected with a substantial carbon footprint, which may be true for some leisure activities e.g. playing cards or going for a walk but not for others e.g. tourism.

[20] In the TRGT-LEIS scenario, the labour supply multiplier *lsm* for each household *h* and time period *t* adjusts labour supply taking into account expenses for Access *A*, Shelter *S* and other consumption *W*, as well as lower income requirements *L* compared to the AUTO scenario, whose variables are denoted using upper-bars:

$$lsm_{h,t} = \frac{A_{h,t} + S_{h,t} + W_{h,t}}{\left(\bar{A}_{h,t} + \bar{S}_{h,t} + \bar{W}_{h,t}\right) - L_{h,t}}, lsm_{h,t} \in (0,1)$$

$$L_{h,t} = \left(A_{h,t} + S_{h,t}\right) - \left(\bar{A}_{h,t} + \bar{S}_{h,t}\right)$$

schedule adjustments in the TRGT-LEIS scenario are costly from a traditional evaluation perspective. However, with the extended evaluation perspective, which comprises not only material consumption but also leisure and co-benefits, further emission reductions based on working time reductions are substantially beneficial. Wellbeing is +2.5% higher compared to AUTO resulting in 1,200 EUR higher economy-wide wellbeing per mitigated ton of CO_2 (derived by around 12 Bn. EUR increase in wellbeing over 10 $MtCO_2$ reduction of emissions), almost doubling the effects from the TARGET scenario.

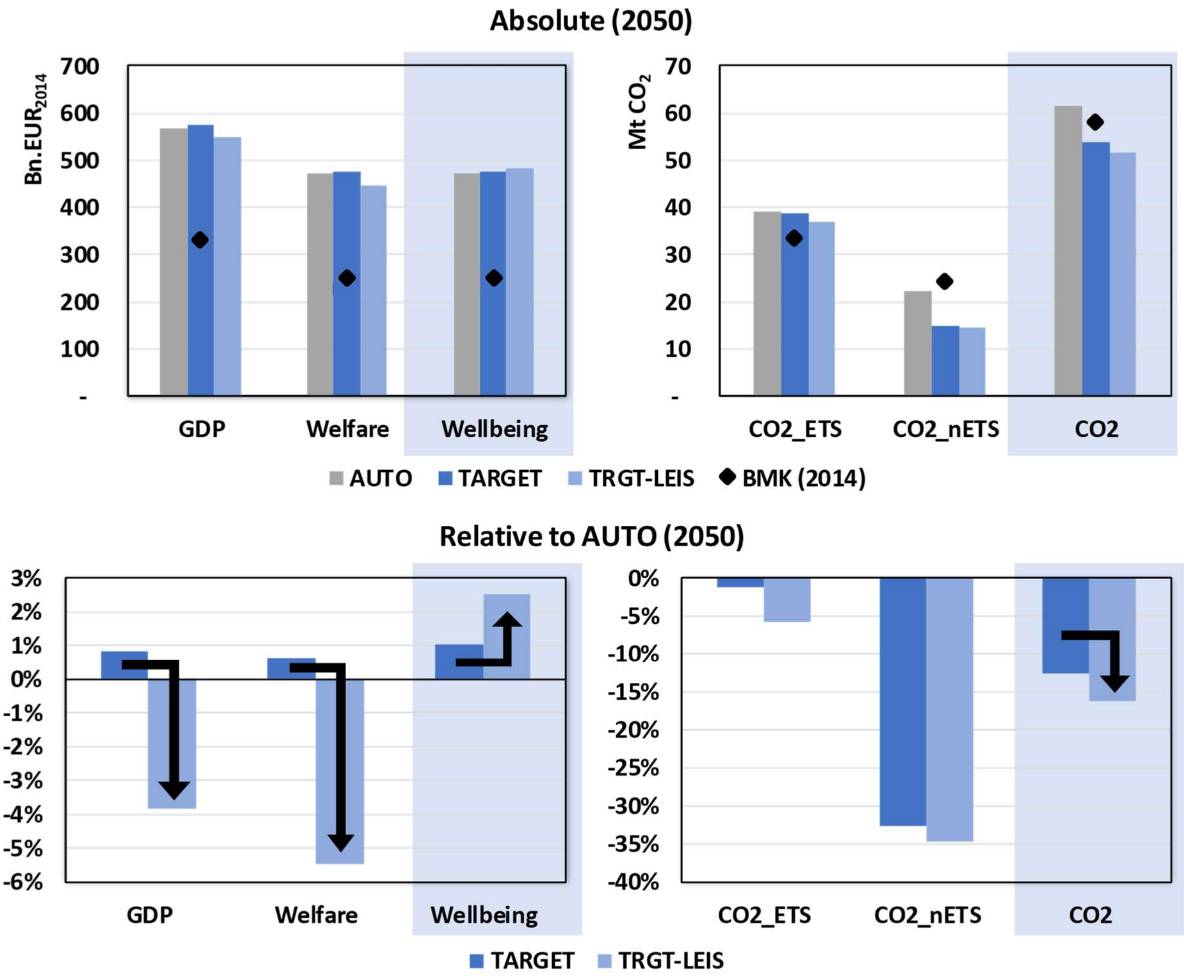

Figure 23: TARGET, TRGT-LEIS and AUTO 2050 GDP, welfare, wellbeing (left) and CO_2 emissions (right).

After having discussed the effects at the macro level, we now take a look at distributional effects. Note that the modelled groups of households are myopic (i.e. bounded rational) and we impose the full labour-leisure trade-off as a rather extreme case, which triggers further indirect effects. Also note, at this stage, that these results are still connected to a state in which Access and Shelter are fully met. This clearly points to the question, whether the traditional view focuses on the most relevant and meaningful (set of) indicator(s) of interest.

In the top panels of Figure 24, distributional effects of income per capita are shown for the traditional perspective (TARGET relative to AUTO). While capital income effects are negative, increased labour income more than compensates these reductions in capital income for all groups of households analysed (with transfers being fixed to the level of the AUTO scenario). Assuming that households opt for a reduction of labour supply (scenario TRGT-LEIS shown in the bottom panels), impacts are more pronounced (cf. different scale of y-axis) and income effects turn negative for Q4 high-income households. This originates from the widening gap between wages and capital rents relative to the TARGET scenario (as labour gets relatively scarce, Figure A 1) paired with these households' larger dependence on capital income (see Figure A 7). This also explains why Q4 high-income households are the only ones choosing to keep full employment (Figure A 2). On average, labour supply is 3.1% lower in TRGT-LEIS than in AUTO. Hence, although the income effect of Q1-Q3 households is positive, Q4 high-income households (as well as the nationally representative agent) are worse off in terms of income due to the indirect effects of the imposed household-specific labour-leisure trade-off.

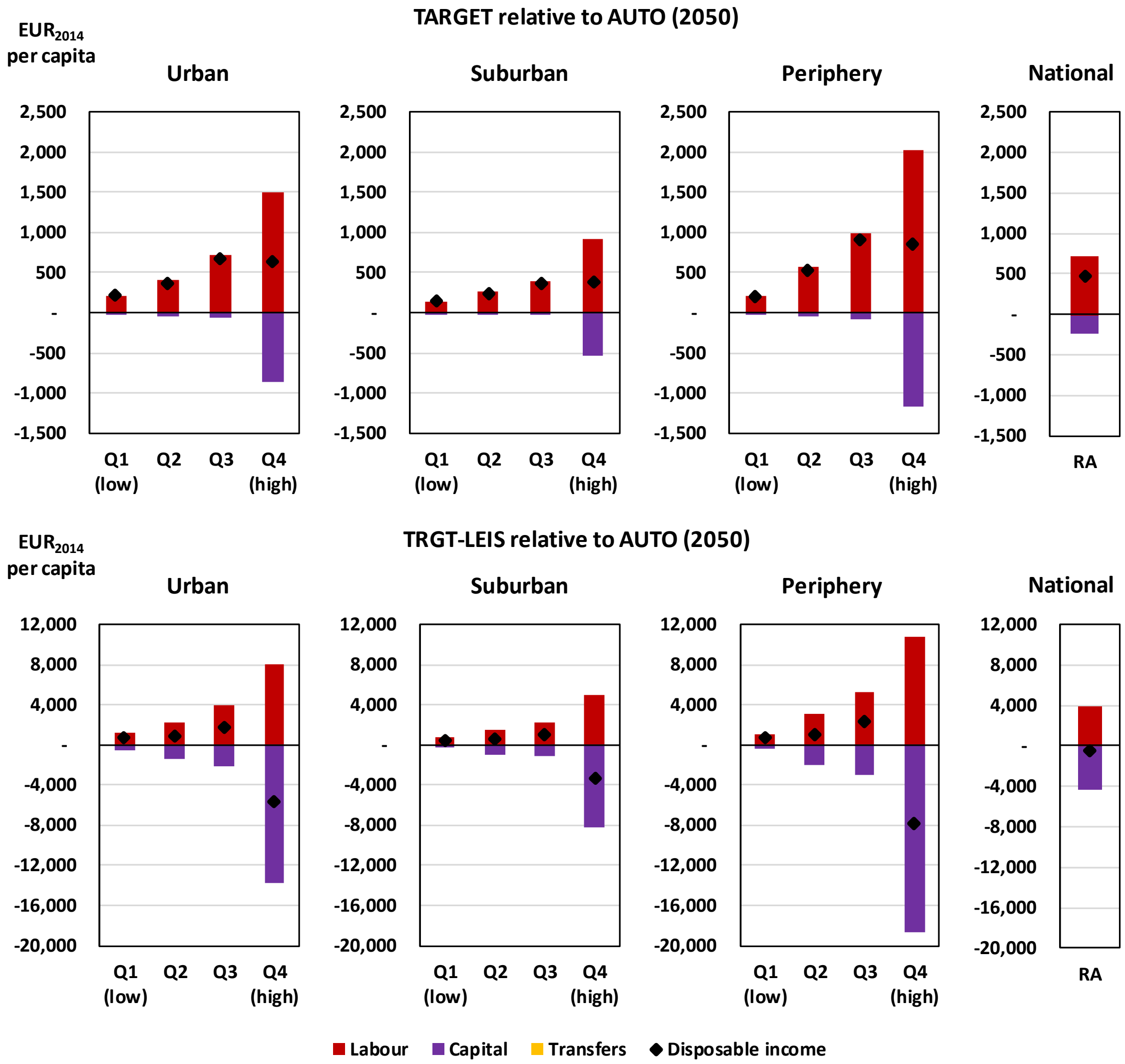

Figure 24: TARGET (top) and TRGT_LEIS (bottom) 2050 distributional impacts by income source.

The identified income effects are translated to private consumption effects (by taking into account changes in the consumer price index (CPI) of households and by subtracting savings from household income). For the TARGET scenario (top panels), income effects are positive for all households with peripheral households benefitting the most in relative terms. Changes in CPI are almost nil for low(er) income households and decline for high(er) income households. Hence, private consumption increases for all household groups. For the TRGT-LEIS scenario (bottom panels), positive income effects for Q1-Q3 households are further amplified (despite a reduction of labour supply), as they benefit from higher wages and their relative higher dependence on labour relative to capital income. However, in this scenario they are compensated via increased leisure. This also implies that the same utility is experienced with much lower monetary expenses. Since a change in welfare in the traditional narrow sense measures the *monetary* change in the utility from consumption *U(C)* associated with changed relative prices, the *experienced* utility needs to be adjusted for this aspect. Put differently, although utility measured in monetary terms declines, the experienced utility from the now lower consumption expenditure remains at the AUTO level. This aspect is shown in the bottom panel of Figure 25 as difference between the green (zero) and yellow bars. This difference is – besides leisure and co-benefits effects – an additional driver of the wedge between welfare and wellbeing. Contrary to Q1-Q3, Q4 high-income households experience strong negative income effects but their experienced utility out of consumption is kept constant due to lower expenditure requirements.

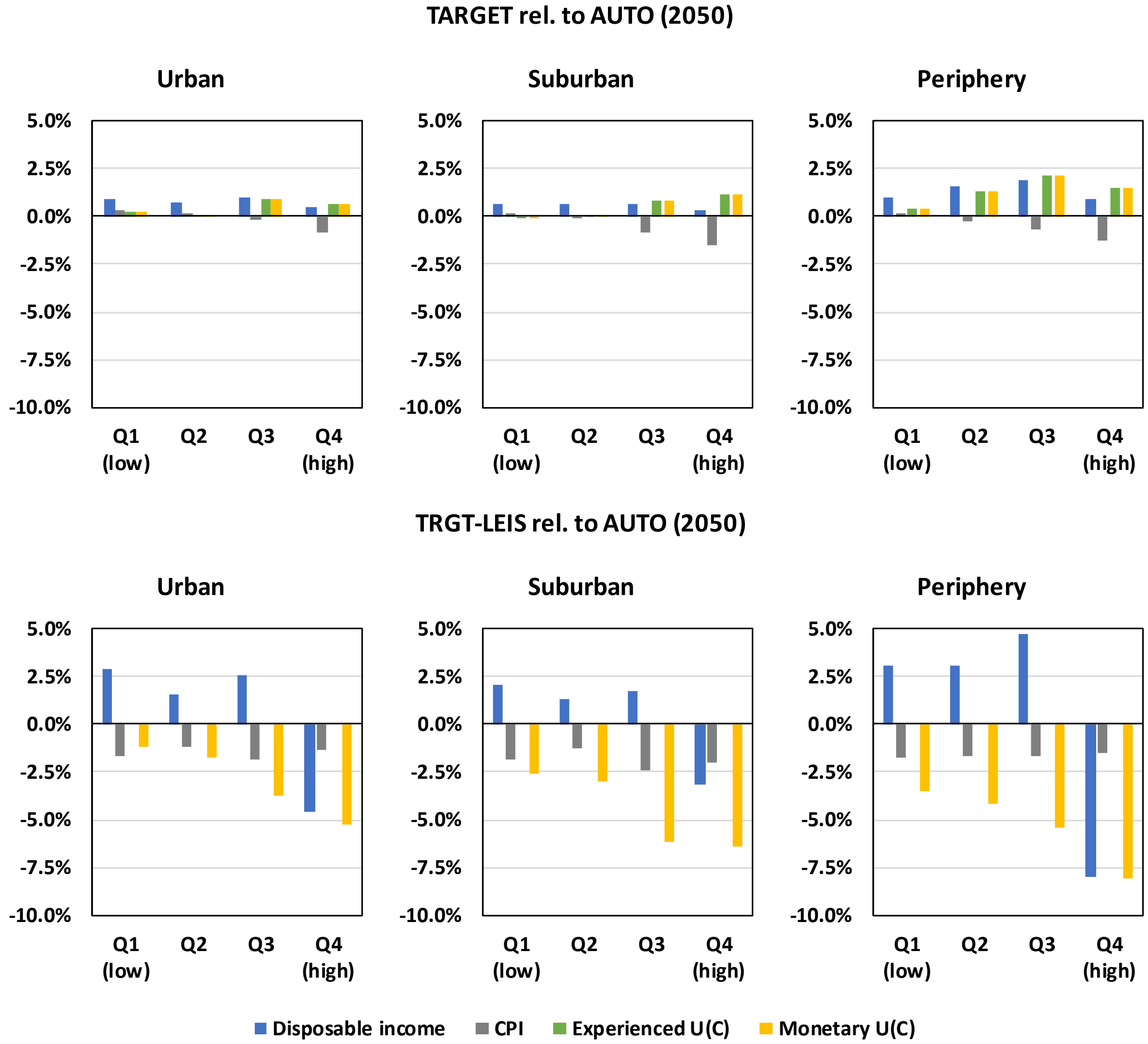

Figure 25: TARGET and TRGT-LEIS relative to AUTO 2050 disposable income, consumer price index, experienced and monetary utility out of private consumption U(C) across households; the experienced U(C) adjusts the monetary U(C) (=HEV) due to constant functionality fulfilment at lower expenses.

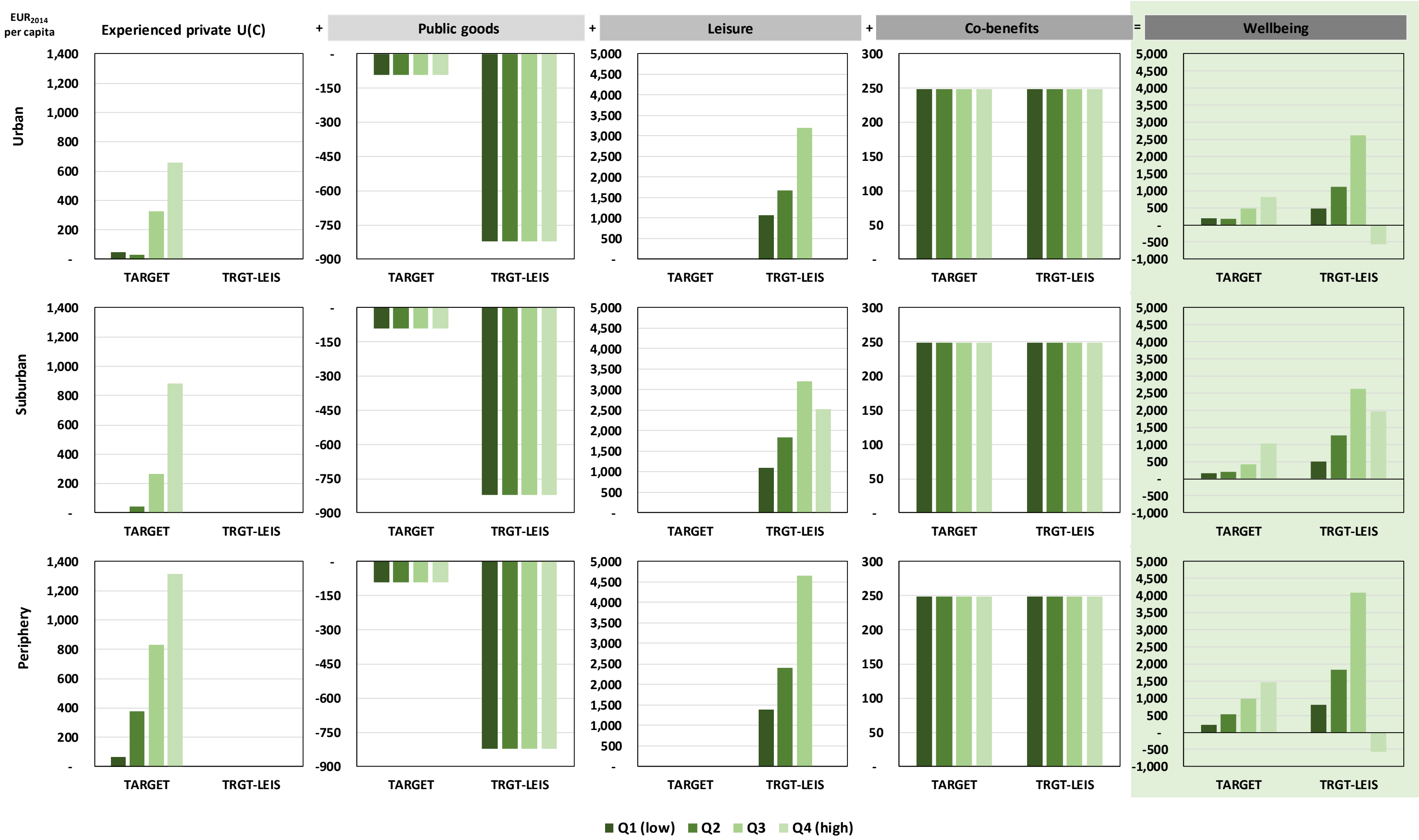

Figure 26: TARGET and TRGT-LEIS 2050 distributional effects in absolute changes in EUR$_{2014}$ per capita relative to AUTO. The experienced private utility out of consumption U(C) adjusts the monetary U(C) (=Hicks'ian Equivalent Variation) since functionality fulfilment is possible at lower expenses which however do not reduce utility. Changes in provision of public goods and co-benefits are allocated on an equal per capita basis. Leisure effects are evaluated via the wage rate to reflect its opportunity costs. Note the different scaling of y-axis across columns.

Based on income and consumption effects, we now turn to wellbeing effects as shown and decomposed in Figure 26. The effects on private consumption are metrics used from a traditional perspective and are shown in the very left column of the panels (i.e. experienced utility from consumption). However, these need to be complemented by further crucial dimensions of wellbeing. First, government consumption effects are translated to per capita impacts as shown in the second column, reflecting that the services of public and merit goods provision accrue in the end to private households. Second, for leisure we use the evaluated change in labour supply. Third, co-benefits are distributed per capita as shown in the fourth column. The last green-shaded column of panels sums up, reflecting distributional effects in terms of wellbeing of the TARGET and TRGT-LEIS scenarios relative to AUTO in 2050.

In the TARGET scenario, all households are better off in terms of wellbeing. Effects are more pronounced for peripheral households and, in an absolute sense, rise with income class. Note also, that wellbeing effects for low(er) income households are driven more by co-benefit effects than pure consumption effects. As shown previously, the TRGT-LEIS scenario is connected to further emission reductions because potential economy-wide income gains are not materialized but used to increased leisure time such that experienced utility from private consumption is held constant. However, the reduced labour supply also reduces the available public budget because of a lower tax base. Thus, with fixed transfers, public provision of goods and services declines even further having a weakening effect on wellbeing, an indirect consequence of the implemented labour-leisure trade-off. This effect dominates the experienced wellbeing from increased leisure time only for the two high-income Q4 households in urban and peripheral locations. For the remaining households, the effect of increased leisure overcompensates the negative public consumption effect. A more detailed representation of the drivers of wellbeing across residence locations and income groups is shown in Figure A 3 in the Appendix. Readers interested in percentage deviations of household-specific wellbeing effects (instead of absolute changes) are referred to Figure A 4 in the Appendix.

5. Discussion, conclusions and further recommendations

5.1 Socio-economic consequences

Based on the Extended Model analysis, we discuss scenario-specific socio-economic implications of replacing conventional satisfiers of Shelter and Access by climate neutral ones. For the TARGET scenario, we derive strong positive wellbeing, welfare and GDP gains, absolutely and per ton of CO_2 emission reductions. Hence, the social costs of emission reduction turn into social benefits with the investigated structural change of fulfilling functionalities Access and Shelter. Moreover, results do not point to eventual CO_2 emission rebound effects from potential increases in GDP, mainly due to strong avoidance of physical transport and absolute decoupling of wellbeing and emissions.

Given that the respective satisfiers of Shelter and Access in the TARGET scenario are (close to) available and affordable (such as heat pumps, electric vehicles, Superblocks/organisation of space in quarters, active mobility, refurbishments, etc.), we conclude that these changes might not be as radical as often asked for in the literature, but still very effective. Further breakthrough technologies such as 3D printing (of products but also buildings) or aspects subsumed under the term "Industry 4.0" might reduce emissions even further, without negatively influencing wellbeing (Bonilla et al., 2018; Zhong et al., 2017).

Furthermore, strong avoidance also retains strong rises in electricity demand, taking pressure from mitigation options of other areas such as the electrification of industrial processes. This also points to further research avenues, because the concept of functionalities starts with basic needs and thus takes a final demand perspective. Hence, we also need to ask for relevant supply-side changes along the energy chain, such as decarbonisation of iron and steel supply or carbon management in chemical industry. Besides further supply side modelling implementations, this will also require a different modelling of foreign trade relations than in the underlying study, in which we implement the small open economy assumption.

Overall, the combination of satisfiers for fulfilling Shelter and Access shows a clear synergy. Rising capital demand due to the shifts from motorized individual transport towards public and shared transportation, paired with higher rents for dwellings renders capital scarce. However, additional investments takes pressure from the capital market via stronger capital accumulation and thus stronger economic growth. Crucially, these investments are associated with substantial quality improvements of the stock of satisfiers and come along with strong energy demand and emission reductions.

A related question is, if private households are well-informed such that the quantity and quality of their investments are in line with the needed structural changes as identified for the TARGET scenario. In an Austrian survey Beer et al. (2015) challenge this claim and point to limitations and biases in people's perception. In line with that, Wang et al. (2011) surveyed the Suisse lay public and find that perceived and objective measures of investment risk are only moderately correlated. Contrary, self-reported difficulties to understand investment products almost perfectly correlate with perceived risks. Hence, a possible policy implication could be to strengthen the provision of investment incentives, for instance, through indirect measures (e.g. information campaigns and financial literacy activities) or more directed activities (e.g. private-public-partnerships, direct financial support).

For the TRGT-LEIS scenario, the derived CO_2 emission reduction as well as the absolute gain in wellbeing is increasing even stronger than in TARGET, although GDP and welfare are affected strongly negatively. We thus demonstrate that GDP and welfare (in the narrow sense of consumption possibilities) aren't comprehensive enough indicators and are thus possibly misleading for climate change mitigation policy. This is because non-monetary benefits from mitigation options such as working time reductions (leisure) and further co-benefits of abatement are neglected. This finding is in line with conclusion made by the 'Commission on the measurement of economic performance and social progress' (Stiglitz et al., 2009, p. 4), which emphasizes that "*advances both in our conceptual understanding of [economic, environmental and social] issues and [increasing] data availability mean that it is now possible to construct better indicators.*"

Although national wellbeing rises with the investigated structural changes in functionality fulfilment, these effects are unevenly distributed across groups of private households. In its tendency, we derive positive but regressive distributional implications as well as stronger impacts in peripheral regions. An exemption relates to effects to high-income households (4^{th} quantile) in the TRGT-LEIS scenario, because no positive leisure effects can be generated and at the same time, negative impacts from lower public goods provision emerge.

The Extended Model allows exploring multiple dimensions of wellbeing across broad income classes and residence locations. Hence, the analysis of a refined (e.g. within-group) distribution could be valuable, but it is left open for future research. Additionally, the per capita allocation of public good provision may be correct for mostly non-rival services (e.g. public order and safety). However, the positive externality of providing merit goods (e.g. health) may depend on socio-demographic characteristics (Fiorito and Kollintzas, 2004). A more fine-grained resolution for these dimensions can certainly be useful. Also for co-benefits, equally distributed here across a number of people in groups of households, different allocations could be used reflecting, for instance, that greater health benefits may accrue for urban low(er) income households (Fagliano and Diez Roux, 2018). Hence, a more progressive allocation of the identified negative impacts on public goods provision (positive co-benefits), as it was done here, would put pressure on low (high) income groups.

As a further outlook, it could also be interesting to facilitate broader equity holding also for low(er) income households, which means compensating productivity increases or higher profitability of capital assets (i.e. capital rents) by offering company shares instead of increased salaries. This could also further improve the inclusivity of the transformation because more similar sources of income might lead to convergence of household interests, i.e. in their most narrow sense, of workers and capitalists. As demonstrated, indirect effects of such a change in compensation mechanisms need scrutiny as exemplified here for leisure. In the investigated case a reduction in labour supply leads to a decreased tax base due to lower general economic activity and thus in turn also to a reduced provision of public goods and services.

Overall, the treatment of employment in both approaches (the Core and Extended Models) extends the conventional evaluations which in a further step could also cover shifts in skill demands associated with structural changes. Also, unemployment effects could be explored, because – within our set of scenarios – the rising wage rate indicates higher demand for labour and thus possibly lower unemployment. However, this aspect should be contextualised carefully because employment is rather one of the means to a specific end (i.e. wellbeing). This is illustrated here with leisure. Hence the focus should remain on functionality fulfilment and their manifold climate-neutral satisfiers as well as on wellbeing and its (sub)dimensions.

5.2 Methodological lessons learned

Radical structural changes as explored here are needed for absolute decoupling of wellbeing and anthropogenic forcing of climate change and, as shown, they are possible by rethinking the structural basis of fulfilling functionalities, which are the result of stocks and flows. These findings and the connected autonomous and policy-induced uptake of the satisfiers of functionalities should find a more prominent role in macroeconomic evaluations of mitigation options because reliance on, for instance, marginal structural changes based on price-induced historical changes (i.e. elasticities) falls short of such substantial shifts. The focus could rather be to observe the plausibility and persistence of emerging and ongoing trends in the satisfiers of functionalities such as Superblocks/quarters and home-office/-schooling or healthy lifestyle changes leading to more active mobility. Such (mega-)trends help to reflect on the options of mitigation and are more often than not disregarded in the traditional evaluation perspective. Based on this, one could analyse the extent to which such trends could further be accelerated by climate policy without inducing unintended consequences but at the same time taking into account possible inertia of the system (Jonas and Żebrowski, 2019).

The core limits of such an approach are its extensive data needs (physical, monetary and technological) for constructing plausible scenarios, which requires to rely on a number of assumptions. The approach relies on fine-grained and up-to-date observance of emerging transformational trends and requires critical as well as iterative plausibility checks, which can be achieved by transparency and open debate within and across disciplines and stakeholders.

In terms of the ultimate goal of keeping human wellbeing of current and future generations at least constant, a crucial methodological learning relates to measuring economic performance and social-environmental progress. For instance, the level of access to people, goods, and services is implicit, and the approach rather allows to explicitly measure the underlying satisfiers needed to fulfil it (in physical – stocks and flows – and monetary terms). A relevant aspect is that Access is not restricted to physical transport, be it improved (e.g. electrified) or shifted (e.g. more shared transport or active mobility). As shown, the 'avoid' component is an immensely important dimension of functionality fulfilment. Similar arguments apply for Shelter, where we explicitly measure its climate-neutral satisfiers and imply functionality fulfilment. Doing so allows for monetizing the experienced utility from consumption, which adjusts the conventionally monetized utility by lower required expenses, that are induced by structural changes, stemming from the interaction of different stocks and flows.

Finally, the monetization of wellbeing is helpful but bounded by data availability and a meaningful translation. The effects on and of ecosystem amenities as well as subjective wellbeing (based on relative deprivation) are certainly relevant and should be qualitatively discussed because it may not always be meaningful to put a €-tag on them. A key take-away of this first attempt to operationalize functionalities in macroeconomic modelling is that structure and its quality outperforms mere economic expansion in terms of wellbeing.

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Appendix A: Detailed Information on Scenario generation

Access

BAU: Development of passenger kilometres and modal split

The starting point for the development of passenger kilometres in Austria is provided by the mobility survey "Österreich Unterwegs 2013/2014" (Tomschy et al., 2016). As shown in Figure 27, passenger transport is divided into motorized individual transport (MIT), public transport, active mobility and a residual. Public transport is further split into the subcategories public transport by rail (RailPT), by road (RoadPT) and local city public transport (CityPT). Active mobility includes slow traffic, which is composed of bicycling and walking. The residual includes, for example, taxi rides and e-scooters.

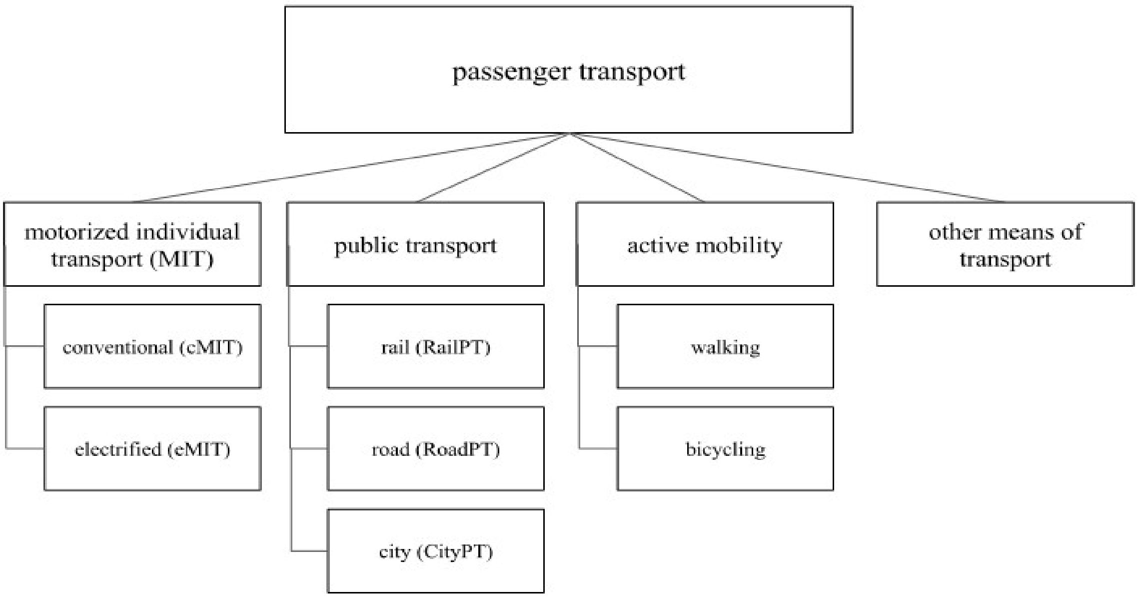

Figure 27: Passenger transport categories

The total pkm in passenger transport is determined by the addition of the individual transport modes in each year up until 2050. In line with Umweltbundesamt (2019a) we assume that – without any intervention – the total mileage would increases by 35.8% from 2014 to 2050. The following subsections describe the development of pkm in the respective modes of passenger transport. The pkm of other means of transport are assumed to remain constant until 2050.

Motorized individual transport

Motorized individual traffic (MIT) makes up the largest share of the total traffic volume of passenger transport and can be divided into conventional (cMIT) and electrified (eMIT). The demand for MIT is assumed to increase moderately until 2050, "annual growth rates of MIT drop linearly from 0.8% per year to 0.5% per year based on Capros et al. (2016), while the vehicle occupation rate is assumed constant at 1.22 (mean value between two estimates for Austria; see Tomschy et al. (Tomschy et al., 2016) and VCÖ (2018)). Furthermore, we assume an average car mileage per year of 13,300 kilometres (Tomschy et al., 2016) and an economic lifetime of 15 years for both conventional and electric cars. Based on these assumptions we compute the path of demand for both conventional MIT and electrified MIT using a spreadsheet module. We assume the share of electrified MIT to be negligible in the benchmark year 2014. In the baseline scenario, the share of electrified MIT is assumed to rise to 30% in 2050 in a quadratic fashion. This reflects the slow onset of electric vehicle sales, which only gain momentum after several years. As our target share of 30% in 2050 does not imply saturation in the market for electric vehicles, we do not implement decreasing marginal growth in demand for electrified MIT. The residual demand is satisfied with conventional MIT" (Dugan et al., 2020, p. 34).

Public transport

As mentioned above public transport is composed of public transport by rail, by road as well as inner-city public transport. The passenger kilometers (pkm) in the years 2014 to 2017 are based on EU transport data base (European Commission and Directorate General for Mobility and Transport, 2019). In order to adjust the allocation to the individual modes of transport, as already mentioned above, bus transport was added partly to the inner city public transport system. Since data on passenger kilometers in the local traffic area are not available, the estimation was based on the passenger number analysis (WKO, 2019).

The development of the required RailPT pkm in the future is described as logistical growth. The general trend corresponds to the projections from "Verkehrsprognose Österreich 2025+" (Trafico et al., 2009) as well as a weaker expectation of the "Zielnetz 2025+" (ÖBB Infrastruktur AG, 2010). Furthermore, an expert interview was conducted. The pkm development of CityPT and RoadPT continues with a constant growth rate, which is based on the average growth rate of the past years.

Active mobility

Active mobility includes slow traffic, which is composed of bicycling and walking. For both modes of transport, the values used in 2014 are those of "Österreich Unterwegs 2013/2014" and "Österreich unterwegs 2013/2014 mit dem Fahrrad". In general, there is a lack of comparable statistics concerning walking and cycling for pkm (Steenberghen et al., 2017). The pkm until 2050 are continued at constant rates for both bicycling and walking. Here, bicycle traffic increases slightly, while walking traffic decreases slightly. The underlying trend is in line with the

"Verkehrsprognose Österreich 2025+" (Trafico et al., 2009) and the development described in the "Sachstandsbericht Mobilität" (Umweltbundesamt, 2019a).

Changes in modal split

Figure 28 illustrates the change of the modal split. The shares of active mobility, public transport and MIT change only slightly. Walking and bicycling are decreasing in percentage terms, with the former's share decreasing more strongly (from 1.98% in 2014 to 0.97% in 2050). The modal split share of MIT remains roughly constant from 2014 to 2050. Due to the increasing penetration of e-mobility, eMIT increases and cMIT decreases. Public transport rises slightly from 25.95% in 2014 to 27.33% in 2050, with RailPT rising by 1.59% and RoadPT and CityPT falling slightly (by 0.2% and 0.01% respectively). The share of other means of transport decreases slightly, as the pkm remain the same with an increasing total passenger volume.

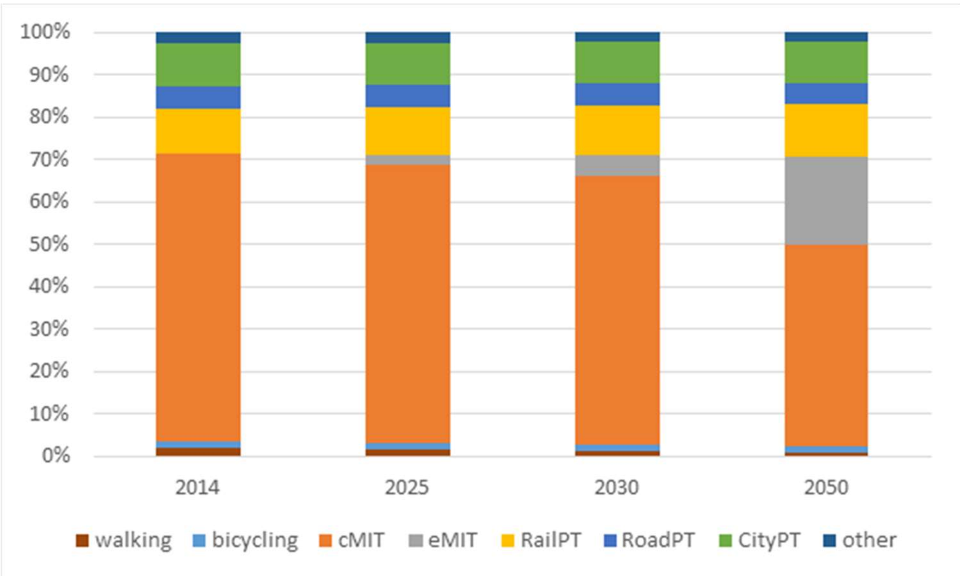

Figure 28: Baseline and business as usual modal split change

Sub-scenarios for Access in the TARGET scenario

Scenario avoid

In the avoid scenario the demand for individual transport is reduced by regulatory measures. The demand for pkm is lowered on the one hand by an increased implementation of home office at work and by working hours reduction in the areas of commuting, business trips as well as school and apprenticeship. In the first step, both reduction areas are considered separately and then merged in the scenario avoid. The description of the development of the pkm and the effects on the modal split is given below.

Home office

The concept of telework and its assumed reducing effects on traffic emissions date back to the 1970s. Jack Nilles had created the term "telework" with the hypothesis that the exchange of work data between employees and workplaces is preferable to commuting to work (Nilles, 1991). The significant development of information and communication technologies over the last 40 years has brought teleworking more and more into focus and made it a mode of work. In addition to commuting, home office can offer also other advantages such as a more equal work-life balance, as well as higher motivation and job satisfaction. However, some studies investigating the effects on traffic emissions show that increased shopping and leisure activities can replace the kilometers saved on the way to work. In some cases, such as in single households, the distance travelled with home office is even higher (Kitou and Horvath, 2006; Stiles, 2020). These rebound effects are not considered further in this analysis.

A survey of employers in Austria in 2017 showed that 90% of companies offer some form of home office, but in 47% of all cases it is only offered to a few individuals. However, the acceptance of teleworking and the will to expand it is evident in the large majority (Deloitte et al., 2017). By 2019, the share of companies with a home office has already risen to 97%, and in only 38% home office is only offered to a few individuals (Deloitte et al., 2019). Due to the Austria-wide lockdown as a result of the Corona pandemic, which has forced a large proportion of the population to telework, both the possibilities and the acceptance of home office could be observed. The Federal Environment Agency conducted a survey on the potential of virtual mobility both before and during the lockdown. The interviewed persons predict an increase in the share of telework in the total working time in Austria from 15% (expectations before corona) to 35% (expectations after corona) in the next 10 to 20 years (Umweltbundesamt, 2020).

For the derivation of the passenger kilometers that can be saved by home office, we considered only the pkm that serve the purpose of commuting to work. Their share is assumed to be the same for all modes of transport and is reduced by the home office share. The share of home office consists of the potential for telework and the number of days worked per week in the home office. For the former, a concave increasing function is assumed, where in 2050 35% of the pkm with purpose to work can be saved. It is anticipated that on average two out of five working days per week are commuted. Home office will save around 5 billion pkm in 2050. This equals a share of 3.34% compared to total traffic performance in the baseline. The development of the reduction over time is shown Figure 29.

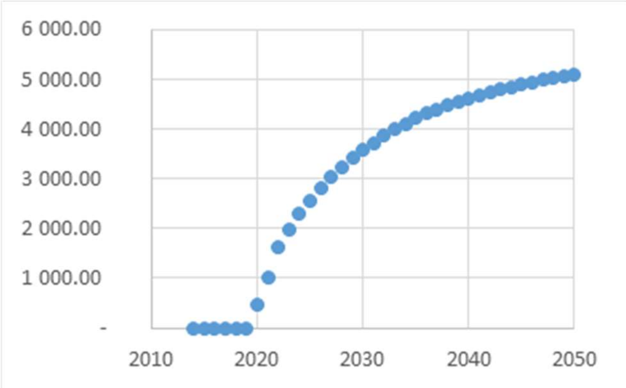

Figure 29: pkm avoidance through home office

Reduction of working hours

In Austria, the average working time per week fell and the proportion of part-time employees rose over the past 15 years. In 2005, the average working time per week was 39.4 hours, in 2019 it was down to 36.6 hours (Statitik Austria, 2020). The trend is towards a reduction in working hours and the demand for a 35-hour week is increasing in many areas such as care. This can be implemented through regulatory measures.

A reduction in working time also has an effect on the demanded pkm. This affects commuting and business trips as well as school and training. The commuting and business trips pkm have been adjusted for part-time work and by the reduction in working hours. A 35-hour week in 2030 and a 30-hour week in 2050 was assumed. In between, the values were interpolated linearly. In education, which includes both school and apprenticeship, a 4.5 day week of students present in class was assumed in 2030 and a 4 day week in 2050, the rest is assumed to take place online or autodidactic. The intermediate values were also interpolated linearly. The reduction of working time for all three purposes leads to a pkm reduction of 11 billion pkm in 2050, which corresponds to 7.43% of the total traffic performance in the baseline. The development of pkm avoidance over time is shown in Figure 30.

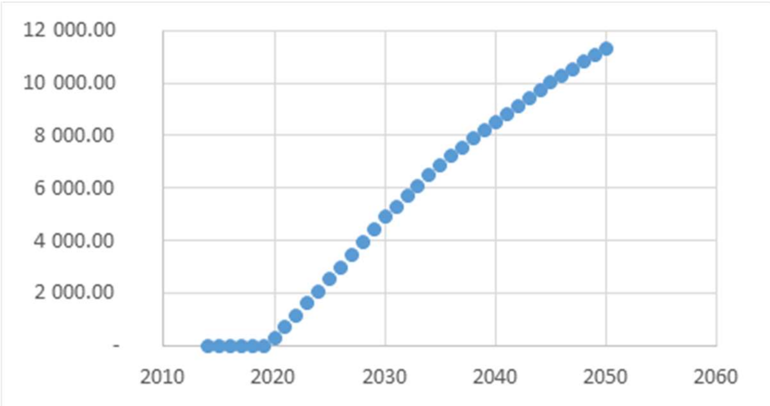

Figure 30: pkm avoidance through reduction of working hours

Combined avoidance

In the next step, the reduction of working hours and the increased use of home office were combined. Figure 6 shows the development of pkm in the baseline and in the scenario avoid in the years 2014, 2025, 2030 and 2050.

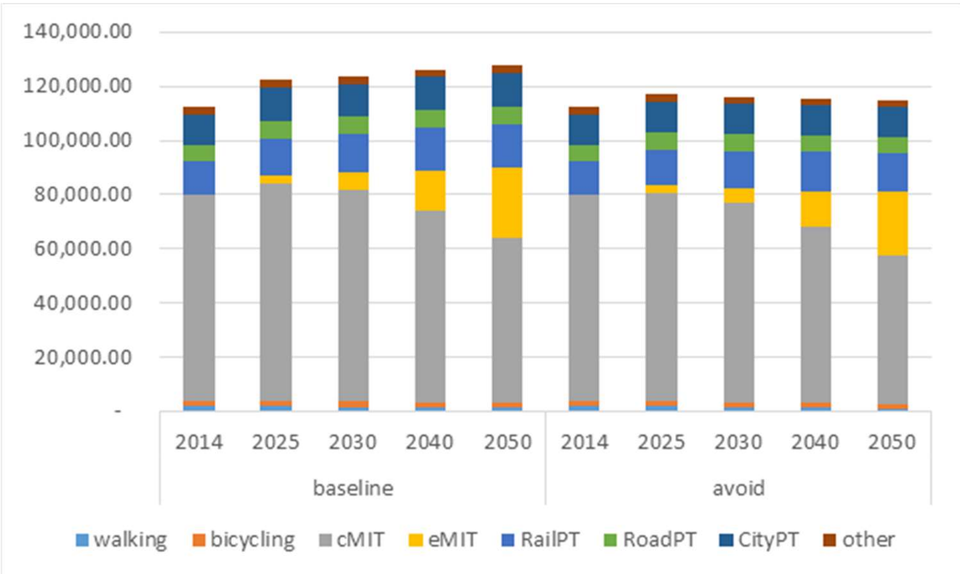

Figure 31: pkm developement baseline compared to scenario avoid

Changes in modal split

The modal split in the scenario avoid is assumed to be the same as in the baseline. This modal split is transferred and the pkm is reduced by the number of kilometers saved. Thus, the modal split is the same in all years as in the baseline, only the demanded passenger kilometers are reduced.

Scenario shift

In the scenario shift, regulatory measures and infrastructure expansion will lead to an increased shift of pkm to rail passenger transport, inner-city public transport and active mobility. In the following, the development of the kilometers, the subsequent change of the modal split as well as the infrastructure investments are examined in more detail.

The pkm needed for public transport are assumed to develop similarly to the baseline. For the development of the RailPT pkm the assumptions of the "Zielnetz 2025+" (ÖBB Infrastruktur AG, 2010) were adopted. Overall, there is a pronounced logistic growth, which is driven by a strong annual increase until the realization of the target network and a decreasing growth afterwards due to saturation effects. CityPT and RoadPT will continue to grow at a constant rate similar to the baseline, resulting in a slight increase in pkm compared to the baseline.

The modes of transport walking and bicycling will develop until 2030 according to the respective master plans, whereby the implementation period has been extended by five years from 2025 to 2030 (BMLFUW, 2015a, 2015b). In the period to 2050, the pkm for both will grow at a constant rate, so that the share of both will increase compared to the baseline.

Changes in modal split

Since the same total traffic performance is assumed as in the baseline, the modal split will change significantly by 2050. Due to the increase of pkm in public transport as well as in active mobility, the pkm performance of MIT will decrease (we take it as a residual variable). Figure 7 shows the development over time.

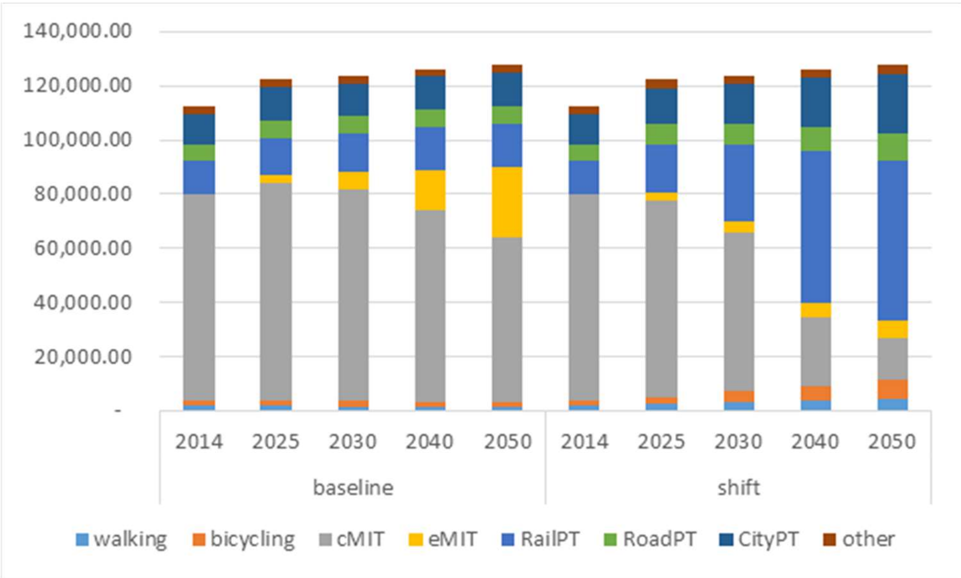

Figure 32: pkm development in baseline and scenario shift over time

Investment

In order to create capacities for the increase in pkm in public transport and active mobility, the infrastructure must be expanded. For this purpose, the required investment costs are analyzed corresponding to the development of passenger kilometers.

The investment costs in rail passenger transport were extrapolated with a logarithmic trend until 2050 on the basis of the annual reports of ÖBB Holding AG (ÖBB Holding AG, 2020) and the "Sachstandsbericht Mobilität" (Umweltbundesamt, 2019a).

The investments in CityPT are calculated in correlation to those in RailPT. The share of CityPT investments in RailPT has been analyzed in the past (Mitterer et al., 2016) and projected to remain constant until 2050. The resulting future development is in line with the values of two studies that assess the investment requirements (Augustrin et al., 2018; Mitterer et al., 2018).

The basis for the investments in cycling infrastructure is the per capita expenditure of the federal government, the states and the municipalities, which add up to 6.3€ per inhabitant and year (BMVIT, 2017). In 2025 this value was set at 15€ and in 2030 at 20€. From 2030 to 2050 it remains constant. To calculate the total expenditure, this value was multiplied by the respective predicted population (Kc and Lutz, 2017). As a result of the Corona Pandemic in 2020, cycling has become more important as an everyday form of mobility. More extensive promotion programs were already announced in 2020, which explains the sharp increase in per capita spending between 2020 and 2025 (e.g. Das Land Steiermark; BMK Infothek 2020).

Figure 8 illustrates the investments in rail passenger transport, local public transport and bicycle infrastructure. It can be recognized that the investments for RailPT make up the largest part, but the increase over the years is moderate. The same applies to the investments in CityPT.

Investments in bicycle infrastructure account for the smallest share, but in relative terms they are increasing the most until 2050.

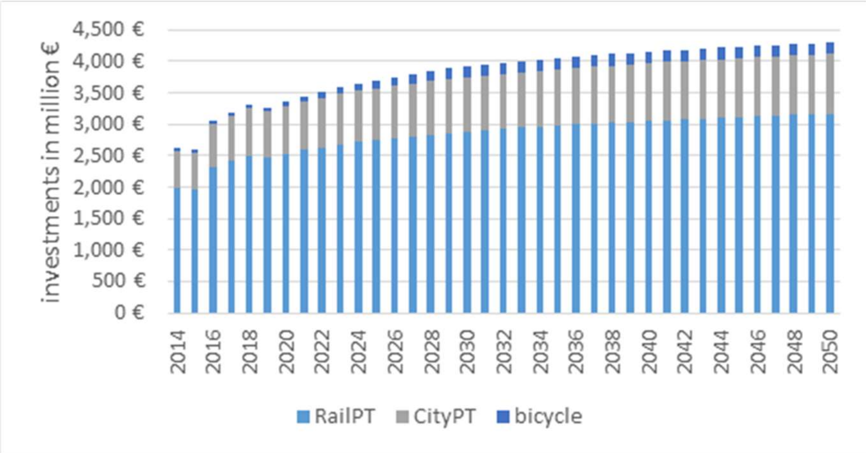

Figure 33: Investments in RailPT, CityPT and bicycle infrastructure over time

Scenario improve

For the scenario improve, regulatory measures are assumed to increase the share of electrified vehicles within the MIT. In the following the development of the demanded pkm and the resulting change of the modal split as well as the associated expenditures are described.

The pkm develop in the same way as in the baseline, only the composition of motorized individual traffic made up of eMIT and cMIT changes over time. "[…] we assume all new vehicles after 2035 to be electric vehicles. Households are assumed to act in a myopic fashion, which means that the share of electrified individual transport is the same as in the baseline scenario until 2035, after which no additional conventional vehicles are allowed to be sold" (Dugan et al., 2020, p. 34). "This leads to a crowding out of conventional MIT by electrified MIT such that by 2050 MIT is completely electrified" (Dugan et al., 2020, p. 14).

Changes in modal split

Since the pkm development of the modes of transport, except the composition of the MIT, is the same as in the baseline, there is only a change in the modal split within motorized individual transport. From 2035 onwards, eMIT increases strongly and takes over the share of cMIT. Figure 9 compares the development of pkm in the baseline with that in the improve scenario.

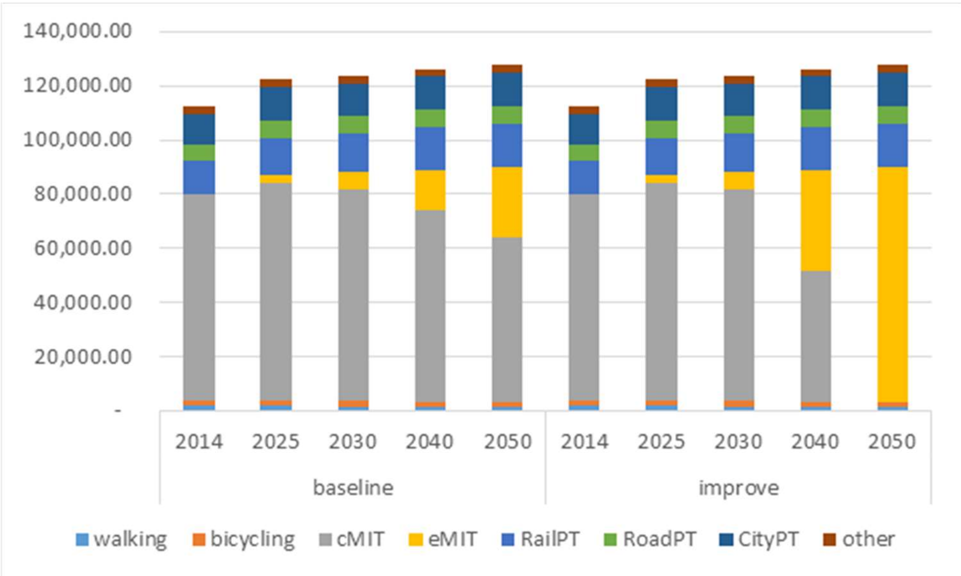

Figure 34: pkm developement in baseline and scenario improve over time

Scenario shelter

The shelter scenario assumes a reduction in traffic due to a change in the settlement structure. The increased focus in spatial planning on superblocks and neighborhoods in urban areas as well as village center attractivization in suburban and rural areas will change the transport performance. In Frey et al. (2020), the possible effects of three superblocks in different districts in Vienna on traffic, among other things, are analyzed. The potential surveyed in this study served as the basis for the reduction of traffic performance in this scenario. In order to include the time lag of the effect of spatial planning measures, the reduction of passenger kilometers between 2014 and 2050 is concave. Since the spatial planning measures affect all transport modes, the modal split is the same as in the baseline and the reduction in transport performance is subtracted equally from all modes of transport. Figure 10 compares the development of passenger kilometers of the baseline and the scenario shelter.

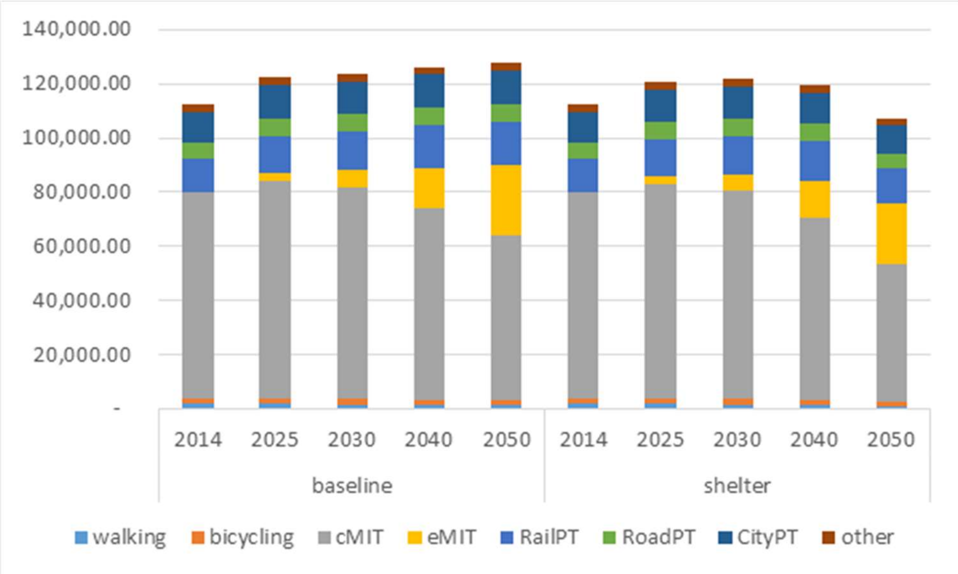

Figure 35: pkm development in baseline and scenario shelter

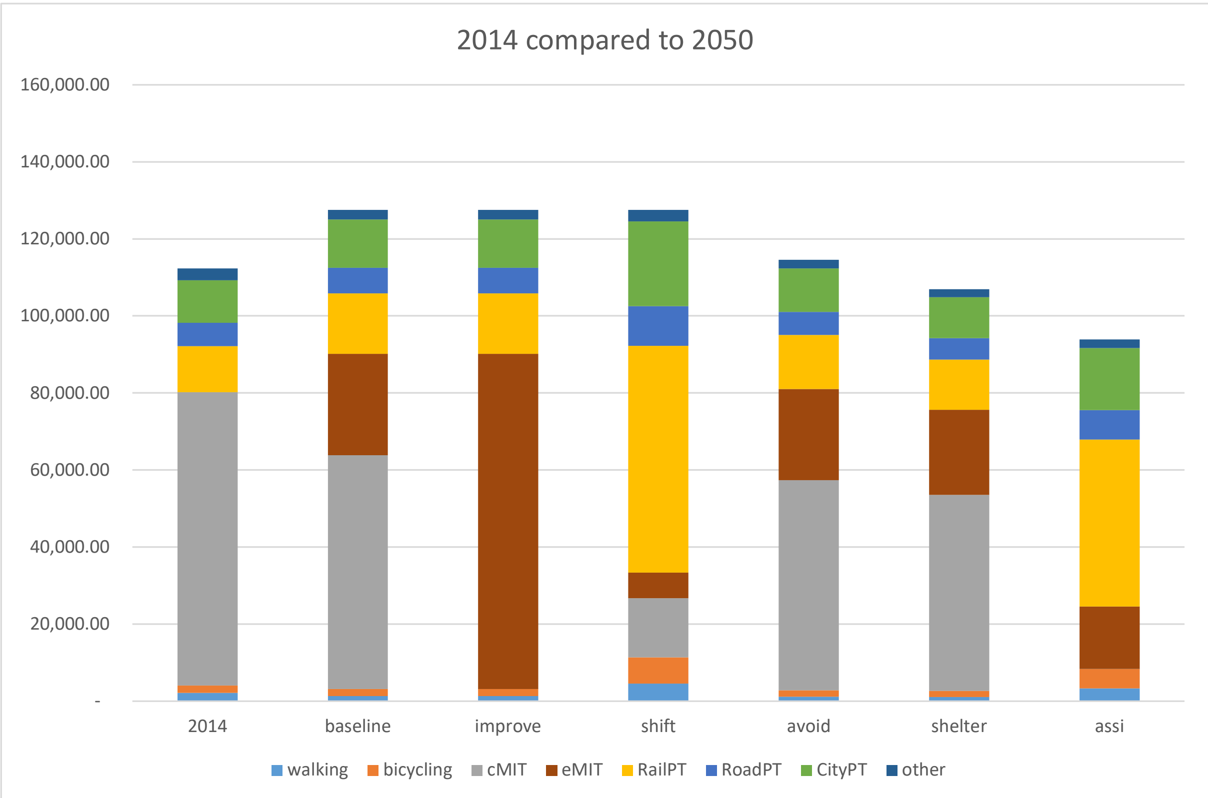

Figure 36: pkm demand in 2014 compared to 2050 in scenarios

Shelter

Detailed information and assumptions for the AUTO scenario

Floor area, Buildings structure and heating energy demand

The starting point is the floor area and buildings structure in the base year. We build up on the structure developed in the project EKS (Schleicher et al., 2018). this determines the need for new constructed dwellings. The stock is differentiated between the building type in which the dwelling is located, the age structure (Figure 37) and a higher and lower energy standard. For buildings younger than 1991 with a better energy standard underwent thermal refurbishment. Due to economic reasons, dwellings that have been constructed between 1991 and 2015 are not seen as subject to thermal refurbishment. Dwellings that are built after the base year can be built in two variants. First in accordance to the *normal* thermal standard present in 2015 or second by an *improved* thermal standard with less than half energy for heating per square meter.

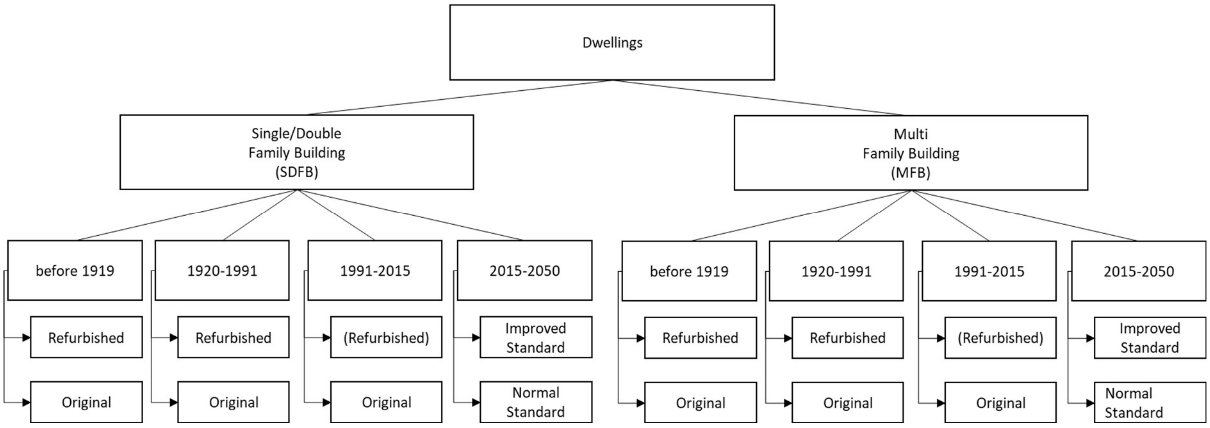

Figure 37: Structure of the Buildings Stock

The **total energy use for** room heating in Austria's dwellings is **driven by two aspects**. First the **floor area** that needs to be heated and second the **thermal quality** of the building stocks. The **total floor area** is driven by the demographic developments but also by the buildings structure. The demographic developments are taken from the prognosis of the statistical office whereas the building structure undergoes a constant change over time because a part of the building stock depreciates, is demolished and is replaced by new buildings. Multi-Family buildings (MFB) have a lower[1] area need per household as Single/Double-Family buildings (SDFB). Therefore, the composition of new buildings between those two types influences the development of the total demand for floor area. Regarding the **thermal quality** we apply energy efficiency parameters on energy demand per square meter (Figure 38) from a previous project (EKS) shown in

[1] Average floor space of dwellings in Multi-family buildings is about 40% less than the floor space of dwellings in Single/Double family buildings according to the 2011 census (Statistik Austria, 2021e)

for all building types. Depending on the scenario, a certain percentage of buildings older than 1991 can be thermally refurbished and new buildings can have a higher energy efficiency standard.

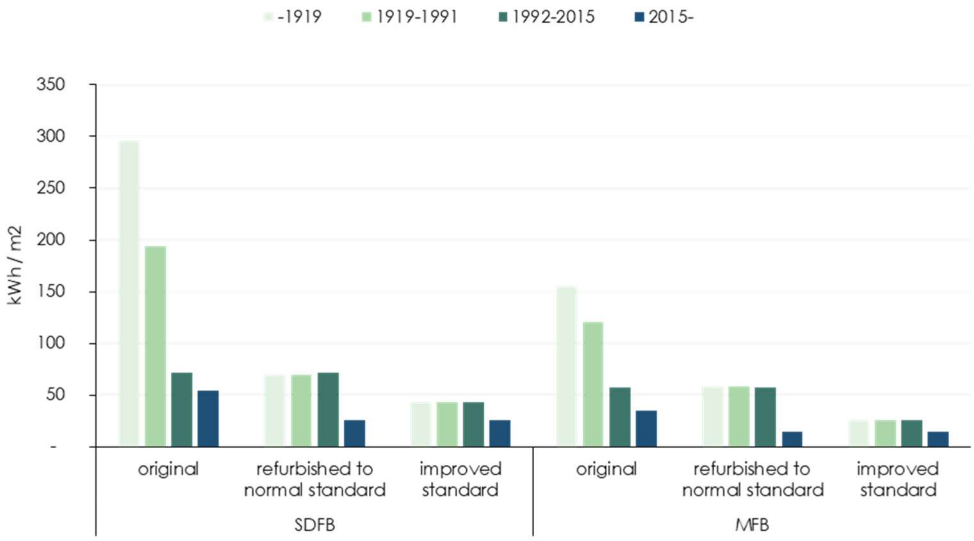

Figure 38: Heating Energy demand per m2 per building type
S: EKS

The following chapters show the baseline development regarding the **floor area demand**, **building stock** and resulting **energy demand for heating**.

Floor area demand until 2050

According to estimations of the Austrian Statistical Institute the population is expected to grow by 8% until 2050. Assuming a continuation of the decreasing occupation rate of dwellings the number of households would increase even stronger by 12%. After an increase in the 2000's the average household size stagnated between 2015 and 2020 (Table 2). In the baseline scenario this stagnation of floor area is prolonged up to 2050. Due to the expected decrease in dwelling occupation this still leads to a growing area per person (4%) and a total increase of floor area by 12% between 2020 and 2050.

Table 2: Population and Dwelling size 2004 – 2020 in Baseline

	Population	Households*					Share in New Buildings	
		Quantity	Occupation rate	Floor area	area per household	area per person	S/DFH	MFH
	Mio. persons	*Mio.units*	*person/unit*	*Mio.m2*	*m2*	*m2*	*%*	*%*
2004	8,2	3,4	2,4	330	96	40		
2010	8,4	3,6	2,3	358	99	43		
2015	8,6	3,8	2,3	379	99	44	54	46
2020	8,9	4,0	2,2	399	100	45	54	46
2025	9,1	4,1	2,2	410	100	45	54	46
2030	9,2	4,2	2,2	419	100	45	54	46
2040	9,4	4,4	2,2	436	100	46	54	46
2050	9,6	4,5	2,1	448	100	47	54	46
Δ 04-20	**9%**	**16%**	**-6%**	**21%**	**4%**	**10%**		
Δ 20-50	**8%**	**12%**	**-4%**	**12%**	**0%**	**4%**	**0%**	**0%**

** data on households refers to principal residence*

S: Own calculations, Statistik Austria (2021f), (2021b), (2021a)

Structure of building stock until 2050

Based on the information of building types, state of refurbishment, respective area and energy demand from the previous project (EKS) a baseline development of the stock thermal quality is designed. This concerns the refurbishment rate, the quality of the refurbishment and the depreciation rate.

Table 3: Input parameters for building structure in Baseline

Constrution period	SDFB	MFB	SDFB	MFB	SDFB	MFB	SDFB	MFB	SDFB	MFB
	Refurbishment rate normal standard		Refurbishment rate improved standard		Depreciation rate original		Depreciation rate if refurbished		Share of New Building with	
-1919	1,80%	1,80%	0%	0%	1,2%	1,2%	0,6%	0,6%	*n.a.*	*n.a.*
1919-1991	1,80%	1,80%	0%	0%	0,4%	0,4%	0,2%	0,2%	*n.a.*	*n.a.*
1992-2015	0%	0%	0%	0%	0,0%	0,0%	0,0%	0,0%	*n.a.*	*n.a.*
2015-	0%	0%	0%	0%	0,0%	0,0%	0,0%	0,0%	0%	0%

S: Own assumptions

The average refurbishment rate between 2010 and 2020 is estimated to be 1,8%[2] and prolonged to 2050. New buildings and refurbished dwellings are set to have *normal thermal standard* (Figure 38) is for the whole period. Buildings that have been constructed before 1919 are

[2] IIBW (2020, pp. 34, Tabelle 17), Total refurbishment rate in 2010's 1,8%

set to depreciate about 1.2%[3] per year between buildings built between 1919 and 1991 are set to 0,4%[3] and structures built between 1992 and 2015 are assumed not to be demolished in the near future. Refurbished buildings are assumed to have half the depreciation rate than original buildings. In the baseline new buildings are not built at an improved energy efficiency standard than present in 2015. The gap between the area demand and the depreciated stock is filled by new buildings that need to be constructed each year. In average over 3 Mio.m² are built each year resembling over 116 Mio.m² that are built after 2015 and make 26% of the building stock in 2050.

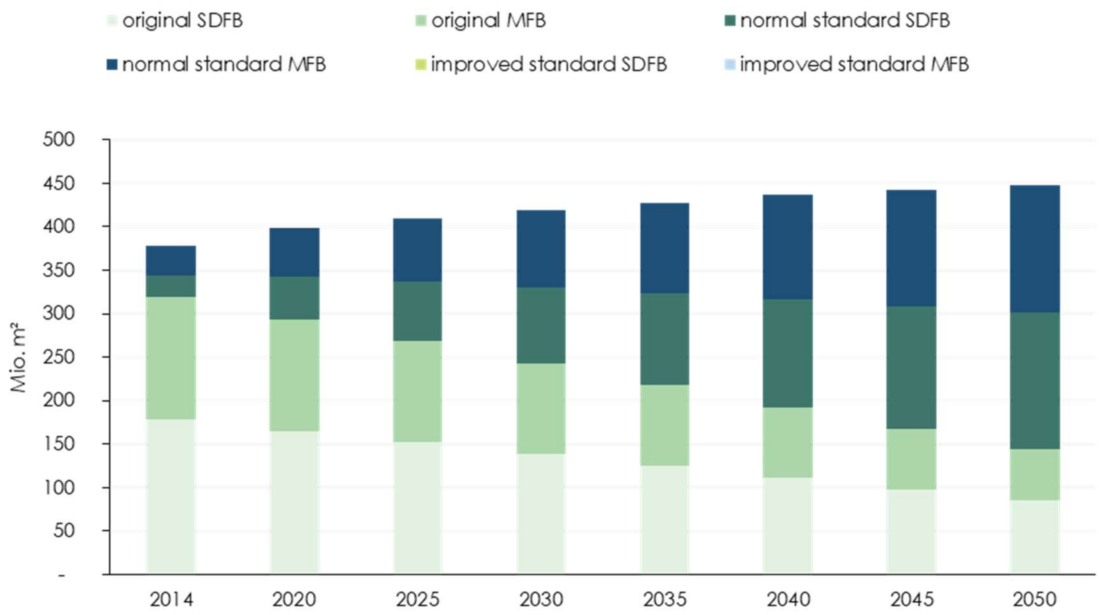

Figure 39: Building structure per refurbishment status in Baseline
S: EKS, own calculations

The presented input parameters lead to a total floor area of about 450 Mio.m² in 2050. A third (32%) of this area has the thermal quality of its original construction whereas two thirds have been refurbished thermally by the *normal standard* present in 2015.

[3] According to the outflow of buildings in this area in Statistik Austria's censuses (Statistik Austria, 2021g)

Energy demand of building stock

Based on the thermal quality of the building stock and the respective area, the necessary energy demand for heating is derived. Figure 40 shows that, even in the baseline, the energy demand decreases strongly by 32% to 132 PJ mainly due to the depreciation of the old stock that is less energy efficient and to the high level of refurbishment observed in the 2010's that has been prolonged. The energy use for heating per capita decreases by 1.1% per year in this scenario which is almost triple the decrease observed between 1995 and 2020 (-0,45%).

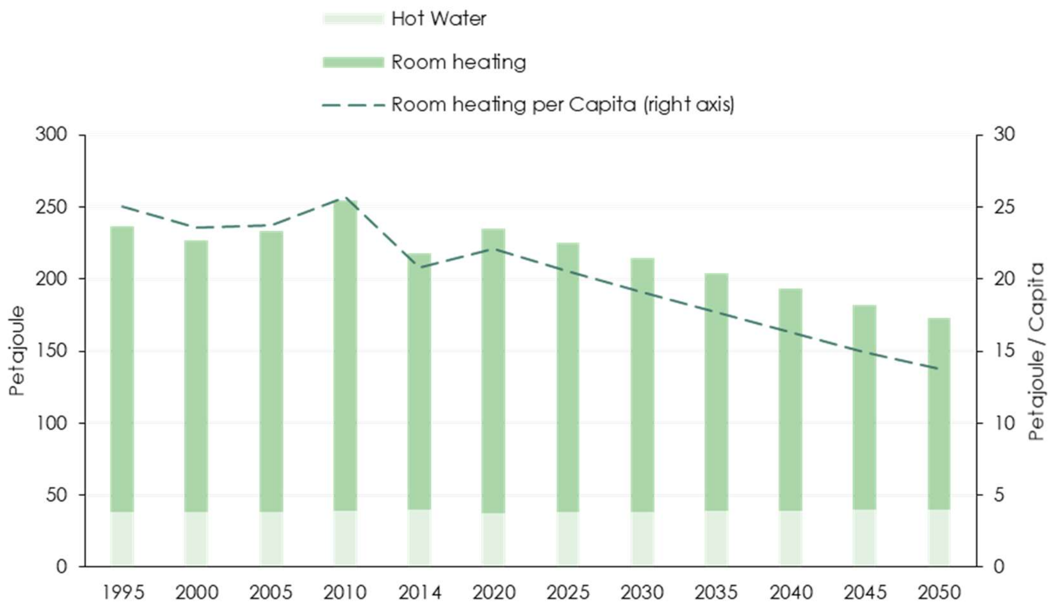

Figure 40: Energy demand for room heating and hot water in Baseline;
S: (Statistik Austria, 2021h) and own calculations

The need for hot water per person is assumed to be constant and therefore is not affected by the building structure. Hence the energy demand for hot water increases by 3PJ compared to 2020.

Heating Systems & Energy fuels

The energy source used to provide room heating is crucial for the related GHG emissions. Therefore, the structure of heating systems that is installed in the existing buildings is an important factor in the Core Model. Regarding the heating system, the energy statistics of Statistik Austria have been analyzed and a data set composed that represents the heat system stock comprising primary and secondary heating systems by fuel type. For the development until 2050 two parameter sets are relevant.

First the need for new installations which is determined by the depreciation rate (4% for all heating technologies) and the total demand for heating systems. Similar to new buildings we assume that new heating systems replace the outflow of old appliances or satisfy a growing demand by new buildings. The total demand is driven by the number of households that is given by the prognosis of statistical institute (see previous chapter).

The second relevant set of parameters is the composition of new heating systems by fuel input type. Regarding to this issue, the decision of Austria's government to phase out from oil based heating system is included in the baseline (Bundeskanzleramt, 2020). Hence no new installed oil heating systems are allowed after 2025 and no system should be active after 2035. This is shown in Figure 41 where the oil heating systems phase out while the overall number of heating systems[4] increase.

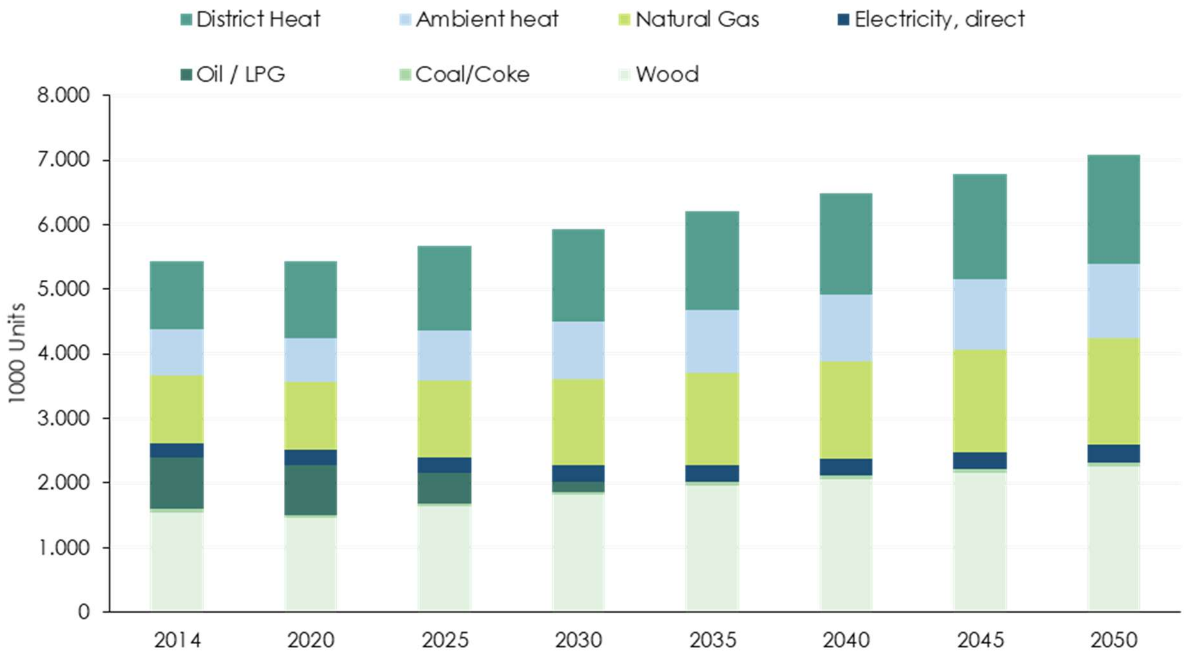

Figure 41: Heating Systems in baseline
S: (Statistik Austria, 2021c) and own calculations

[4] Heating systems exceed the number of households due to the possibility of primary and secondary systems

In 2014 the total number of primary heating systems is about 3.8 million units[5] which is referring to the number of principal residences. According to the energy use cencus[6] secondary heating systems are additionally covering 32% of the area that is already heated by primary systems. By assuming that this covered area relates to the number of secondary units we approximate that 1.6 mio. secondary heating systems are in place. The total number of heating systems in Figure 41 then reaches 5.4 mio. units in 2014 and increases analogous to the number of households up to 7,2 mio. units in 2050.

Sub-scenarios for Shelter in the TARGET scenario

Sub-scenario avoid

In this sub-scenario assumptions on the type of new buildings and material inputs are defined. A key parameter for is altered, the share of multi-family buildings in new constructed buildings. This share is increased from the 2014 level of 46% to 73% in 2050. Dwellings in Multi-Family buildings (MFB) provide more shared space and therefore have a lower[7] need for floor area than Single/Double-Family buildings (SDFB). This alteration leads to reduction of the average floor area per household to 95 m², the level observed in 2004 and a stagnation in floor area per person. This translates to a total floor area of 427 mio.m², about 21 Mio.m² below the baseline scenario.

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[5] Cf. „Energieeinsatz der Haushalte - Heizungen 2003 bis 2018 nach Bundesländern, verwendetem Energieträger und Art der Heizung" (Statistik Austria, 2021c)

[6] Cf. Einsatz aller Energieträger in allen Haushalten nach Verwendungszwecken 2003 bis 2018 (Statistik Austria, 2021d)

[7] Average floor space of dwellings in Multi-family buildings is about 40% less than the floor space of dwellings in Single/Double family buildings according to the 2011 census (Statistik Austria, 2021e)

Table 4: Population and Dwelling size 2004 – 2020 in Transition

	Population	Households*					New Buildings	
		Quantity	Occupation rate	Floor area	area per household	area per person	S/DFH	MFH
	Mio. persons	*Mio.units*	*person/unit*	*Mio.m2*	*m2*	*m2*	*%*	*%*
2004	8,2	3,4	2,4	330	96	40		
2010	8,4	3,6	2,3	358	99	43		
2015	8,6	3,8	2,3	379	99	44	54	46
2020	8,9	4,0	2,2	399	100	45	54	46
2025	9,1	4,1	2,2	409	100	45	49	51
2030	9,2	4,2	2,2	416	99	45	45	55
2040	9,4	4,4	2,2	426	98	45	36	64
2050	9,6	4,5	2,1	427	95	44	27	73
Δ 04-20	**9%**	**16%**	**-6%**	**21%**	**4%**	**10%**		
Δ 20-50 Transition	**8%**	**12%**	**-4%**	**7%**	**-5%**	**0%**	**-50%**	**58%**
Δ 20-50 Baseline	**8%**	**12%**	**-4%**	**12%**	**0%**	**4%**	**0%**	**0%**

** data on households refers to principal residence*

S: Own calculations, Statistik Austria (2021f), (2021b), (2021a)

Furthermore, assumptions on the material composition of buildings for dwellings are defined, based on the report on Material Efficiency Strategies for a Low-Carbon Future (U.N. Environment, 2020). Out of the 8 material efficiency strategies in this report, 3 were selected to be suitable for EconTrans (Table 5). In the first case, the strategy *reuse*, we assume that 27% of the concrete demand in new dwelling buildings stems from demolished old building stocks. In costs this is reflected in reduced investment expenditures for (primary) concrete and an identical increase of costs for logistics services. Steel is not assumed to be reused further because literature on the recycling rate of construction waste indicates that the recycling rate of construction waste is quite high ((EUROSTAT, 2021b) and (Bundesministerium für Nachhaltigkeit und Tourismus, 2019)).

Regarding the second strategy, *material substitution*, the U.N. Report mentions timber construction as an alternative to concrete and bricks. In EconTrans we apply an increasing share of timber constructions in new dwelling buildings that reaches 25% in 2050. This 25% relate to a recent study (Sinabell and Streicher, 2021) that states that an additional 1 Mio. solid cubic meter wood can potentially be harvested and used for buildings construction to reduce the consumption of ferroconcrete. Regarding costs take a simplified assumption that the reduced costs for materials is identical to additional costs for planning and technical services.

The third strategy covers light-construction of buildings. The U.N. report assumes in its scenarios that 35-85% of the new buildings can be built this way but describes the consequence for material consumption only qualitatively. Therefore, we take a conservative assumption that a reduction of 10% of materials is possible for 35% of the new buildings. Here we also assume, that the reduced material costs are compensated by costs for design planning and other services.

Table 5: Selected Material efficiency strategies for buildings

Material efficiency strategies	Transfer to EconTrans	Argument
Reuse	Reuse of Concrete 27 %	Novel reuse of concrete for dwelling buildings is assumed as in U.N. Environment report
	Reuse of Steel: 0%	No additional steel reuse assumed. Austria already is recycling steel scrap from construction waste (EUROSTAT, 2021b)
Material substitution	Up to 25% of the new buildings in 2050 are timber based.	Possible range 10-85% of new buildings (timber buildings[8]) according to U.N. Environment report
Down-sizing/less material by design	10% reduction in Materials (Concrete, Steel) in 35% of new buildings	Range of 35-85% of new buildings but without no concrete Numbers[9] on material reduction in U.N. Environment report

S: (U.N. Environment, 2020)

These assumptions on costs are reflected in the change of the investment structure outlined in the next chapter where investment costs on steel and concrete decrease whereas the share of wood and services increases.

Sub-scenario shift

The sub-scenario shift relates to a shift in heating systems focusing on the phase-out of fossil heating systems and a shift in the material use for new buildings.

The main shift is set in the consumption of natural gas. It is assumed that heat pumps and anergy heat nets, also known as *cold district heating,* replace natural gas boiler and heating systems to a large extend. From 2025 onwards only 9% of new installed primary and 2% of the secondary heating systems are natural gas based instead of the 28% (primary) and 9% (secondary) in the

[8] Table 4 in U.N. Environment (2020)

[9] For this specific Material Efficiency strategy no specific number was mentioned in U.N. Environment (2020)

baseline. This takes into account that natural gas cannot replaced in all areas. This shift resembles in the heat system composition shown in Figure 42 where the share of fossil based in all heating systems shrinks to 7%.

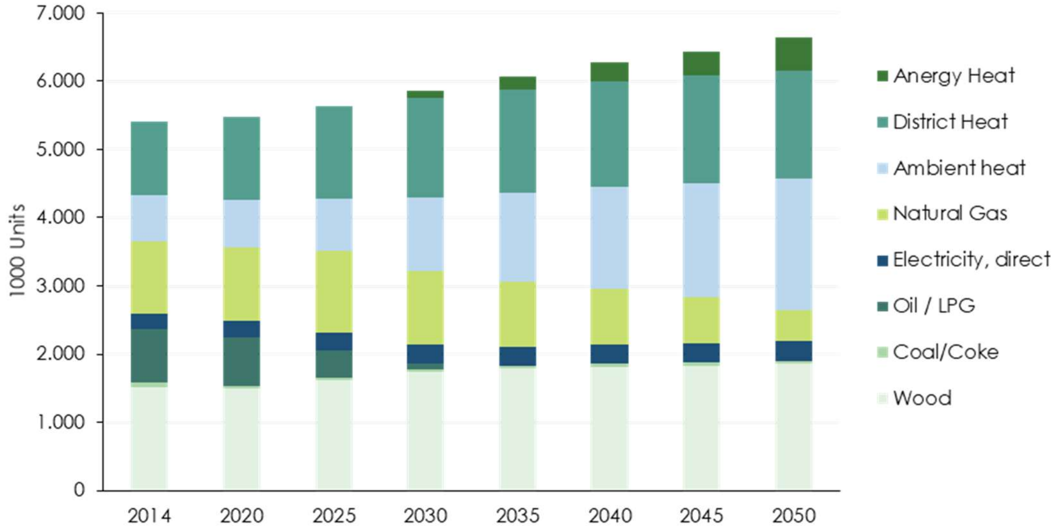

Figure 42: Heating Systems in Transition

The assumed shift of materials in the construction of new buildings for dwellings concerns the share of wood-based constructions. In Transition it is assumed that the share of these types increases to 20% until 2050. Recent literature shows, that wood materials can substitute a substantial amount of concrete without a significant cost increase (Sinabell and Streicher, 2021).

Sub-scenario improve

The improvement of the building stock refers to the thermal quality. Here two aspects are altered in the Transition scenario. First the refurbishment rate. According to the publication of IIBW (IIBW, 2020) a refurbishment rate of up to 3,2% is possible and necessary to reduce the energy demand of Austria's building stock substantially. Based on this estimates the refurbishment rate in the Transition scenario is set a little bit more conservative to 2,5% from 2025 onwards for buildings constructed before 1991 and aiming for the improved standard. The second aspect is the share of new buildings that are built in accordance with the improved standard which is set to be 100% (Table 6).

Table 6 Input parameters for building structure in Transition, in %

Constrution period	SDFB Refurbishment rate normal standard	MFB Refurbishment rate normal standard	SDFB Refurbishment rate improved standard	MFB Refurbishment rate improved standard	SDFB Depreciation rate original	MFB Depreciation rate original	SDFB Depreciation rate if refurbished	MFB Depreciation rate if refurbished	SDFB Share of New Building with improved standard	MFB Share of New Building with improved standard
-1919	0	0	2,5	2,5	1,2	1,2	0,6	0,6	*n.a.*	*n.a.*
1919-1991	0	0	2,5	2,5	0,4	0,4	0,2	0,2	*n.a.*	*n.a.*
1992-2015	0	0	0	0	0	0	0	0	*n.a.*	*n.a.*
2015-	0	0	0	0	0	0	0	0	100	100

S: Own assumptions

This set of input parameter leads to the composition of building types shown in Figure 43. The share of non-refurbished buildings decreases to 25% compared to over 30% in the baseline. The total energy demand for heating is decreasing by almost 60% from 196 PJ in 2019 to 80 PJ in 2050.

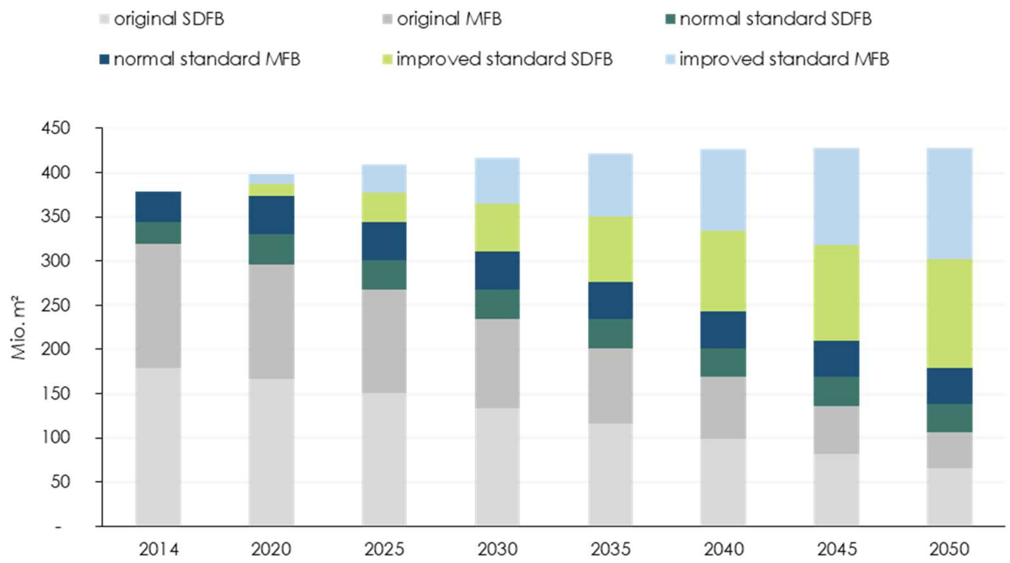

Figure 43: Building structure per refurbishment status in Transition
S: EKS, own calculations

Appendix B: Detailed Information on Co-Benefits

Method

Air Pollution

Co-benefits from reduced levels of air pollution are expected to arise due to lower emission levels of pollutants. The external costs for public transport as well as that for internal combustion engine vehicles (ICEVs) include effects on human health, crop losses, material and building damage as well as biodiversity loss (van Essen et al., 2019). For conventional passenger cars 1.209 EUR-cent/pkm are applied. For public transport on road and in the city 1.187 EUR-cent/pkm for the former and 1.243 EUR-cent/pkm for the latter are used. For public transport on rail a cost of 0.01 EUR-cent/pkm is used in van Essen et al. (2019). We apply this value to the passenger kilometers modelled for 2014, but assume that 50% of the subsequent increases in passenger kilometers on rail are met with an increase in occupancy rate, subsequent increases in pkm are this evalued with half of the external cost. Emissions are assumed to be 0 for walking and bicycling. While electric vehicles (EVs) have 0 tailpipe emissions, non-exhaust emissions of particulate matter (PM) from the abrasion of brake pads, release from tyres and road surface as well as the resuspension of existing road dust remain (Hooftman et al., 2016; Timmers and Achten, 2016; EEA, 2018). Using data on the share of MIT in different area classifications (metropolitan, urban, rural) from "Österreich Unterwegs" (BMVIT, 2016), averages for the sector specific costs of pollutants by van Essen et al. (2019, p. 55) are calculated. Using these, information on the average emission of the transport sector retrieved from Anderl et al. (2020) as well as and the estimation of Timmers and Achten (2016) that non-exhaust PM emissions account for approximately 90% of PM10 and 85% of PM2.5 emissions from traffic the total cost of a 100% conventional and a 100% electric fleet is estimated. For the electric fleet only non-exhaust emissions are counted. By setting the external costs of both fleets in relation, a conversion factor from the average external cost factor used for ICEVs to EVs is calculated. Thereby pkm of EVs are evaluated at 6.69% of the air pollution costs of ICEVs. The rather low value is due to the low external cost per ton of non-exhaust PM.

Congestion

As the share of motorized individual transport decreases, co-benefits connected to reduced levels of congestion are expected. The data used for the monetarization of such co-benefits reflects the average external costs of congestion calculated in the "European Handbook on external costs of transport" by using a deadweight-loss approach. This calculates the demand in excess to a socially optimal solution which is estimated using a social marginal cost function. The social marginal cost function includes the average travel cost born by road users and adds the additional travel time generated by the marginal vehicle that reduces speed for all other vehicles (van Essen *et al.*, 2019, p. 105). Following this approach 0.56 EUR-cent/pkm are applied for passenger cars, where no difference between ICEVs and EVs is assumed. For public transport on road a value of 0.09 EUR-cent/pkm is used and public transport within cities is evaluated with an external cost factor of 0.24 EUR-cent/pkm. Public transport on rail is not considered in the calculations as it is a scheduled mode of transport and hence generally not subject to congestion. Following Gössling et al. (2019, p. 71) external costs of 0 are applied for walking as well as bicycling. In van Essen *et al.* (2019) a second approach to estimating the external cost of congestion is presented. In the delay cost approach congestion cost is defined as the value of travel time lost relative to a free flow situation. The values using this approach are much higher with 3.2 EUR-cent/pkm for cars, 0.51 EUR-cent/pkm for public transport on road and 1.35 for public transport in the city. Using the delay cost approach would lead to co-benefits from congestion dominating the results with yearly co-benefits above 1 billion EUR from 2032 and reaching their maximum at 2.254 bil. EUR in 2050. Using the deadweight-loss approach we calculate a more conservative estimation for co-benefits from congestion that reach their maximum at 387.3 mil. EUR in 2050. For a more detailed discussion on the two approaches to monetization see Chapter 7 and Annex F of van Essen *et al.* (2019).

Noise

Co-benefits connected to noise are expected from a shift towards active mobility, as well as from reduced vehicle numbers as mobility transitions towards using public transportation. The noise reduction potential of EVs as opposed to ICEVs is only significant for urban areas with speeds below or around 30 km/h and commonly stationary traffic (RIVM, 2010; UBA-DE, 2013; Campello-Vicente et al., 2017; EEA, 2018). This is because noise emissions are only dominated by engine noise at low speeds. The contribution of tyre-road noise increases with increased velocity and starts to dominate noise pollution at around 30 km/h (UBA-DE, 2013; Campello-Vicente et al., 2017). The noise reductuion potential of EVs compared to ICEVs sinks to 1 dB at 50 km/h and becomes insignificant at higher velocities (RIVM, 2010; Campello-Vicente et al., 2017; EEA, 2018). No differentiation in MIT velocities is made within the model, hence the same value for external costs of noise of 0.57 EUR-cent/pkm is applied for EVs and ICEVs resulting in the calculated co-benefits being an underestimation especially for urban areas. The same assumption of increasing occupancy rates within public transport on rail as in subsection air quality is made. Hence 2014 passenger kilometers are evaluated at 100% cost of 1.72 EUR-cent/pkm while subsequent increases in pkm are valued at half cost. All passenger kilometers of road PT and city PT are evaluated at 0.23 EUR-cent/pkm and 0.24 EUR-cent/pkm respectively. For walking and cycling an external cost of 0 is assumed.

Physical Activity

With a modal split shifting towards increased levels of active transport health benefits connected to the increased levels of physical activity arise. Active mobility brings benefits including reduced risk of cardiovascular disease, reduced levels of obesity and the relief of symptoms of depression and anxiety (Gössling et al., 2019; Maier, Posch and Proß, 2020). These are quantifiable when taking into account reduced costs of medical treatments, fewer sick leaves and longer life expectancy. For the calculation of the co-benefits the HEAT tool was used. HEAT evaluates the monetary benefits of increased activity levels by calculating the deaths prevented by additional minutes of walking/cycling and monetizing mortality with a value of statistical life (VSL) which for Austria is calculated at 3750000 EUR/death. HEAT uses the active passenger kilometers per person per day for the population aged between 20 and 64 in biking and 20 and 74 in walking as inputs. To calculate the share of modelled passenger kilometers travelled by the age groups covered in HEAT, information on the expected development of the population and age composition from O'Neill *et al.* (2017) is used. The population grouped by age is then multiplied with a factor for the percentage share of the age group in total pkm on foot and bike and the modelled passenger kilometers to retrieve the passenger kilometers per person for the respective age group. Information of the percentage share of age groups is calculated using data of Österreich Unterwegs (BMVIT, 2016, Annex C Part 4) which show the passenger kilometers travelled in different modes of transportation classified by age group. The passenger kilometers are then divided by 365 and the total population (20-64 or 20-74) to convert them to the needed passenger kilometers per person per day. For the calculations a discount factor of 0% is applied.

prices used for external costs (EUR/pkm)

	air pollution	congestion	noise
walking	0	0	0
bicycling	0	0	0
cMIT	1.209	0.56	0.57
eMIT	0.081	0.56	0.57
RailPT	0.01	0	1.72
RoadPT	1.187	0.09	0.23
CityPT	1.243	0.24	0.24

Source: values taken from the "European Handbook on external costs of transport" (van Essen *et al.*, 2019)

Detailed results

Results from increased physical activity using the HEAT tool

The results for co-benefits arising from increased physical activity are calculated in five-year steps as the underlying data on population developments by O'Neill *et al.* (2017) are modelled in the same time steps.

Table 7 Source: calculations using HEAT (WHO, 2017)

year	change in mobility/person/day (minutes)	death prevented/year	economic value (€)
2014	0	0	0
2015	0	0	0
2020	0.04	1	3,610,000
2025	2	40	152,000,000
2030	8	141	530,000,000
2035	10	185	695,000,000
2040	12	214	802,000,000
2045	13	230	863,000,000
2050	13	233	847,000,000

Results Co-benefits in total

Table 8 Detailled results of the co-benefits from Access

Year	co-benefits congestion (€)	co-benefits noise (€)	co-benefits air pollution (€)	co-benefits physical health (€)	co-benefits total (€)
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0		0
2017	0	0	0		0
2018	677,808	623,448	-47,716		1,253,540
2019	1,372,506	1,262,804	-109,098		2,526,212
2020	12,633,737	11,992,663	24,988,663	3,710,000	53,325,063
2021	21,087,900	17,368,284	41,608,110		80,064,294

Year	co-benefits congestion (€)	co-benefits noise (€)	co-benefits air pollution (€)	co-benefits physical health (€)	co-benefits to-tal (€)
2022	30,679,092	23,272,227	60,597,804		114,549,122
2023	40,000,294	27,670,435	78,414,919		146,085,648
2024	50,144,282	31,732,681	97,646,921		179,523,884
2025	61,300,979	35,410,087	118,640,859	153,000,000	368,351,926
2026	73,509,298	38,355,826	141,317,544		253,182,667
2027	87,219,568	40,750,237	166,633,278		294,603,083
2028	102,741,977	42,470,725	195,130,968		340,343,670
2029	120,445,112	43,361,776	227,446,592		391,253,480
2030	143,542,823	46,053,160	269,916,223	534,000,000	993,512,206
2031	165,214,773	42,407,275	308,286,913		515,908,961
2032	198,622,675	33,384,768	368,903,159		600,910,602
2033	225,303,985	27,363,834	414,969,999		667,637,819
2034	246,765,818	23,632,871	449,711,358		720,110,047
2035	264,174,813	21,647,364	475,612,168	698,000,000	1,459,434,345
2036	278,340,548	20,718,365	515,751,245		814,810,157
2037	291,706,649	25,548,297	551,436,413		868,691,359
2038	303,182,145	31,571,163	580,172,402		914,925,710
2039	313,206,959	38,579,171	603,447,991		955,234,121
2040	322,122,507	46,411,288	622,370,151	806,000,000	1,796,903,947
2041	330,135,661	54,764,480	637,330,676		1,022,230,817
2042	337,508,335	63,719,086	649,370,894		1,050,598,315
2043	344,398,182	73,199,526	658,947,220		1,076,544,929
2044	350,926,663	83,146,627	666,402,926		1,100,476,216
2045	357,187,022	93,513,817	673,962,100	868,000,000	1,992,662,939
2046	363,146,808	103,961,282	678,776,441		1,145,884,531
2047	368,960,099	114,761,754	681,800,463		1,165,522,317
2048	374,667,118	125,891,282	683,181,760		1,183,740,159
2049	380,297,752	137,330,158	683,042,502		1,200,670,412
2050	387,318,228	154,589,422	684,736,871	877,000,000	2,103,644,521

Appendix C: Further results

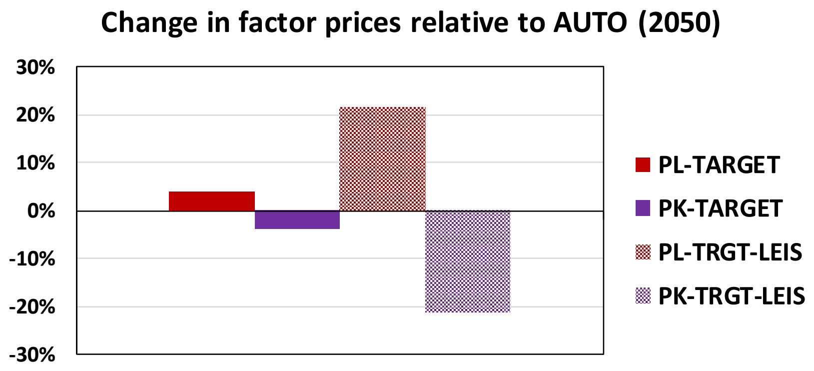

Figure A 1: TARGET and TRGT-LEIS relative to AUTO 2050 factor prices; PL … wage rate, PK … capital rent.

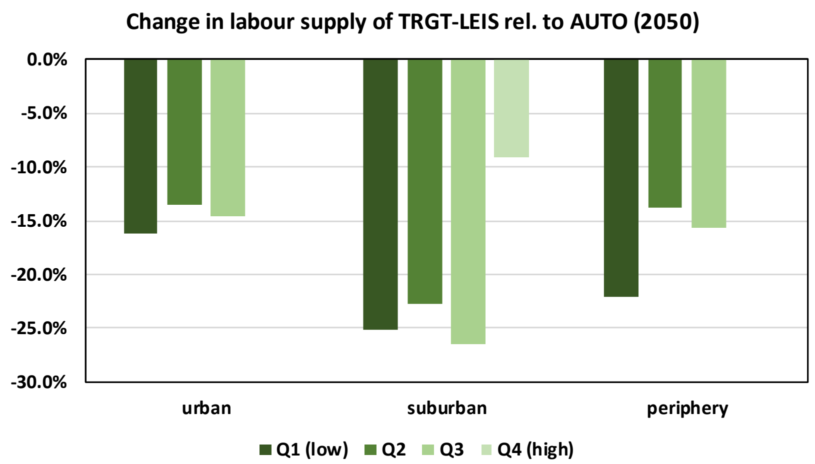

Figure A 2: TRGT-LEIS relative to AUTO 2050 labour supply adjustments across households.

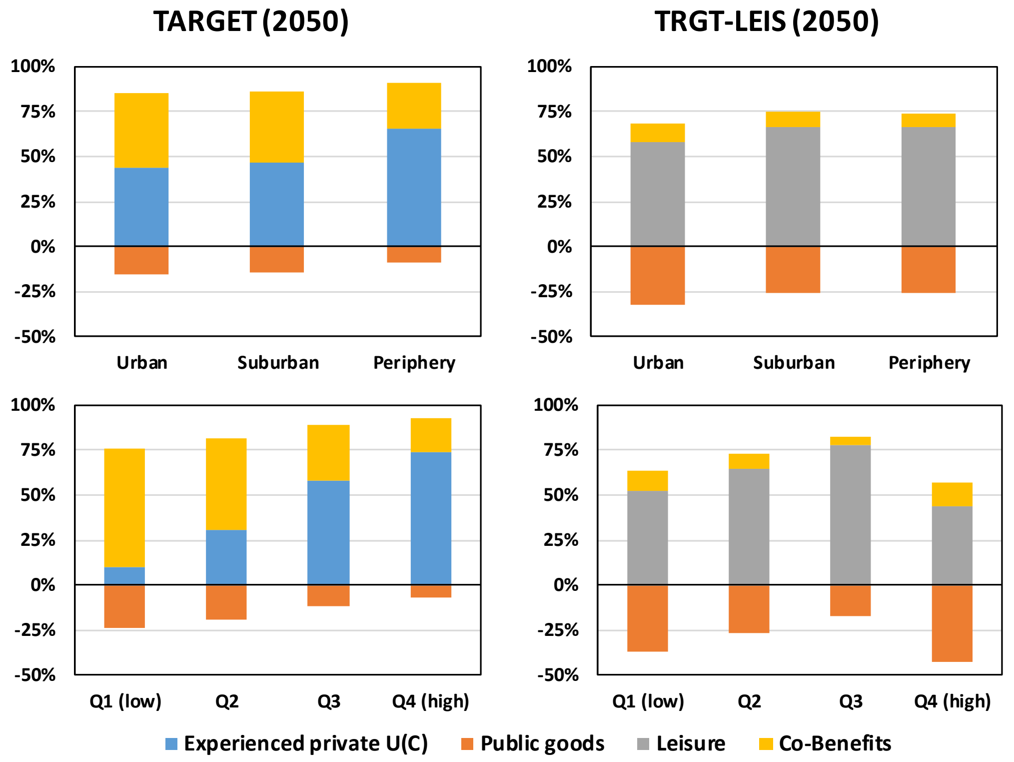

Figure A 3: TARGET and TRGT-LEIS 2050 wellbeing drivers across residence locations (top) and across income groups (bottom).

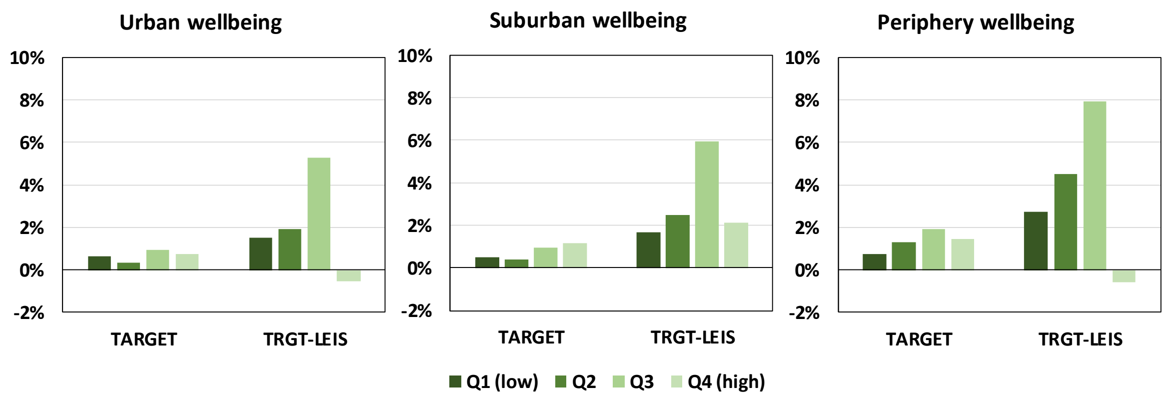

Figure A 4: TARGET and TRGT-LEIS 2050 distributional effects; percentage deviation to AUTO.

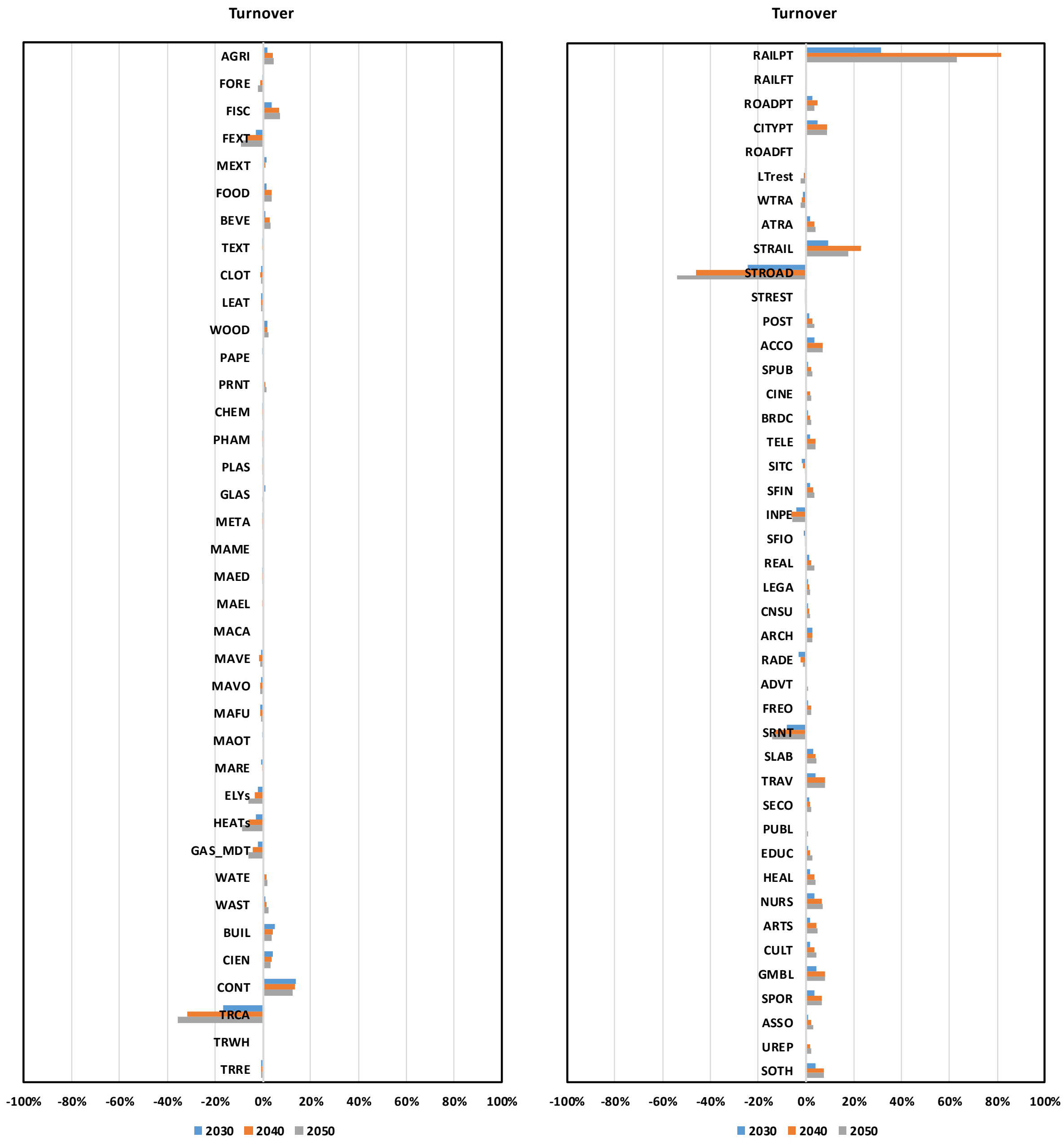

Figure A 5: TARGET 2050 sector turnover impacts relative to AUTO.

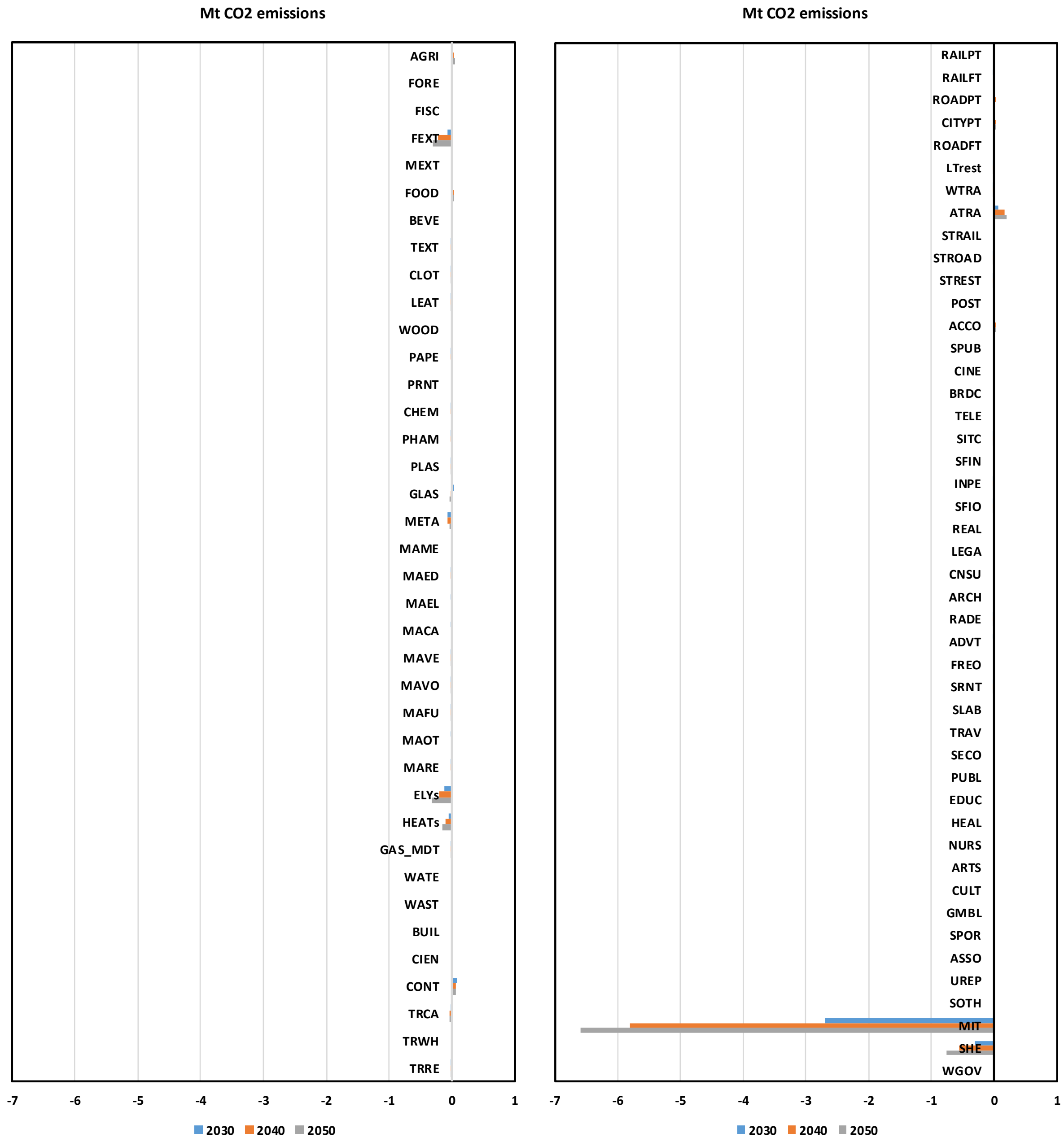

Figure A 6: TARGET 2050 sector CO2 emissions relative to AUTO.

Appendix D: Extended Model information

Table A 1: List of economic sectors in the Extended Model (WEGDYN-AT CGE model); OeNACE sector classification.

#	Model sector	OeNACE	Description	Capital-to-labour ratio
1	AGRI	A 01	Crop and animal production, hunting and related service activities	16.6
2	FORE	A 02	Forestry and logging	6.2
3	FISC	A 03	Fishing and aquaculture	7.7
4	FEXT	B 05-07; C 19	Mining of coal and lignite; Extraction of crude petroleum and natural gas; Mining of metal ores; Manufacture of coke and refined petroleum products	4
5	MEXT	B 08-09	Other mining and quarrying; Mining support service activities	1.5
6	FOOD	C 10	Manufacture of food products	1.1
7	BEVE	C 11 - C 12	Manufacture of beverages; Manufacture of tobacco products	2.5
8	TEXT	C 13	Manufacture of textiles	0.7
9	CLOT	C 14	Manufacture of wearing apparel	0.6
10	LEAT	C 15	Manufacture of leather and related products	1.2
11	WOOD	C 16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	1
12	PAPE	C 17	Manufacture of paper and paper products	1.2
13	PRNT	C 18	Printing and reproduction of recorded media	0.9
14	CHEM	C 20	Manufacture of chemicals and chemical products	1.6
15	PHAM	C 21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	1.8
16	PLAS	C 22	Manufacture of rubber and plastic products	1
17	GLAS	C 23	Manufacture of other non-metallic mineral products	0.8
18	META	C 24	Manufacture of basic metals	1
19	MAME	C 25	Manufacture of fabricated metal products, except machinery and equipment	0.8
20	MAED	C 26	Manufacture of computer, electronic and optical products	1.7
21	MAEL	C 27	Manufacture of electrical equipment	1.3
22	MACA	C 28	Manufacture of machinery and equipment n.e.c.	1
23	MAVE	C 29	Manufacture of motor vehicles, trailers and semi-trailers	1.8
24	MAVO	C 30	Manufacture of other transport equipment	1.4
25	MAFU	C 31	Manufacture of furniture	0.6
26	MAOT	C 32	Other manufacturing	1.5
27	MARE	C 33	Repair and installation of machinery and equipment	0.7
28	ELYs		Electricity supply	2.7
29	HEATs	D 35	Steam and air conditioning supply	1
30	GAS_MDT		Gas supply	0.3
31	WATE	E 36	Water collection, treatment and supply	4.7
32	WAST	E 37-39	Sewerage; Waste collection, treatment and disposal activities; materials recovery; Remediation activities and other waste management services	2.7
33	BUIL	F 41	Construction of buildings	2.3
34	CIEN	F 42	Civil engineering	0.3
35	CONT	F 43	Specialised construction activities	0.7

#	Model sector	OeNACE	Description	Capital-to-labour ratio
36	TRCA	G 45	Wholesale and retail trade and repair of motor vehicles and motorcycles	0.6
37	TRWH	G 46	Wholesale trade, except of motor vehicles and motorcycles	1.3
38	TRRE	G 47	Retail trade, except of motor vehicles and motorcycles	0.9
39	RAILPT	H 49	Rail passenger transport	1.6
40	RAILFT		Rail freight transport	0.8
41	ROADPT		Road passenger transport	2.7
42	CITYPT		City passenger transport	0.8
43	ROADFT		Road freight transport	1
44	LTrest		Land transport rest	3.1
45	WTRA	H 50	Water transport	0.8
46	ATRA	H 51	Air transport	2.7
47	STRAIL	H 52	Warehousing and support activities for rail transportation	1.9
48	STROAD		Warehousing and support activities for road transportation	1.9
49	STREST		Warehousing and support activities for rest	1.9
50	POST	H 53	Postal and courier activities	1
51	ACCO	I 55-56	Accommodation; Food and beverage service activities	3.1
52	SPUB	J 58	Publishing activities	2.7
53	CINE	J 59	Motion picture, video and television programme production, sound recording and music publishing activities	0.2
54	BRDC	J 60	Programming and broadcasting activities	1.9
55	TELE	J 61	Telecommunications	1.9
56	SITC	J 62-63	Computer programming, consultancy and related activities; Information service activities	1.9
57	SFIN	K 64	Financial service activities, except insurance and pension funding	0.4
58	INPE	K 65	Insurance, reinsurance and pension funding, except compulsory social security	1.8
59	SFIO	K 66	Activities auxiliary to financial services and insurance activities	0.8
60	REAL	L 68	Real estate activities	2.4
61	LEGA	M 69	Legal and accounting activities	0.8
62	CNSU	M 70	Activities of head offices; management consultancy activities	2.1
63	ARCH	M 71	Architectural and engineering activities; technical testing and analysis	0.9
64	RADE	M 72	Scientific research and development	0.7
65	ADVT	M 73	Advertising and market research	0.4
66	FREO	M 74-75	Other professional, scientific and technical activities; Veterinary activities	0.9
67	SRNT	N 77	Rental and leasing activities	23
68	SLAB	N 78	Employment activities	1.9
69	TRAV	N 79	Travel agency, tour operator and other reservation service and related activities	0.5
70	SECO	N 80-82	Security and investigation activities; Services to buildings and landscape activities; Office administrative, office support and other business support activities	1.4
71	PUBL	O 84	Public administration and defence; compulsory social security	0.1
72	EDUC	P 85	Education	1.2
73	HEAL	Q 86	Human health activities	3.1
74	NURS	Q 87-88	Residential care activities; Social work activities without accommodation	13.2

#	Model sector	OeNACE	Description	Capital-to-labour ratio
75	ARTS	R 90	Creative, arts and entertainment activities	0.1
76	CULT	R 91	Libraries, archives, museums and other cultural activities	0.3
77	GMBL	R 92	Gambling and betting activities	0.8
78	SPOR	R 93	Sports activities and amusement and recreation activities	0.3
79	ASSO	S 94	Activities of membership organisations	0.3
80	UREP	S 95	Repair of computers and personal and household goods	0.8
81	SOTH	S 96	Other personal service activities	0.2

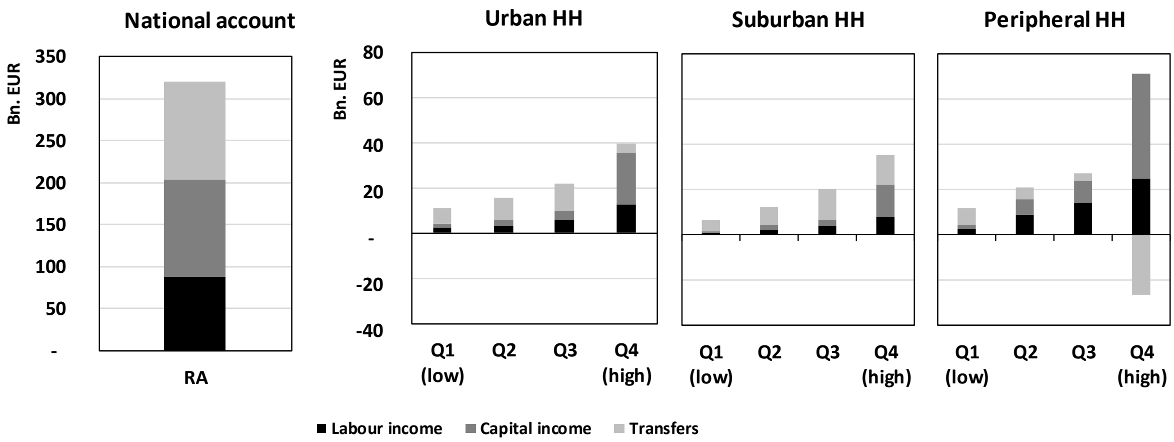

Figure A 7: Distribution and sources of income for the representative private agent (RA) of national account statistics and across private households groups (Q1 - low income and Q4 - high income) based on (Statistik Austria, 2014b, 2014c; Fessler and Schürz, 2017).

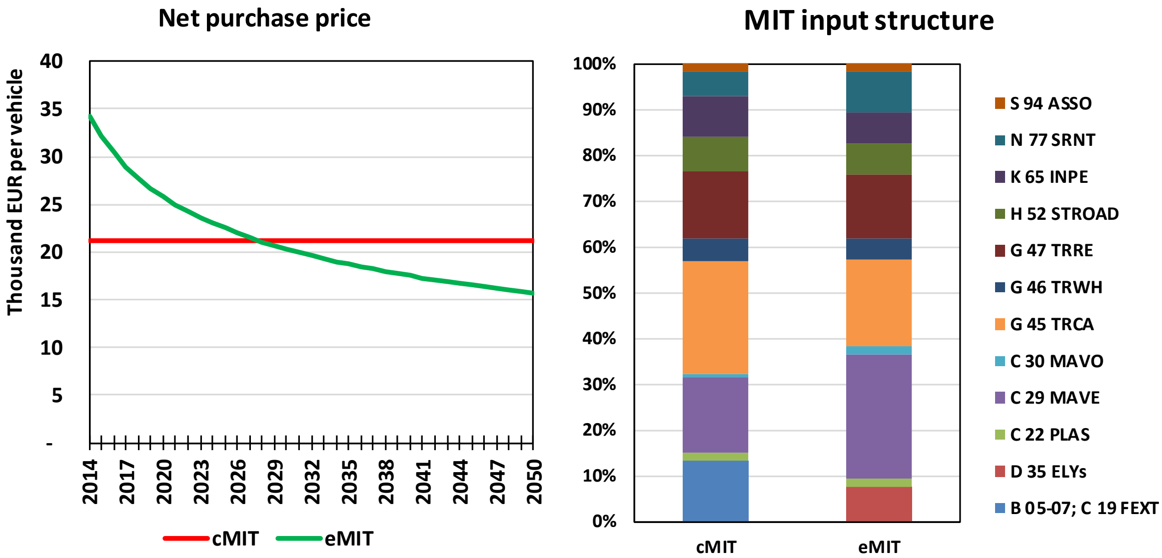

Figure A 8: Net purchase price of MIT (left) and input structure (right) based on (Lutsey and Nicholas, 2019) and (Kreyenberg, 2016).