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## Abstract

While the potential of carbon pricing to curb $CO_2$ emissions is widely acknowledged, the instrument keeps being disputed due to its potential regressivity and the burden it places on low-income households. Recently also the issue of horizontal inequalities has gained in importance in political and scientific discussions, especially with respect to regional differences in the impacts of carbon pricing. We link the macroeconomic model DYNK with the microsimulation model EASI_AT to analyse the effects of carbon pricing under various revenue recycling options, focusing on the regional dimension of the distributional effects of carbon pricing policies. This approach allows combining the detailed household representation of the microsimulation approach with information on the macroeconomic feedback effects. Our results confirm that carbon pricing, without revenue recycling, generally places a higher burden on households living in peripheral regions due to their higher dependence on motorised individual transport, larger dwellings, and a higher prevalence of oil heating systems. However, lump-sum payments targeted at low incomes significantly improve the situation for peripheral regions (the cost of living decreases for 94 percent of households in the lowest income quintile). Ultimately, targeted support (e.g., subsidies for exchanging heating systems) is required to alleviate the burden for low-income households.

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# Investigating equity and efficiency in carbon pricing with revenue recycling: A combined macro- and micro-modelling approach

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**Abstract**

While the potential of carbon pricing to curb $CO_2$ emissions is widely acknowledged, the instrument keeps being disputed due to its potential regressivity and the burden it places on low-income households. Recently also the issue of horizontal inequalities has gained in importance in political and scientific discussions, especially with respect to regional differences in the impacts of carbon pricing. We link the macroeconomic model DYNK with the microsimulation model EASI_AT to analyze the effects of carbon pricing under various revenue recycling options, focusing on the regional dimension of the distributional effects of carbon pricing policies. This approach allows combining the detailed household representation of the microsimulation approach with information on the macroeconomic feedback effects. Our results confirm that carbon pricing, without revenue recycling, generally places a higher burden on households living in peripheral regions due to their higher dependence on motorized individual transport, larger dwellings, and a higher prevalence of oil heating systems. However, lump-sum payments targeted at low incomes significantly improve the situation for peripheral regions (the cost of living decreases for 94% of households in the lowest income quintile). Ultimately, targeted support (e.g. subsidies for exchanging heating systems) is required to alleviate the burden for low-income households.

**Keywords**: carbon pricing, revenue recycling, distributional impacts, macro-micro-linkage, Austria

**JEL codes:** Q54, Q58, H23

# 1. Introduction

In recent years, the question of the distributional effects of climate policy instruments has become increasingly relevant both in research (e.g. Heindl and Löschel, 2015; Ohlendorf et al., 2021; Wang et al., 2016) and in political discussions (reflected e.g. in the development of the EU Just Transition Mechanism). This development is closely linked to the fact that the acceptance of climate policies is strongly linked to their perceived fairness (e.g. Clayton, 2018; Eriksson et al., 2008; Maestre-Andrés et al., 2019).

Distributional issues are particularly debated in the context of carbon taxation and emissions trading, which can affect households through multiple channels. The number of countries that have already implemented or are exploring options to introduce a carbon price is growing globally (World Bank, 2023). In the European Union (EU), numerous Member States have already implemented carbon prices and the EU's emissions trading scheme (EU ETS) is set to be complemented by a second emissions trading scheme (ETS 2) to include housing and mobility in 2027. Research on public support for carbon taxes as well as the example of the yellow vest movement in France, where plans to implement a fuel tax increase triggered wide-ranging social protests, highlight how important it is to address the distributional concerns that the population associates with policies directly affecting the price levels of consumption goods (Driscoll, 2023; Sommer et al., 2022; Tatham and Peters, 2023). The design and appropriate communication of carbon taxation policies requires an accurate understanding of the impact that these policies have on the welfare of different social groups. This paper contributes to this research effort, drawing on combined micro- and macroeconomic modelling to shed light on the impacts of carbon pricing and different revenue recycling options in Austria.

For high-income countries, the literature (e.g. Bureau, 2011; Callan et al., 2009; Douenne, 2020; Grainger and Kolstad, 2010; Verde and Tol, 2009; Wier et al., 2005) shows that carbon pricing tends to be regressive, since lower-income households tend to spend a higher proportion of their income on energy and also do not have the financial means to switch to emission-free technologies. This is also confirmed for Austria (e.g. Eisner et al., 2021; Kettner et al., 2024; Kirchner et al., 2019). Just as important as the vertical dimension of inequality in this context is the horizontal dimension of inequality: Households living in rural areas without access to high-quality public transport are more dependent on the use of a car than those in urban centers with good public transport infrastructure. By recycling the revenues from carbon pricing, the regressive effects can be cushioned (e.g. Berry, 2019; Kirchner et al., 2019). Thereby, in addition to a reduction in greenhouse gas emissions, positive distribution effects can be achieved.

Two general approaches for analyzing the distributional effects of carbon pricing can be distinguished in the literature: macroeconomic modeling with little detail in the representation of households (e.g. Beck et al., 2016, 2015; de Bruin and Yakut, 2024; Ekins et al., 2011; Mayer et al., 2021; Orlov and Grethe, 2012) and microsimulation approaches, which comprise a wide range of household details but cannot take macroeconomic feedbacks into account (e.g. Berry, 2019; Douenne, 2020; Flues and Thomas, 2015; Tovar Reaños and Lynch, 2022; van der Ploeg et al., 2022). To combine the advantages of these two model types, they have been increasingly linked in recent years (see Table 1). The results of these analyses confirm that regressive effects of carbon pricing can be compensated by targeted recycling measures (in particular lump-sum payments). However, the positive distribution effects come at the cost of losses in competitiveness, i.e. the combined model approaches also find a trade-off between equity and efficiency in recycling. Although both the vertical and the horizontal distributional dimensions are of importance to assess comprehensively the impact of carbon pricing on households, most of the existing studies focus only on the income distribution (and thus on the vertical dimension) to differentiate between households.

Table 1. Summary of combined macro- and micro-simulation studies on the effects of carbon pricing and energy taxation

| Source | Country(ies) | Target Year | Household Types | Carbon Price/ Tax Design | Tax Coverage | Revenue Recycling Option(s) | Distribution Effects (Carbon Pricing + Recycling) | Macroeconomic Effects compared to Baseline |
|---|---|---|---|---|---|---|---|---|
| Bach et al. (2002) | Germany | 2030 | Income terciles + Other characteristics[1] | Energy taxes differentiated by energy source | Economy-wide | Non-wage labor cost reductions | Regressive | GDP: Neutral - negative[2]<br>Employment: positive |
| Araar et al. (2011) | Canada | Not reported | Income quintiles | ETS price | Economy-wide | Output-based allocation | U-shaped | GDP: negative,<br>Employment: positive |
| | | | | | | Non-wage labor cost reductions | U-shaped | GDP: positive,<br>Employment: positive |
| | | | | | | VAT reduction | U-shaped | GDP: negative,<br>Employment: positive |
| Buddelmeyer et al. (2011) | Australia | 2030 | Income quintiles | Not reported | ETS | Lump-sum payments | Progressive | Not reported |
| Vandyck & Regemorter (2014) | Belgium | 2050 | Income deciles | Mineral oil tax | Economy-wide | Non-wage labor cost reductions | Regressive | GDP: negative,<br>Employment: positive |
| | | | | | | Increase in social transfers | Progressive | GDP: negative,<br>Employment: negative |
| Landis (2019) | Switzerland | 2050 | Income quintiles | Carbon price | Economy-wide | Lump-sum payments | Progressive | Not reported |
| | | | | | | Non-wage labor cost reductions | Regressive | |
| | | | | | | VAT reduction[3] | Regressive | |
| Fremstad & Paul (2019) | USA | Not reported | Income deciles[5] | Uniform carbon price | Economy-wide | Lump-sum payments | Progressive | Not reported |
| | | | | | | Labor tax reductions[4] | Regressive | |
| | | | | | | Payroll tax reductions[4] | Regressive | |
| Goulder et al. (2019) | USA | 2050 | Income quintiles | Uniform carbon price | Economy-wide | Lump sum payments | Progressive | GDP: negative |
| | | | | | | Income tax reduction[4] | Regressive | GDP: negative |
| | | | | | | Non-wage labor cost reductions | Regressive | GDP: negative |
| Vandyck et al. (2021) | 11 EU countries[6] | 2030 | Income deciles | ETS price | ETS | Lump-sum payments | Progressive | Not reported |
| Malerba et al. (2021) | Peru | Not reported | Households in poverty[7] + Other characteristics[8] | Uniform carbon price | Economy-wide | Increase in social transfers | Progressive | Not reported |
| | | | | | | Lump-sum payments | Progressive | |
| Ravigné et al. (2022) | France | 2035 | Income deciles + Other characteristics[9] | Uniform carbon price | Economy-wide | Lump-sum per-capita rebate | Progressive | Not reported |
| | | | | | | Lump-sum poverty-targeted rebate | Progressive | |
| | | | | | | Lump-sum living-standard rebate | Regressive | |
| | | | | | | Lump-sum rural-targeted rebate | Neutral | |
| Antosiewiecz et al. (2022) | Poland | 2030 | Income deciles | Uniform carbon price | Economy-wide | Lump sum payments | Progressive | GDP: negative,<br>Employment: negative |
| | | | | | | Energy price subsidies | Progressive | GDP: negative,<br>Employment: negative |
| | | | | | | Labor tax reductions[2] | Regressive | GDP: negative,<br>Employment: positive |

Notes: [1]Household composition, employment status. [2]Depending on macroeconomic model used. [3]On necessary commodities. [4]For employees. [5]Additional disaggregations available: race & ethnicity, age, urban/rural. [6]AUT, BEL, CZE, EST, FIN, FRA, GER, GRC, ITA, ROU, ESP. [7]Different metrics. [8]Geographical region, type of region. [9]E.g. size of urban unit, type of dwelling, region.

In this paper, we link the macroeconomic model DYNK with the microsimulation model EASI_AT to study the effects of unilateral carbon pricing in Austria under seven revenue recycling mechanisms. Our central contribution is to analyze a broad range of different recycling options and to examine in detail the regional dimension of the distributional effects of carbon pricing. Moreover, we are among the few studies not only presenting detailed distributional effects but also macroeconomic results. Our findings extend previous results for Austria based on a comparison of different macro-modelling approaches, which have highlighted how challenging it is to identify policy designs that can advance environmental, social and economic objectives at the same time (Kirchner et al., 2024; Kettner et al., 2024). While we focus on one country, the results represent a benchmark for other highly industrialized countries (with small, open economies) and provide general insights for the design of revenue recycling measures.

The structure of the paper is as follows: Section 2 outlines the policy scenarios and introduces the macroeconomic model DYNK and the microsimulation model EASI_AT used for analyzing the macroeconomic and distributional effects. In section 3, we then describe the simulation outcomes. Section 4 delves into the limitations and potential expansions of our analysis, and section 5 concludes.

# 2. Methods

## 2.1 Policy Scenarios

We analyze the effects of carbon pricing in combination with seven options for revenue recycling and compare the results to a reference scenario without national carbon pricing:

- PDS – Public Debt Service: no revenue recycling;
- CBR – Climate Bonus Recycling: equal per capita payments to all Austrian households;
- CBRlow – Climate Bonus Recycling for low- and middle-income households: equal per capita payments to low- and middle-income households only, i.e. households in the first three quintiles in terms of equivalized household income;
- LCR – Non-wage Labor Cost Reduction: reduction in employers' non-wage labor costs;
- VTR – Value Added Tax Reduction: further reduction in the value added tax on basic necessity goods currently covered by reduced rates (e.g. food and beverages, books, etc.);
- MIX, MIXlow – Combinations of Reductions in Non-wage Labor Costs and Climate Bonus Payments to all Austrian households (MIX) or to low- and middle-income households (MIXlow).

For all recycling options we assume that all revenues generated by national carbon pricing are spent on the recycling measures. The option without revenue recycling (PDS) can be considered as a second baseline scenario, in the sense that we simulate the full effects of higher carbon prices without direct compensatory measures for households or firms. The other recycling options chosen for the analysis represent well-established options that have already been implemented and should be able to significantly mitigate the impacts of carbon pricing on vulnerable households and/or on the economy's competitiveness. For a detailed discussion of all revenue recycling options, please refer to Kettner et al. (2024). Green spending – i.e. investments in renewable energy or energy efficiency – was not considered as a recycling option, since neither DYNK nor EASI_AT can adequately assess this option without information from bottom-up energy system models.

With respect to carbon pricing, a national carbon price is defined for fossil fuels sectors not covered by the EU Emission Trading Scheme (EU ETS). The carbon price hence applies primarily to transport and buildings as well as industry not included in the EU ETS and as of YEAR covers approximately 41% of total Austrian $CO_2$ emissions. We take the price path for the development of the national carbon price implemented by the Austrian government in September 2022 (Austrian Government, 2022) as a starting point: The carbon price started at €30 per t $CO_2$ in 2022 and in annual steps is increased to €55 in 2025 (see Table 2)[1]. After 2025, we assume a moderate price development increasing linearly to €90 per t $CO_2$ in 2030 (in nominal terms). This increase between 2025 and 2030 amounts to approximately 10% p.a., a growth rate that e.g. was also assumed by Edenhofer et al. (2019), developing a lower carbon price path for Germany until 2030[2]. In addition, we perform sensitivity analysis on the results for a higher national carbon price: For this analysis, we start with a higher price of 50 € per ton of $CO_2$ – i.e. the average price level observed in the EU ETS between January and October 2021 – which is then linearly increased to 156 € per ton in 2030. This price increase corresponds to the increase of the carbon price for current non-ETS sectors up to 2030 as assumed in the 'Mix-CP' scenario in the Impact Assessment of the 'Fit for 55' Package (European Commission, 2021). Results for the sensitivity analysis are displayed in Appendices B and E.

Table 2: Assumed development of carbon prices in €/t $CO_2$

| | ETS Price (Baseline)* | | Non-ETS Price | | Non-ETS Price Sensitivity Analysis | |
|---|---|---|---|---|---|---|
| | nominal | real | nominal | real | nominal | real |
| 2022 | 50 | 46 | 30 | 27 | 50 | 46 |
| 2023 | linear increase | | 35[#] | 31 | …..<br>linear increase<br>…. | |
| 2024 | | | 45 | 40 | | |
| 2025 | 69 | 60 | 55 | 48 | | |
| 2026-2029 | linear increase | | linear increase | | | |
| **Target 2030** | **102** | **83** | **90** | **73** | **156** | **127** |

Note: Real prices refer to the price level 2015; *ETS price already active in baseline in order to isolate effects of non-ETS $CO_2$ pricing. [#]Note that due to the large increase in energy prices following the war in Ukraine, in 2023 the Austrian carbon price was reduced to 32.5 €/t $CO_2$ (see Kettner et al., 2024).

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[1] While the Austrian emissions trading system follows the German model in many respects, it contains a major deviation in the form of a price stabilization mechanism. This provides for the increase in the $CO_2$ price to be adjusted if energy prices rise or fall significantly. If, in year t, energy prices rise or fall by more than 12.5% year-on-year in the first three quarters, the price increase planned for year t+1 is halved or doubled. For example, in 2023 the price would be €32.5 instead of €35 if the price index for fossil fuels in the first three quarters of 2022 is more than 12.5% higher than in the previous year. By contrast, if the index falls by more than 12.5%, the $CO_2$ price for 2023 would rise to €37.5. The $CO_2$ prices set for subsequent years would remain unaffected by such adjustments. They would only be adjusted in the event of a renewed undercutting or overshooting.

[2] The Austrian price path corresponds to the initial price development defined for the German emissions trading system in the period until 2030.

## 2.2 Macroeconomic Modelling

The model DYNK (Dynamic New Keynesian) is an economic model that covers the economy of a specific region, in this case Austria, on a macro level. This means that the monetary flows within this economic entity are aggregated to specified agents, i.e. firms as well as public and private consumers. Firms and the provided products and services are aggregated into 76 sectors and 76 commodity groups. Private and public households have specific consumption structures and sources of income. Private households receive income in the form of wages, surplus and transfers, whereas public households collect taxes and consume these products.

The model is based on the Input-Output model approach but expands it by implementing behavioral functions of consumers and producers as well as a dynamic development using trend extrapolation (e.g. for exports). Thereby the model's behavior partly resembles DSGE (Dynamic Stochastic General Equilibrium) models as it trends towards a long-term equilibrium on the labor market. The simulation – using time series analysis – of institutional rigidities on this labor market in the short-term reflects the New-Keynesian feature.

Like CGE (Computable General Equilibrium) models, DYNK inherits a price system based on the unit-cost approach where the output price is defined by input prices. Input prices are determined by the prices of intermediary products, imported products, taxes as well as labor and capital costs. The firms face these costs and minimize them within the framework of an econometrically estimated Translog production function that comprises five factors: capital, labor, imports, domestic products, and energy. The expenditure of private households is modelled in a two-layer nesting consumption function: On the first layer, the demand for durable and non-durable commodities is determined in dependence of disposable income and prices. On the second layer of non-durable commodities, the share between energy and non-energy commodities is calculated. Furthermore, expenditure for energy is determined in specific equations for mobility, heating, and electricity demand. The structure of non-energy commodities is further determined by an Almost Ideal Demand System (AIDS) model.

A main feature of the model is the linkage of the monetary consumption of energy commodities to physical energy usage as well as energy related emissions. This allows us to implement emission specific taxes on commodities and to show how agents (as private households) are affected by that, and how emissions develop under the given assumptions.

Another central feature of DYNK is the flexible disaggregation of private households. Based on data from the Austrian Household Budget Survey (HBS), households can be disaggregated into specific groups which then differ in terms of income and the structure of consumption. For this analysis of the effects of carbon pricing in Austria, 20 household groups have been defined, along income quintiles and four areas of residence by degree of urbanization (Vienna, other urban, suburban, peripheral).[3]

A more detailed description of the DYNK model is provided in the Annex to Kirchner et al. (2019)[4].

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[3] I.e. household groups are formed by first assigning all Austrian households to income quintiles based on their equivalized household income and then distribute these households to regions based on their area of residence. This ensures that income quintiles have the same thresholds in all regions.

[4] https://ars.els-cdn.com/content/image/1-s2.0-S0301421518307535-mmc2.pdf

## 2.3 Microsimulation Modelling and Linking with the Macroeconomic Model

The applied EASI demand system for Austria – referred to as EASI_AT in the following – is a static microsimulation model that simulates the effects of exogenously given price and expenditure changes on private household demand. It is an updated version of the model used in Eisner et al. (2021), which itself is based on Lewbel and Pendakur (2009). The EASI demand system with the budget shares $w_j$ for each of the *j* goods has the following linear-in-parameter form:

$$w_j = \sum_{r=0}^{5} b_{rj} y^r + \sum_{l=1}^{L} \left( C_{lj} z_l + D_{lj} z_l y \right) + \sum_{l=0}^{L} \sum_{k=1}^{J} A_{lkj} z_l p_k + \sum_{k=1}^{J} B_{kj} p_k y + \varepsilon_j$$

where $y$ is the implicit utility, also interpretable as a measure of log real expenditure, and given by

$$y = \frac{\left( \log(x) - \boldsymbol{p}'\boldsymbol{w} - \sum_{l=0}^{L} \frac{z_l \boldsymbol{p}' \boldsymbol{A_l} \boldsymbol{p}}{2} \right)}{1 - \frac{\boldsymbol{p}' \boldsymbol{B} \boldsymbol{p}}{2}}.$$

The $L$ considered household characteristics are denoted with $z_l$, with the intercept $z_0 = 1$, $p_k$ is the log price of each good $k$, and $x$ is the nominal total expenditure. The demand system includes the interaction terms of household characteristics and utility ($z_l y$), of household characteristics and log prices ($z_l p_k$), and of log prices and utility ($p_k y$). However, we set the interaction term of log prices and utility ($p_k y$) to zero. $A$, $B$, $C$, $D$ and $b$ denote matrices and vectors consisting of the coefficients. Finally, $\varepsilon_j$ represents an individual error term. For more details on the algebraic formulation see Eisner et al. (2021) and Lewbel and Pendakur (2009).

EASI_AT is estimated with data from the four most recent waves of the HBS, i.e. 2004/05, 2009/10, 2014/15, 2019/20, provided by Statistics Austria. Household data is matched with consumer price indices at the state level for the years 2004, 2005, 2009, 2010, 2014, 2015, 2019 and 2020, published by Statistics Austria. The base year of the EASI_AT model is 2019. The goods classification matches the one of HBS, which is classified according to the Classification of Individual Consumption by Purpose (COICOP). The model comprises eight commodity groups: motor fuels, electricity, heating, housing, food, non-durables, durables and others.

To account for heterogeneous household preferences, EASI_AT includes socio-demographic variables and housing attributes that allow differentiating the consumption behavior of different groups in society. This includes household composition (i.e. single with/without child, couple with/without child), the construction year of the dwelling, primary energy source of the heating system, floor space, age of the main person in the household, legal status of the dwelling (rented or owned), and the degree of urbanization of the dwelling location based on the classification of EUROSTAT (2019). Following the same procedure as in DYNK, household income or expenditure is equalized using the OECD-modified equivalence scale (Hagenaars et al., 1994), which assigns a value of 1 to the first household member, a value of 0.5 to each additional adult member and a value of 0.3 to each child.

The linking between DYNK und EASI_AT is based on the changes in consumption expenditures and in commodity prices taking place over the simulation period. For the baseline and each considered recycling scenario, DYNK provides EASI_AT with the relative changes between 2019 and 2030 in consumption expenditures (i.e. available income minus savings) per household type (defined by income quintile and degree of urbanization) and in commodity prices according to the COICOP classification. EASI_AT treats the relative changes in consumption like sudden exogenous shocks.

Considering the data of thousands of different households, the microsimulations allow for additional detail in the analysis of the impacts of carbon pricing on households compared to the macrosimulations, including distributional effects. Different approaches and numerous indicators are available to assess the distributional impact that carbon pricing and the associated recycling options can have on households. We use the cost-of-living index (CoL) to measure the impacts on households' consumption possibilities. Evaluations at the level of expenditure deciles in combination with socio-demographic variables already give a first impression of the distributional impact. In addition, we apply two widely used inequality indicators, the Gini index and the Atkinson index, which can provide a comprehensive picture of changes in inequality because they are sensitive to changes in different parts of the distribution (Safar, 2022).

***Cost of living index***

The cost-of-living index (CoL) measures the relative change in total expenditure required by a private household to maintain the initial level of utility after a change in prices (see e.g. Lewbel and Pendakur, 2009). The applied version of the index also accounts for any potential compensating transfers accompanying this change in prices:

$$CoL = \frac{C(\boldsymbol{p}_1, u_0, \boldsymbol{z}, \varepsilon) - t_1}{C(\boldsymbol{p}_0, u_0, \boldsymbol{z}, \varepsilon)} - 1$$

where $x = C(\boldsymbol{p}, u, \boldsymbol{z}, \varepsilon)$ represents the minimum total expenditure required by an individual household with observable characteristics $\boldsymbol{z}$, unobserved preference characteristics $\varepsilon$ and facing log price vector $\boldsymbol{p}$ to obtain utility level $u$. While $\boldsymbol{p}_0$ and $u_0$ denote the initial log price vector and utility level in the baseline, $\boldsymbol{p}_1$ refers to the final log price vector including the carbon price. The term $t_1$ denotes any compensating transfer accompanying carbon pricing.

***Gini index***

The Gini index (Gini, 1912) is a measure of statistical dispersion and intended to indicate the income or wealth inequality across the population. It is based on the Lorenz curve, which plots the cumulative percentages of total income against the cumulative population. The Gini index indicates how much the Lorenz curve deviates from the line of total equality (i.e. the 45-degree line):

$$G = \frac{S}{(S + T)}$$

where $S$ is the area between the hypothetical line of total equality and the Lorenz curve, and $T$ is the area between the Lorenz curve and the line of total inequality (i.e. the axes). A Gini index of zero indicates total equality, a Gini index of one total inequality.

***Atkinson index***

The Atkinson index ($A_\varepsilon$) can be used as a measure of distributional fairness to rank policy options by considering both efficiency and equity. Its central feature is a parameter for inequality aversion that explicitly links social welfare with inequality (Cowell, 2000). The Atkinson index lies between zero and one, where zero indicates complete equality. Intuitively, an index value of 0.2, for example, indicates that, if incomes were distributed equally, the same level of social welfare could be achieved with only 80% of the current income (Maio, 2007).

The Atkinson index includes the metric of "equivalent income", which – according to King (1983) – is the income level that gives the same utility as the current income level, but under a set of different prices. Note that in demand systems, consumption expenditure is a proxy for income. Following Creedy and Sleeman (2006) and Tovar Reaños and Wölfing (2018), we define "equivalent income" – or "equivalent expenditure" – $x_e$ as the solution to:

$$V(x_e,\, p_0,\, z,\, \varepsilon) = V(x_0 + t_1,\, p_1,\, z,\, \varepsilon)$$

where $u = V(x,\, p,\, z,\, \varepsilon)$ is the indirect utility for an optimal consumption vector of an individual household with total expenditure $x$, observable characteristics $z$, unobserved preference characteristics $\varepsilon$ and facing log price vector $p$. While $p_0$ and $x_0$ denote the initial log price vector and the initial total expenditure in the baseline, $p_1$ refers to the final log price vector including the carbon price. The term $t_1$ again denotes any compensating transfer accompanying carbon pricing.

When calculating the Atkinson index, we largely follow Landis (2019) with some minor adjustments. First, we apply the OECD-modified equivalence scale (Hagenaars et al., 1994) instead of the square root scale in deriving the mean equivalent income ($MEI$) to stay consistent in our analyses. Second, we define the mean equivalent income as a per-household figure rather than a per-capita figure:

$$MEI = \frac{1}{\sum_{h\in H} w_h} \sum_{h\in H} \frac{w_h x_{e,h}}{hsize_h}$$

$$A_\varepsilon = 1 - \frac{1}{MEI}\left[\frac{\sum_{h\in H} w_h \left(\frac{x_{e,h}}{hsize_h}\right)^{1-\varepsilon}}{\sum_{h\in H} w_h}\right]^{\frac{1}{1-\varepsilon}}$$

where $w_h$ is the statistical weight of household $h$ and $\varepsilon$ is the parameter of inequality aversion. The inequality aversion parameter reflects a value judgement on inequality and can take values between 0 and infinity. A value of $\varepsilon = 0$ would imply that social welfare depends only on mean income whereas, with increasing values for $\varepsilon$, changes in lower incomes receive relatively more weight in the assessment of social welfare. Typically, values for ε between 0.5 and 2 are used for the parametrization of inequality aversion (De Maio, 2007). We follow Landis (2019) and choose $\varepsilon = 1.25$, a value which is derived from empirical estimates for the marginal utility of income provided by Layard et al. (2008).

# 3. Results

In the following we first present and discuss the findings of the macroeconomic model DYNK and then focus on the detailed distributional impacts estimated by the microsimulation model EASI_AT.

The reduction in non-ETS $CO_2$ emissions achieved by national carbon pricing in scenario A ranges between 5.3% and 5.5% in 2030 compared to the baseline and depending on the recycling scenario chosen (see Table A1 in Appendix A). This very low sensitivity of emission reduction with regard to the recycling scenarios indicates that, in the simulations with the DYNK model, no significant rebound effects are assumed.

The introduction of carbon pricing without revenue recycling to households and companies (PDS scenario) is associated with significant negative impacts on GDP (-0.37% compared to the baseline without carbon pricing in non-ETS sectors in 2030). Climate bonus payments to all households (CBR) also lead to a decline in GDP. Climate bonus payments to low- and middle-income households (CBRlow), by contrast, result in a neutral GDP effect, as do the recycling options assuming a reduction in VAT (VTR) and a mix of climate bonus recycling to all households and a reduction in non-wage labor costs (MIX). With a pure reduction in non-wage labor costs (LCR), on the other hand, GDP increases by 0.09% compared to the reference scenario without national carbon pricing. A combination of non-wage labor cost reduction and targeted climate bonus payments for low to medium incomes (MIXlow) can also increase GDP compared to the reference scenario.

A reduction in non-wage labor costs is naturally associated with positive employment effects. For the LCR recycling option, employment increases by 0.58% in 2030 compared to the reference scenario without national carbon pricing, while both in the MIX and MIXlow scenario, where the reduction in non-wage labor costs is combined with climate bonus payments to households, it still increases by approximately 0.25%. The VAT reduction option is also characterized by a slightly positive effect on employment. Although pure climate bonus recycling (CBR and CBRlow) reduces the negative effect of $CO_2$ pricing on employment, the net effect remains negative for both variants.

In terms of household consumption expenditure, carbon pricing in non-ETS sectors without revenue recycling (PDS) has a strongly negative effect (-0.67% compared to the reference scenario without national carbon pricing in 2030). A reduction in non-wage labor costs (LCR) delivers a neutral result, while the other reimbursement options have a positive effect. The highest increases are shown for the option of climate bonus payments to low and medium incomes (CBRlow, +0.67%), followed by the VAT reduction option (+0.53%). The considerably stronger increase in CBRlow as compared to CBR reflects the fact that the payments to low-income households are directly used for consumption.

Finally, the consumer price index (CPI) which is a key variable for linking with the microsimulation model EASI_AT compared to the baseline without carbon pricing increases for all recycling options except for the reductions in VAT. This is a direct result of the price increases resulting from carbon pricing that are not mitigated by the other forms of revenue recycling. Particularly high increases in the CPI show for climate bonus recycling, which reflects higher consumer spending.

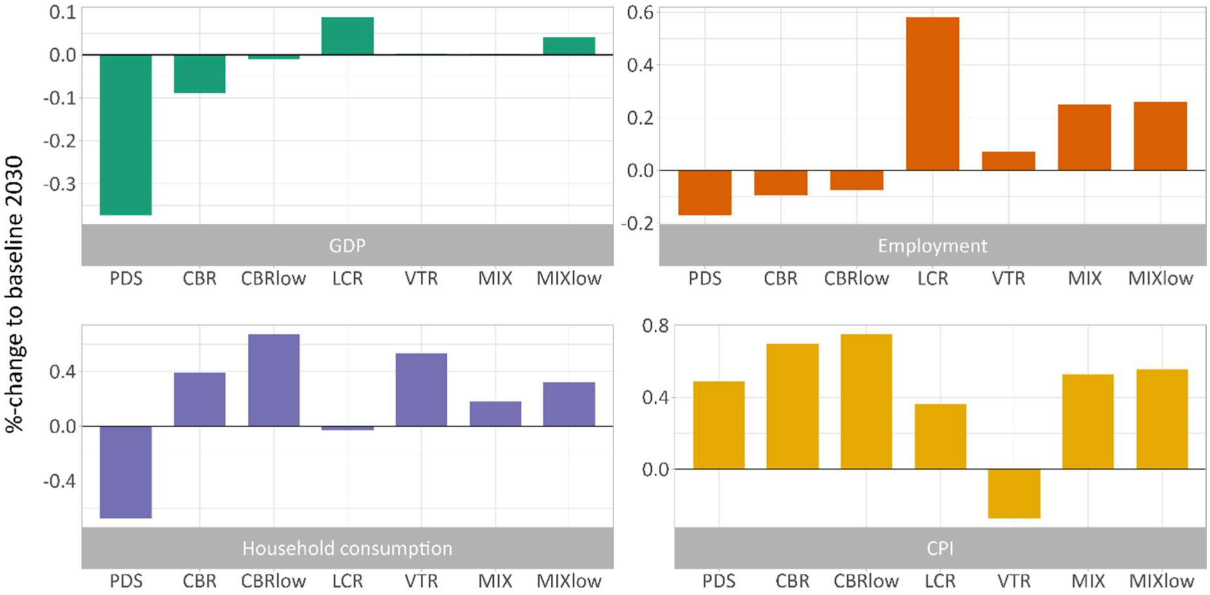

Figure 1: Effects of the policy scenarios on GDP, employment and household consumption compared to the baseline scenario without national carbon pricing in 2030 (DYNK)

In Figure 2, we assess the distributional impacts associated with the different recycling options, distinguishing between income quintiles and regions by degree of urbanization. When revenue is used to service public debt (PDS) as well as in the labor-cost reduction (LCR) and the VAT-reduction (VTR) options, the policy effects are (broadly speaking) equally distributed along the income distribution. As expected, with all three options households in peripheral regions fare worse than those in urban and especially those in metropolitan areas. This is true both at the aggregate level over all income quintiles and when we look more in detail at regional differences within income quintile (see also Table A. 2 in Appendix A). In all subgroups we consistently see that households in Vienna benefit more (or are affected less negatively) than those in peripheral areas, although the distribution is not always monotonic along density in all quintiles and recycling options. The differences, however, are comparatively low, ranging for the most part between 0.1 and 0.2 percentage points.

When revenues from carbon pricing are either fully or partially recycled via a climate bonus payment, by contrast, we can observe both horizontal as well as vertical distributional effects. Recycling all revenues towards low- to medium- income households (CBRlow) has the strongest distributional impact, leading to an increase in household consumption by 3.2% in the bottom quintile and a reduction by 0.6% in the top quintile of the income distribution. Lump-sum payments to all households (CBR) clearly have a less skewed distributional effect, but they still lead to an improvement by 1.6% in consumption for the households at the lower and a deterioration by –0.6% at the upper end of the distribution. Combining lump-sum payments to households with a reduction in labor costs (MIX and MIXlow scenarios) leads, as expected, to effects that lie between those of the corresponding pure revenue recycling options. Overall, with both combined recycling options the households in the first three income quintiles profit from the measures, whereas those in the two top quintiles see a reduction in consumption possibilities.

In a horizontal perspective, recycling via climate bonus payments displays similar patterns as the other recycling scenarios, characterized by more favorable outcomes for more densely populated areas and less favorable outcomes for less densely populated ones. The differences are more pronounced in the lower parts than in the upper parts of the income distribution. For instance, consumption increases by 3.3% in the metropolitan area of Vienna and by 2.8% in the peripheral regions for the poorest households in CBRlow, while it decreases by -0.6% and similarly by -0.7% for the richest households. Also, it is noteworthy that in recycling options that involve climate bonus payments, households in urban areas outside Vienna rather than those in the metropolitan area tend to benefit more (or to be affected less negatively). This can be seen most clearly in scenario CBR and concerns particularly the households in the middle of the distribution.

These macro-based results provide useful insights into the impact of various policy measures on different population segments. However, due to the high degree of aggregation and the limited number of data points, with this approach it is not possible to calculate comprehensive distribution measures or to identify more subtle differences between household types. To enable a more thorough evaluation and to assess the equity effects of different policy options, in the next step we turn to the results of the microsimulation analysis.

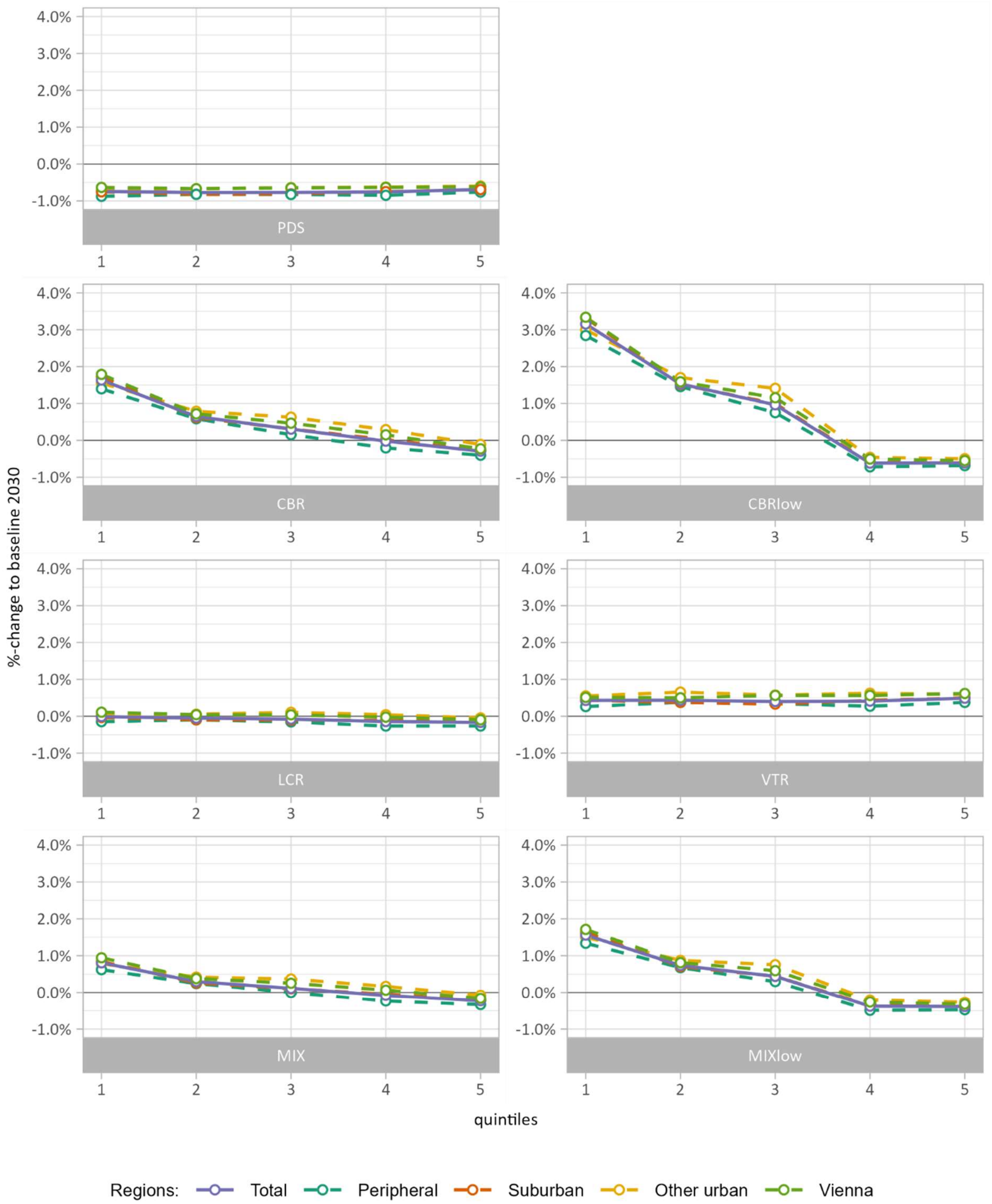

Figure 2: Effects of the main policy scenarios on household consumption by income group and region compared to the baseline scenario without national carbon pricing in 2030 (DYNK)

Taking a closer look at the distributional effects, we analyze the relative change in the households' cost of living for the different recycling scenarios across expenditure deciles, differentiating between various degrees of urbanization. Figure 3 illustrates how much more or less expensive it is for households in the respective scenario to achieve the same level of utility as in the baseline scenario.

As expected, when revenues from carbon pricing are not recycled (PDS), the cost of living increases for all households (see also Table D. 1 in Appendix D). In contrast to the aggregated perspective of the macrosimulation, the disaggregated microsimulation results show a slight regressive nature of carbon pricing in this scenario, i.e. relative increases in the cost of living tend to be more pronounced for poor households than for more affluent ones. Moreover, carbon pricing tends to affect households in rural regions (peripheral, suburban) more strongly than households in urban regions (other urban, Vienna). Reasons include a higher share of oil-heating systems (23% in peripheral regions versus 1% in Vienna), larger living spaces (126 m² in peripheral regions vs. 73 m² in Vienna) and hence higher overall expenditures on heating (2.4% of budget share in peripheral regions vs. 2.0% of budget share in Vienna) as well as higher car dependency and thus higher expenditures on fossil fuels (3.9% of budget share in peripheral regions versus 1.7% of budget share in Vienna).

The regressive effect of carbon pricing is more or less neutralized in the case of the labor cost reduction (LCR) and the VAT reduction (VTR). The latter is the only scenario where the cost of living decreases across all household and population segments. More precisely, the overwhelming majority of households (86%; see Table D. 1) is better off than in the baseline without carbon pricing. The micro-simulation underscores that the decrease in consumer prices in the VTR scenario has positive welfare effects. The opposite, however, is observed for the labor-cost reduction, with an increasing cost of living across all household segments (i.e. only 8% of households are better off than in the baseline without carbon pricing; Table D. 1). The decrease in available income (consumption expenditure) and the rise in consumer prices trigger the relatively high increase in the cost of living in LCR.

We also find that revenue recycling options including direct payments to households (i.e. CBR, CBRlow, MIX and MIXlow) are able to reverse the regressive nature of carbon pricing into a progressive effect, i.e. increases in the cost of living tend to be weaker and decreases tend to be stronger for poorer households than for more affluent ones (see Figure 3). These recycling options also show particularly pronounced regional differences for poorer households. In the case of CBRlow and the two poorest deciles, for instance, the cost of living only decreases by about 1.5% for households in peripheral regions, but by more than 4% for households in any of the three denser regions. The reason is that households from one and the same decile do not distribute evenly across regions. Particularly in the two poorest deciles, the relatively more affluent households tend to live in peripheral regions, implying that poverty is more pronounced in the more urban regions. However, the poorer the household, the higher the relative benefit from lump-sum payments.

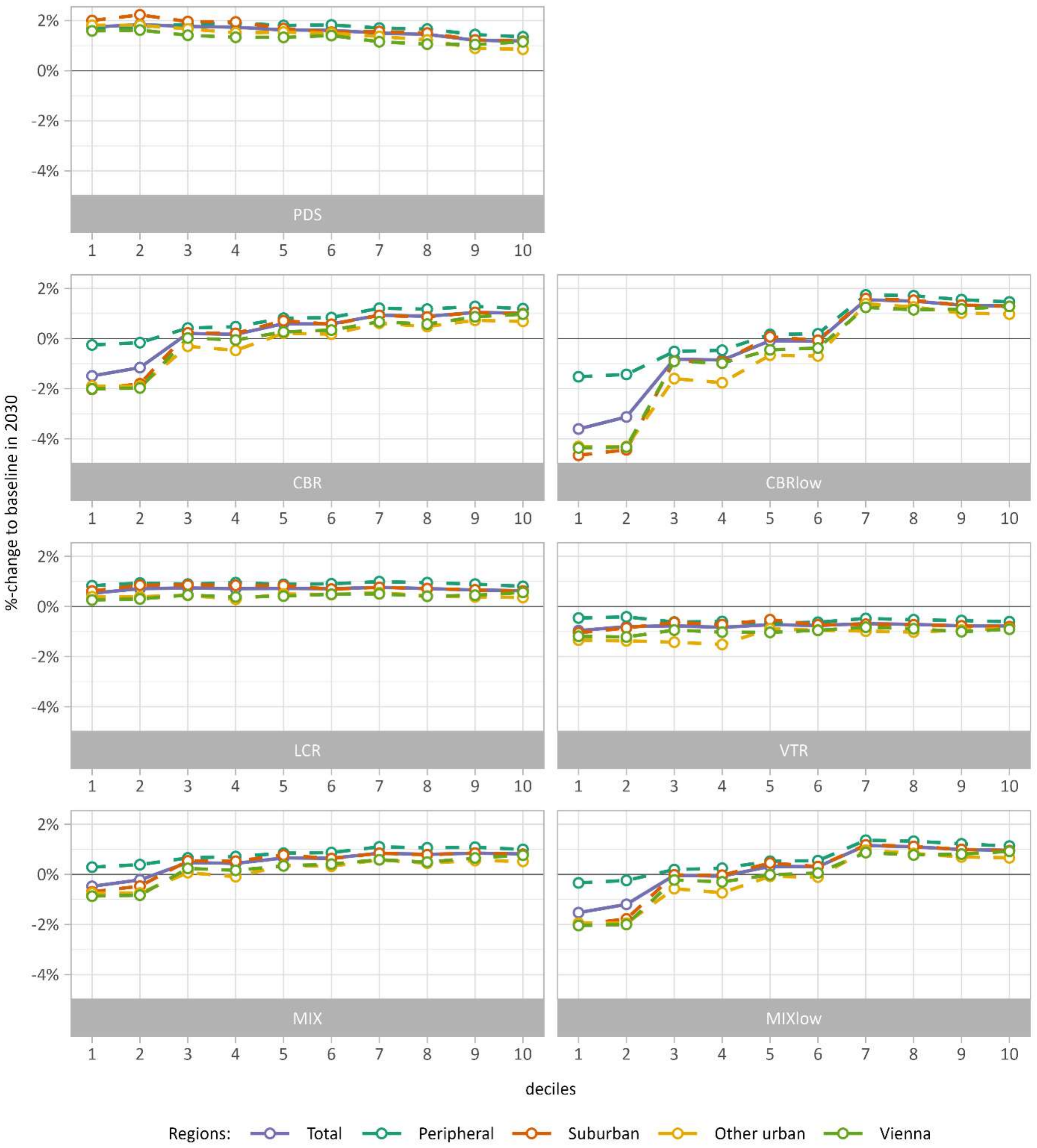

Figure 3: Relative change in cost of living for main policy scenarios across expenditure deciles, differentiating between different degrees of urbanization (EASI_AT)

While the change in the cost of living per decile in Figure 3 already gives an impression of the distributional impact of carbon pricing under different revenue recycling options (progressive, neutral, regressive), the Gini index and the Atkinson index in Table 3 summarize the equity effects in a synthetic measure. Both indices show a very similar pattern across the different revenue recycling options. Relative changes in the Atkinson index are usually more pronounced than the relative changes in the Gini index, but the direction of change and the ranking of the recycling schemes completely coincide. The highest decrease in each index – and hence the strongest improvement in equality and distributional fairness – is found for the lump-sum revenue recycling option CBRlow, followed by MIXlow, CBR and MIX. Recycling via VAT and labor cost reductions (VTR and LCR) show hardly any difference to the baseline in terms of inequality. Without revenue recycling (PDS), by contrast, distributional fairness decreases.

Both VTR and LCR manage to more or less neutralize negative distribution impacts of carbon pricing without recycling (PDS), while those revenue recycling options including direct payments to households result in an overcompensation of negative distribution impacts of carbon pricing. In the CBR, MIX and MIXlow options, increased equality and distributional fairness however come at the cost of a higher overall cost of living. CBRlow, by contrast, results in both a lower overall cost of living and lower income inequality compared to the baseline without carbon pricing. Still, the VTR option provides the highest decrease in the overall cost of living and the majority of households is by far better off, although equity effects are negligible.

Table 3: Aggregated results for the main policy scenarios (EASI_AT)

| | CoL index (%-change in cost of living to baseline) | Gini index | Gini index (%-change to baseline) | Atkinson index | Atkinson index (%-change to baseline) |
|---|---:|---:|---:|---:|---:|
| Baseline | - | 0.2539 | - | 0.1277 | - |
| PDS | +1.57% | 0.2552 | +0.51% | 0.1288 | +0.84% |
| CBR | +0.28% | 0.2509 | -1.21% | 0.1245 | -2.56% |
| CBRlow | -0.29% | **0.2469** | **-2.77%** | **0.1208** | **-5.44%** |
| LCR | +0.69% | 0.2541 | +0.06% | 0.1278 | +0.05% |
| VTR | **-0.78%** | 0.2539 | -0.01% | 0.1276 | -0.07% |
| MIX | +0.48% | 0.2525 | -0.57% | 0.1261 | -1.26% |
| MIXlow | +0.20% | 0.2505 | -1.35% | 0.1243 | -2.73% |

Note: Most favorable outcome for each indicator is printed in bold.

## 4. Discussion

Several conclusions can be drawn from our combined macro-micro analysis. All the investigated revenue recycling options are equally conducive to reducing emissions and thus to achieve the main aim pursued with carbon pricing. However, the implications of revenue recycling mechanisms differ considerably with respect to macroeconomic efficiency and distributional equity. Only policy options that include labor cost reductions are associated with positive macroeconomic effects in terms of both

GDP and employment, while lump-sum transfers to households do not neutralize the distortionary effects of carbon pricing on the economy. By contrast, the latter lead to more favorable outcomes than labor cost reductions in terms of household consumption and, in particular, in terms of distributional effects. Reducing the value added tax occupies an intermediate position, with positive or at least neutral effects on macroeconomic indicators and positive effects on consumption possibilities combined with a neutral impact on the income distribution. Thus, a first contribution of our results is to highlight the challenges of assessing carbon pricing policies with multiple objectives in mind, confirming that "the path to manage distributional effects of climate policies, while achieving the desirable economic and environmental outcomes, is narrower than previously thought" (Vona, 2023, p. 8).

Secondly, our analyses underscore the salience of accounting for the regional dimension of carbon pricing effects on households. The impacts of carbon pricing, without any revenue recycling, vary by region due to different household characteristics and socio-demographics. This is not surprising, when considering that households in peripheral and suburban regions live in larger dwellings and thus need to spend larger shares of their budgets on heating than households in the metropolitan Vienna and other urban regions (see Table C. 2 and Figure C. 1 in Appendix C). Moreover, oil heating systems – in Austria the heating fuel with the highest $CO_2$eq emission factor – are more prevalent in peripheral and suburban regions.

Households in peripheral and suburban regions also show a higher dependence on the private car and thus higher expenditure shares on fossil fuels (see Table C. 3 in Appendix C). Regional differences in the budget shares on fossil fuels are most pronounced among the poorest quartile of households, since budget shares on fossil fuels peak much earlier in peripheral and suburban regions than in the metropolitan Vienna (see Figure C. 1 in Appendix C). In the latter, for example, poor households rarely own cars and therefore spend little money on fuel. Regional differences in household expenditure and income are also reflected in the analysis of the different recycling options. In the case of flat-rate payments households in peripheral regions benefit the least (CBR, CBRlow, Mix, Mixlow), while households in urban areas benefit the most. This effect is particularly strong for low-income households. Nevertheless, also in peripheral regions, for 94% of the households from the lowest income quintile and respectively for 78% of households from the second income quintile the cost of living decreases compared to the baseline if carbon pricing is combined with climate bonus payments for low incomes (CBRlow).

For the remaining cases of hardship in the bottom income quintiles, targeted transfers could cushion cost increases for motorized individual transport until public transport infrastructure in rural (and sub-urban) areas is enhanced. This aligns with previous findings that combining per-capita payments with hardship compensation reduces the variability in burden across household types while simultaneously benefiting poorer households (Edenhofer et al., 2021). Moreover, targeted subsidies for the installment of renewable heating systems in the poorest households could compensate negative impacts related to housing.

This discussion highlights a third point, namely that to address equity and efficiency as well as environmental concerns, the introduction of carbon pricing requires the combination of different revenue recycling mechanisms but possibly also of other flanking measures. This is all the truer as a complete welfare analysis should go beyond income and consumption and include other dimensions of well-being to fully assess distributional impacts (Fullerton, 2011; Vona, 2023). Carbon pricing is thus best understood as part of a range of tools to pursue a broader strategy in which the achievement of climate targets is linked to other sustainable development goals.

# 5. Conclusions

Macroeconomic models might not be sufficiently detailed for identifying revenue recycling options for carbon pricing that address distributional issues, which can be avoided by linking top-down macroeconomic models with microsimulation models. This aspect of the analysis could still be enhanced for Austria by an iterative linking of DYNK and EASI_AT allowing for feedbacks, or by including more information on the income components of the different household types in DYNK. Moreover, carbon pricing just constitutes one element in the policy mix needed for achieving the emission reduction targets. Other instruments, such as bans of fossil heating systems or of cars with combustion engines but also subsidies, might entail different effects regarding the combination of environmental, social and macroeconomic effects should also be addressed by respective macro and micro policy assessments.

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# Appendix A: Detailed macro results for the Main Carbon Price Scenario

Table A. 1: Percentage change in non-ETS emissions, GDP, employment and consumption compared to Baseline in 2030 in the Main Carbon Price Scenario (DYNK)

| | *Employment* | *GDP* | *Household Consumption* | *Non-ETS Emissions* |
|---|---|---|---|---|
| *PDS* | *-0.17* | *-0.37* | *-0.67* | *-5.55* |
| *CBR* | *-0.09* | *-0.09* | *0.39* | *-5.39* |
| *CBRlow* | *-0.07* | *-0.01* | *0.67* | *-5.35* |
| *LCR* | *0.58* | *0.09* | *-0.03* | *-5.34* |
| *VTR* | *0.07* | *0.00* | *0.53* | *-5.47* |
| *MIX* | *0.25* | *0.00* | *0.18* | *-5.37* |
| *MIXlow* | *0.26* | *0.04* | *0.32* | *-5.35* |

Table A. 2: Percentage change in household consumption compared to Baseline in 2030 in the Carbon Price Scenario (DYNK)

| *Scenario* | *Region* | *Q1* | *Q2* | *Q3* | *Q4* | *Q5* | *TOT* |
|---|---|---|---|---|---|---|---|
| *PDS* | *Peripheral* | -0.88 | -0.82 | -0.83 | -0.85 | -0.76 | -0.83 |
|  | *Suburban* | -0.75 | -0.82 | -0.81 | -0.75 | -0.69 | -0.77 |
|  | *Other urban* | -0.71 | -0.67 | -0.64 | -0.62 | -0.60 | -0.65 |
|  | *Vienna* | -0.63 | -0.67 | -0.65 | -0.63 | -0.62 | -0.64 |
|  | *Total* | -0.74 | -0.77 | -0.77 | -0.76 | -0.69 | -0.67 |
| *CBR* | *Peripheral* | 1.40 | 0.59 | 0.15 | -0.21 | -0.40 | 0.31 |
|  | *Suburban* | 1.73 | 0.62 | 0.31 | 0.02 | -0.28 | 0.48 |
|  | *Other urban* | 1.56 | 0.79 | 0.63 | 0.29 | -0.11 | 0.63 |
|  | *Vienna* | 1.79 | 0.72 | 0.47 | 0.15 | -0.23 | 0.58 |
|  | *Total* | 1.64 | 0.65 | 0.31 | -0.02 | -0.29 | 0.39 |
| *CBRlow* | *Peripheral* | 2.84 | 1.46 | 0.75 | -0.72 | -0.69 | 0.73 |
|  | *Suburban* | 3.32 | 1.51 | 1.00 | -0.60 | -0.61 | 0.92 |
|  | *Other urban* | 3.00 | 1.70 | 1.41 | -0.46 | -0.50 | 1.03 |
|  | *Vienna* | 3.34 | 1.59 | 1.16 | -0.51 | -0.55 | 1.01 |
|  | *Total* | 3.15 | 1.53 | 0.96 | -0.62 | -0.61 | 0.67 |
| *LCR* | *Peripheral* | -0.15 | -0.10 | -0.15 | -0.27 | -0.26 | -0.19 |
|  | *Suburban* | -0.03 | -0.09 | -0.11 | -0.11 | -0.16 | -0.10 |
|  | *Other urban* | 0.03 | 0.05 | 0.11 | 0.04 | -0.05 | 0.04 |
|  | *Vienna* | 0.11 | 0.04 | 0.04 | -0.02 | -0.09 | 0.01 |
|  | *Total* | -0.01 | -0.05 | -0.08 | -0.14 | -0.17 | -0.03 |
| *VTR* | *Peripheral* | 0.26 | 0.38 | 0.34 | 0.27 | 0.38 | 0.33 |
|  | *Suburban* | 0.43 | 0.38 | 0.33 | 0.43 | 0.49 | 0.41 |
|  | *Other urban* | 0.55 | 0.65 | 0.57 | 0.62 | 0.59 | 0.60 |
|  | *Vienna* | 0.51 | 0.50 | 0.57 | 0.56 | 0.62 | 0.53 |
|  | *Total* | 0.43 | 0.43 | 0.40 | 0.41 | 0.49 | 0.53 |
| *MIX* | *Peripheral* | 0.62 | 0.24 | 0.00 | -0.24 | -0.33 | 0.06 |
|  | *Suburban* | 0.84 | 0.26 | 0.10 | -0.05 | -0.22 | 0.19 |
|  | *Other urban* | 0.79 | 0.42 | 0.37 | 0.17 | -0.08 | 0.33 |
|  | *Vienna* | 0.94 | 0.38 | 0.25 | 0.06 | -0.16 | 0.30 |
|  | *Total* | 0.81 | 0.30 | 0.11 | -0.08 | -0.23 | 0.18 |
| *MIXlow* | *Peripheral* | 1.34 | 0.67 | 0.30 | -0.49 | -0.47 | 0.27 |
|  | *Suburban* | 1.63 | 0.70 | 0.44 | -0.35 | -0.38 | 0.41 |
|  | *Other urban* | 1.50 | 0.87 | 0.75 | -0.21 | -0.27 | 0.53 |
|  | *Vienna* | 1.71 | 0.81 | 0.59 | -0.26 | -0.32 | 0.51 |
|  | *Total* | 1.56 | 0.73 | 0.44 | -0.38 | -0.39 | 0.32 |

# Appendix B: Detailed macro results for the Sensitivity Carbon Price Scenario

Table B. 1: Percentage change in non-ETS emissions, GDP, employment and consumption compared to Baseline in 2030 in the Sensitivity Carbon Price Scenario B

| | *Employment* | *GDP* | *Consumption* | *Non-ETS Emissions* |
|---|---|---|---|---|
| *PDS* | *-0,30* | *-0.65* | *-1.15* | *-8.49* |
| *CBR* | *-0.16* | *-0.03* | *0.65* | *-8.23* |
| *CBRlow* | *-0.12* | *-0.01* | *1.13* | *-8.16* |
| *LCR* | *0.96* | *0.13* | *-0.06* | *-8.15* |
| *VTR* | *0.12* | *0.01* | *0,95* | *-8.35* |
| *MIX* | *0.41* | *-0.01* | *0.30* | *-8.16* |
| *MIXlow* | *0.43* | *0.05* | *0.54* | *-8.16* |

Table B. 2: Percentage change in household consumption compared to Baseline in 2030 in the Sensitivity Carbon Price Scenario (DYNK)

| *Scenario* | *Region* | *Q1* | *Q2* | *Q3* | *Q4* | *Q5* | *TOT* |
|---|---|---|---|---|---|---|---|
| *PDS* | *Peripheral* | -1.53 | -1.44 | -1.45 | -1.49 | -1.34 | -1.45 |
| | *Suburban* | -1.32 | -1.44 | -1.42 | -1.31 | -1.22 | -1.34 |
| | *Other urban* | -1.24 | -1.18 | -1.12 | -1.09 | -1.05 | -1.13 |
| | *Vienna* | -1.11 | -1.17 | -1.13 | -1.11 | -1.09 | -1.12 |
| | *Total* | -1.30 | -1.35 | -1.35 | -1.21 | -1.33 | -1.15 |
| *CBR* | *Peripheral* | 2.30 | 0.94 | 0.21 | -0.40 | -0.73 | 0.46 |
| | *Suburban* | 2.87 | 0.99 | 0.47 | -0.02 | -0.51 | 0.76 |
| | *Other urban* | 2.59 | 1.29 | 1.03 | 0.45 | -0.22 | 1.03 |
| | *Vienna* | 2.98 | 1.17 | 0.75 | 0.21 | -0.43 | 0.94 |
| | *Total* | 2.72 | 1.04 | 0.47 | -0.08 | -0.54 | 0.65 |
| *CBRlow* | *Peripheral* | 4.75 | 2.41 | 1.21 | -1.26 | -1.21 | 1.18 |
| | *Suburban* | 5.56 | 2.51 | 1.63 | -1.06 | -1.07 | 1.51 |
| | *Other urban* | 5.02 | 2.83 | 2.35 | -0.81 | -0.87 | 1.70 |
| | *Vienna* | 5.60 | 2.64 | 1.91 | -0.89 | -0.96 | 1.66 |
| | *Total* | 5.28 | 2.54 | 1.58 | -1.09 | -1.07 | 1.13 |
| *LCR* | *Peripheral* | -0.30 | -0.22 | -0.31 | -0.50 | -0.50 | -0.37 |
| | *Suburban* | -0.10 | -0.21 | -0.23 | -0.24 | -0.31 | -0.22 |
| | *Other urban* | 0.00 | 0.05 | 0.15 | 0.03 | -0.11 | 0.02 |
| | *Vienna* | 0.15 | 0.03 | 0.03 | -0.08 | -0.20 | -0.02 |
| | *Total* | -0.06 | -0.13 | -0.18 | -0.29 | -0.33 | -0.06 |
| *VTR* | *Peripheral* | 0.40 | 0.61 | 0.54 | 0.42 | 0.60 | 0.51 |
| | *Suburban* | 0.71 | 0.60 | 0.53 | 0.70 | 0.81 | 0.67 |
| | *Other urban* | 0.92 | 1.09 | 0.96 | 1.05 | 0.99 | 1.00 |
| | *Vienna* | 0.85 | 0.83 | 0.94 | 0.94 | 1.02 | 0.92 |
| | *Total* | 0.43 | 0.43 | 0.40 | 0.41 | 0.49 | 0.53 |
| *MIX* | *Peripheral* | 1.01 | 0.37 | -0.05 | -0.45 | -0.61 | 0.05 |
| | *Suburban* | 1.40 | 0.40 | 0.13 | -0.12 | -0.41 | 0.28 |
| | *Other urban* | 1.31 | 0.68 | 0.59 | 0.25 | -0.17 | 0.53 |
| | *Vienna* | 1.58 | 0.61 | 0.39 | 0.07 | -0.31 | 0.47 |
| | *Total* | 1.34 | 0.46 | 0.15 | -0.18 | -0.44 | 0.30 |
| *MIXlow* | *Peripheral* | 2.25 | 1.11 | 0.46 | -0.89 | -0.86 | 0.41 |
| | *Suburban* | 2.75 | 1.16 | 0.71 | -0.65 | -0.69 | 0.66 |
| | *Other urban* | 2.54 | 1.46 | 1.26 | -0.39 | -0.50 | 0.87 |
| | *Vienna* | 2.90 | 1.35 | 0.98 | -0.49 | -0.59 | 0.83 |
| | *Total* | 2.64 | 1.21 | 0.71 | -0.69 | -0.71 | 0.54 |

# Appendix C: Some details on household characteristics

Table C. 1: Mean equivalent expenditures per region type and expenditure quintile

| *Region* | *Q1* | *Q2* | *Q3* | *Q4* | *Q5* | *TOT* |
|---|---|---|---|---|---|---|
| *Peripheral* | 1016.0 | 1501.9 | 1983.4 | 2546.1 | 3949.6 | 2161.2 |
| *Suburban* | 954.8 | 1506.5 | 1966.6 | 2552.1 | 4174.3 | 2326.5 |
| *Other urban* | 955.3 | 1523.9 | 1979.5 | 2516.2 | 4110.2 | 2327.7 |
| *Vienna* | 941.1 | 1511.3 | 1950.5 | 2540.1 | 4218.4 | 2114.9 |

Table C. 2: Median equivalent expenditures per region type and expenditure quintile

| *Region* | *Q1* | *Q2* | *Q3* | *Q4* | *Q5* | *TOT* |
|---|---|---|---|---|---|---|
| *Peripheral* | 1050.8 | 1492.9 | 1980.1 | 2537.9 | 3630.3 | 1953.9 |
| *Suburban* | 997.0 | 1490.5 | 1964.5 | 2531.6 | 3809.8 | 2026.8 |
| *Other urban* | 943.5 | 1536.7 | 1991.8 | 2524.4 | 3527.2 | 2072.0 |
| *Vienna* | 967.6 | 1504.8 | 1944.1 | 2506.5 | 3778.4 | 1825.1 |

Table C. 3: Selected household characteristics per region type

| *Region* | *Share of households with one or more private cars [%]* | *Mean household expenditures on fossil fuels [% of budget share]* | *Share of households with an oil heating system [%]* | *Share of households with a wood heating system [%]* | *Share of households with a gas heating system [%]* | *Share of households with district heating [%]* | *Mean living space per household [m²]* | *Mean household expenditures on heating [% of budget share]* |
|---|---|---|---|---|---|---|---|---|
| *Peripheral* | 89.7 | 3.9 | 23.4 | 36.3 | 13.4 | 10.6 | 125.5 | 2.4 |
| *Suburban* | 83.0 | 3.0 | 13.3 | 12.7 | 32.1 | 26.3 | 101.0 | 2.0 |
| *Other urban* | 70.9 | 2.2 | 6.1 | 2.3 | 18.5 | 61.7 | 79.9 | 1.9 |
| *Vienna* | 51.8 | 1.7 | 1.3 | 0.6 | 43.7 | 48.1 | 73.2 | 2.0 |

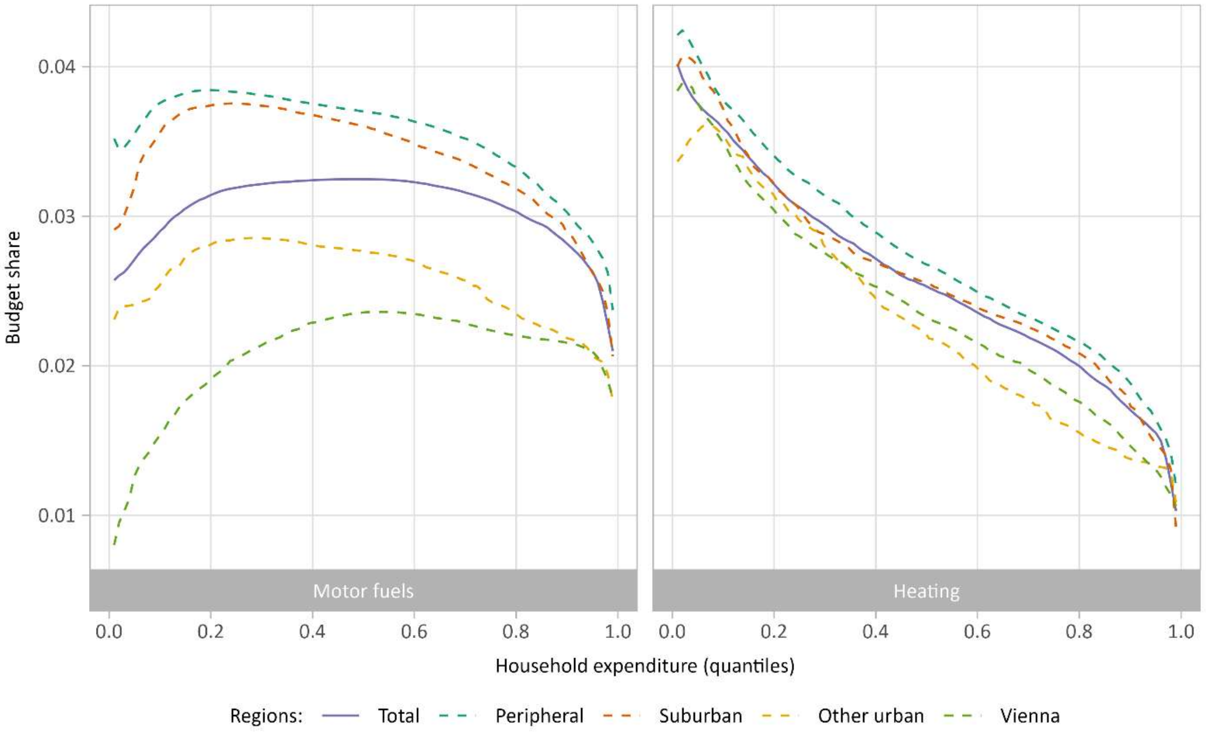

Figure C. 1: Engel curves of the microsimulation model EASI_AT, showing the budget shares of the two energy goods motor fuels and heating over total equalized monthly household consumption (in quantiles; as a proxy for income) differentiated by region type.

# Appendix D: Microsimulation results for the Main Carbon Price Scenario

Table D. 1: Share of households with a lower cost of living than in the baseline, Main Carbon Price Scenario (EASI_AT)

| *Scenario* | *Region* | *Q1* | *Q2* | *Q3* | *Q4* | *Q5* | *TOT* |
|---|---|---|---|---|---|---|---|
| *PDS* | *Peripheral* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Suburban* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Other urban* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Vienna* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Total | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *CBR* | *Peripheral* | 0.67 | 0.31 | 0.00 | 0.00 | 0.00 | 0.20 |
| | *Suburban* | 0.97 | 0.45 | 0.13 | 0.00 | 0.00 | 0.27 |
| | *Other urban* | 1.00 | 0.82 | 0.40 | 0.10 | 0.00 | 0.43 |
| | *Vienna* | 0.99 | 0.66 | 0.30 | 0.00 | 0.00 | 0.44 |
| | Total | 0.87 | 0.49 | 0.15 | 0.01 | 0.00 | 0.30 |
| *CBRlow* | *Peripheral* | 0.94 | 0.78 | 0.46 | 0.00 | 0.00 | 0.44 |
| | *Suburban* | 1.00 | 0.90 | 0.59 | 0.00 | 0.00 | 0.46 |
| | *Other urban* | 1.00 | 0.98 | 0.88 | 0.00 | 0.00 | 0.53 |
| | *Vienna* | 1.00 | 0.93 | 0.84 | 0.00 | 0.00 | 0.60 |
| | *Total* | 0.98 | 0.87 | 0.62 | 0.00 | 0.00 | 0.49 |
| *LCR* | *Peripheral* | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| | *Suburban* | 0.05 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| | *Other urban* | 0.26 | 0.39 | 0.30 | 0.21 | 0.04 | 0.23 |
| | *Vienna* | 0.51 | 0.23 | 0.19 | 0.04 | 0.02 | 0.22 |
| | *Total* | 0.19 | 0.10 | 0.07 | 0.03 | 0.02 | 0.08 |
| *VTR* | *Peripheral* | 0.72 | 0.77 | 0.84 | 0.78 | 0.83 | 0.79 |
| | *Suburban* | 0.91 | 0.81 | 0.82 | 0.86 | 0.90 | 0.86 |
| | *Other urban* | 0.94 | 0.98 | 0.91 | 0.94 | 0.97 | 0.95 |
| | *Vienna* | 0.94 | 0.90 | 0.94 | 0.93 | 0.95 | 0.93 |
| | *Total* | 0.85 | 0.83 | 0.86 | 0.85 | 0.90 | 0.86 |
| *MIX* | *Peripheral* | 0.42 | 0.20 | 0.00 | 0.00 | 0.00 | 0.13 |
| | *Suburban* | 0.83 | 0.29 | 0.01 | 0.00 | 0.00 | 0.19 |
| | *Other urban* | 0.88 | 0.66 | 0.36 | 0.15 | 0.00 | 0.38 |
| | *Vienna* | 0.92 | 0.53 | 0.29 | 0.00 | 0.00 | 0.40 |
| | *Total* | 0.72 | 0.35 | 0.10 | 0.02 | 0.00 | 0.24 |
| *MIXlow* | *Peripheral* | 0.69 | 0.42 | 0.23 | 0.00 | 0.00 | 0.27 |
| | *Suburban* | 0.97 | 0.59 | 0.33 | 0.00 | 0.00 | 0.34 |
| | *Other urban* | 1.00 | 0.85 | 0.55 | 0.00 | 0.00 | 0.45 |
| | *Vienna* | 0.99 | 0.76 | 0.54 | 0.00 | 0.00 | 0.51 |
| | *Total* | 0.88 | 0.59 | 0.36 | 0.00 | 0.00 | 0.37 |

# Appendix E: Microsimulation results for the Sensitivity Carbon Price Scenario

Table E. 1: Aggregated results for the Sensitivity Carbon Price Scenario and different recycling schemes (EASI_AT)

| | CoL index (%-change in cost of living to baseline) | Gini index | Gini index (%-change to baseline) | Atkinson | Atkinson (%-change to baseline) |
|---|---|---|---|---|---|
| Baseline | - | 0.2539 | - | 0.1277 | - |
| PDS | +2.71% | 0.2561 | +0.87% | 0.1296 | +1.45% |
| CBR | +0.53% | 0.2488 | -2.02% | 0.1223 | -4.25% |
| CBRlow | -0.43% | **0.2422** | **-4.63%** | **0.1163** | **-8.96%** |
| LCR | +1.23% | 0.2542 | +0.12% | 0.1279 | +0.10% |
| VTR | **-1.28%** | 0.2539 | -0.02% | 0.1276 | -0.13% |
| MIX | +0.87% | 0.2515 | -0.97% | 0.1250 | -2.13% |
| MIXlow | +0.39% | 0.2481 | -2.30% | 0.1219 | -4.60% |

Note: Most favorable outcome for each indicator is printed in bold.

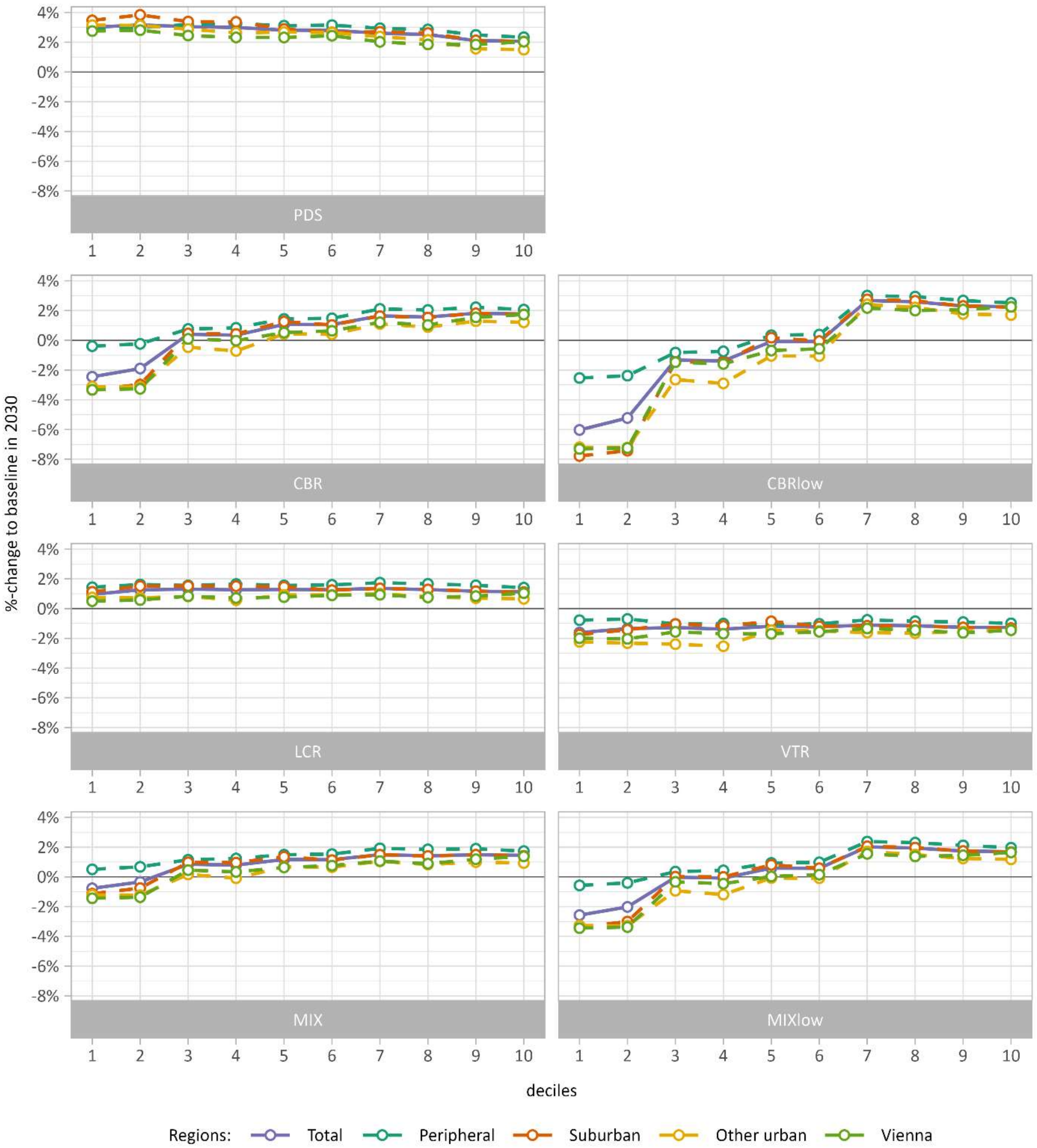

Figure E. 1: Relative change in cost of living for the Sensitivity Carbon Price Scenario and different recycling scenarios across expenditure quintiles, differentiating between different degrees of urbanization (EASI_AT)

Table E. 2: Share of households with a lower cost of living than in the baseline, in the Sensitivity Carbon Price Scenario (EASI_AT)

| *Scenario* | *Region* | *Q1* | *Q2* | *Q3* | *Q4* | *Q5* | *TOT* |
|---|---|---|---|---|---|---|---|
| *PDS* | *Peripheral* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Suburban* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Other urban* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Vienna* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Total | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| *CBR* | *Peripheral* | 0.66 | 0.30 | 0.00 | 0.00 | 0.00 | 0.20 |
| | *Suburban* | 0.97 | 0.42 | 0.08 | 0.00 | 0.00 | 0.25 |
| | *Other urban* | 1.00 | 0.81 | 0.38 | 0.06 | 0.00 | 0.42 |
| | *Vienna* | 0.98 | 0.62 | 0.30 | 0.00 | 0.00 | 0.43 |
| | Total | 0.86 | 0.46 | 0.13 | 0.01 | 0.00 | 0.29 |
| *CBRlow* | *Peripheral* | 0.94 | 0.76 | 0.44 | 0.00 | 0.00 | 0.44 |
| | *Suburban* | 1.00 | 0.89 | 0.57 | 0.00 | 0.00 | 0.46 |
| | *Other urban* | 1.00 | 0.98 | 0.86 | 0.00 | 0.00 | 0.53 |
| | *Vienna* | 1.00 | 0.91 | 0.83 | 0.00 | 0.00 | 0.59 |
| | *Total* | 0.98 | 0.86 | 0.61 | 0.00 | 0.00 | 0.49 |
| *LCR* | *Peripheral* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *Suburban* | 0.02 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 |
| | *Other urban* | 0.12 | 0.26 | 0.28 | 0.16 | 0.04 | 0.16 |
| | *Vienna* | 0.46 | 0.12 | 0.13 | 0.02 | 0.00 | 0.17 |
| | *Total* | 0.15 | 0.06 | 0.05 | 0.02 | 0.01 | 0.06 |
| *VTR* | *Peripheral* | 0.73 | 0.77 | 0.83 | 0.76 | 0.81 | 0.78 |
| | *Suburban* | 0.89 | 0.81 | 0.80 | 0.83 | 0.89 | 0.84 |
| | *Other urban* | 0.94 | 0.98 | 0.90 | 0.90 | 0.97 | 0.94 |
| | *Vienna* | 0.94 | 0.88 | 0.93 | 0.90 | 0.93 | 0.92 |
| | *Total* | 0.85 | 0.83 | 0.85 | 0.83 | 0.88 | 0.85 |
| *MIX* | *Peripheral* | 0.41 | 0.19 | 0.00 | 0.00 | 0.00 | 0.12 |
| | *Suburban* | 0.80 | 0.27 | 0.00 | 0.00 | 0.00 | 0.18 |
| | *Other urban* | 0.88 | 0.64 | 0.35 | 0.09 | 0.00 | 0.37 |
| | *Vienna* | 0.91 | 0.52 | 0.25 | 0.00 | 0.00 | 0.38 |
| | *Total* | 0.70 | 0.34 | 0.09 | 0.01 | 0.00 | 0.23 |
| *MIXlow* | *Peripheral* | 0.71 | 0.43 | 0.21 | 0.00 | 0.00 | 0.28 |
| | *Suburban* | 0.97 | 0.57 | 0.30 | 0.00 | 0.00 | 0.33 |
| | *Other urban* | 1.00 | 0.85 | 0.53 | 0.00 | 0.00 | 0.44 |
| | *Vienna* | 0.99 | 0.75 | 0.51 | 0.00 | 0.00 | 0.50 |
| | *Total* | 0.88 | 0.59 | 0.34 | 0.00 | 0.00 | 0.36 |