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CO_2 Tax Scenarios for Austria

Impacts on Household Income Groups, CO_2 Emissions, and the Economy

Mathias Kirchner, Mark Sommer, Claudia Kettner-Marx, Daniela Kletzan-Slamanig, Katharina Köberl, Kurt Kratena

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JEL codes: C22, C63, C67, E12, E61, H23

Keywords: climate change, CO_2 taxes, distributive impacts, macroeconomic modeling

1 Introduction

1.1 Motivation

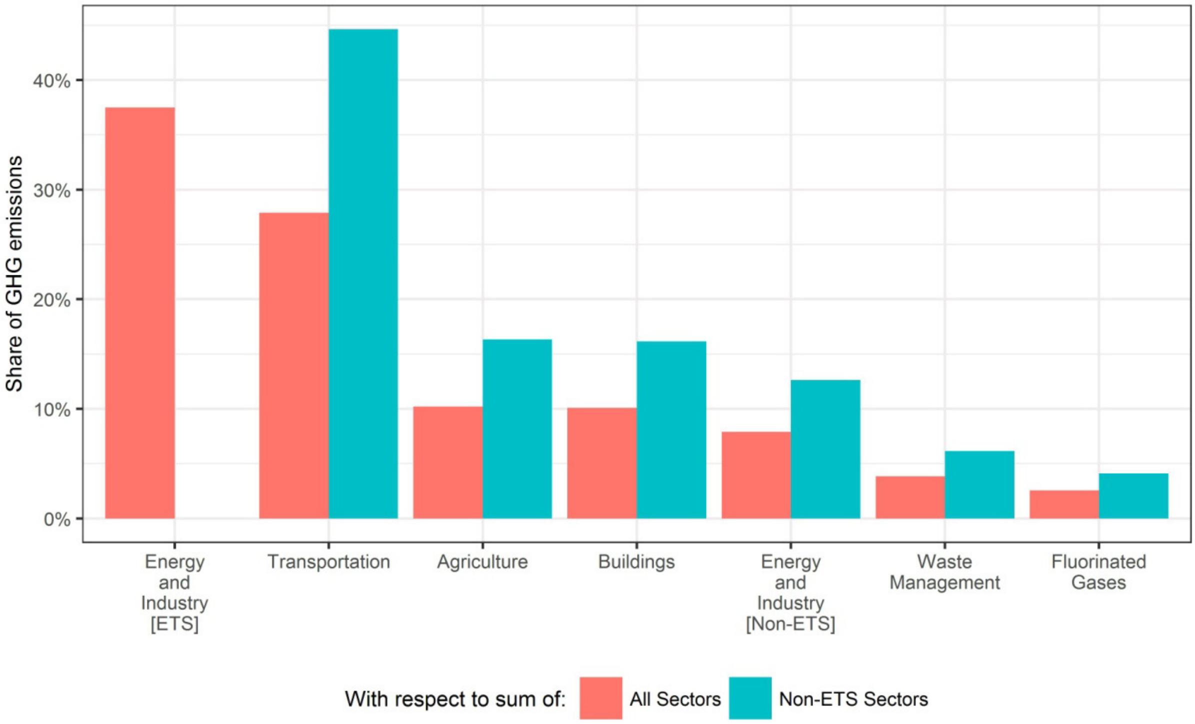
With the adoption of the Paris Agreement (UNFCCC, 2015) many countries will need to adopt more stringent measures in order to achieve their respective greenhouse gas (GHG) mitigation targets required to ensure that mean global surface temperature increase is likely to stay below 2°C in the long term (Rogelj et al., 2016). This temperature target is generally assumed to keep climate change damages and major threats at manageable levels, although uncertainty about temperature trajectories and associated impacts remains high (Brown and Caldeira, 2017; IPCC, 2014a).

In the EU, emissions from energy supply and emission intensive industry are regulated under the European Emission Trading Scheme (ETS). Emissions from other sectors need to be tackled at national level. In Austria the largest share of GHG emissions (almost 2/3) is currently emitted in non-ETS sectors, most notably transport, agriculture, and buildings (see Figure 1). The EU Member States (MS) are responsible for achieving their mandatory (2020) or proposed (2030) targets for non-ETS GHG emissions, as defined in the respective effort sharing decisions. Possible policy instruments to achieve these targets include, inter alia, command and control regulations (like efficiency standards) and market based instruments (e.g. carbon trading, taxes, or subsidies).

CO_2 taxes for non-ETS emissions have been implemented in some MS, most notably in Sweden, Finland and Denmark, but not in Austria. They are generally considered to be an efficient and effective means to achieve CO_2 emission reductions and a core element within a comprehensive set of policy instruments (Baranzini et al., 2017; High-Level Commission on Carbon Prices, 2017; IPCC, 2014b; Stern, 2008) and have been found to be effective in reducing CO_2 emissions in ex-post assessments (see Andersen, 2004 for a review of empirical studies in Nordic countries; Murray and Rivers, 2015 for a review of empirical studies on British Columbia). Furthermore, no significant impacts of a carbon tax have been found for UK manufacturing employment and revenue (Martin et al., 2014), as well as on economic growth in British Colombia (Murray and Rivers, 2015), with a recent study indicating that CO_2 tax recycling schemes seem to have positively affected employment in British Columbia (Yamazaki, 2017). There is thus increasing empirical evidence of the double dividend hypothesis (Goulder, 1995), i.e. less CO_2 emissions and higher economic growth with the introduction of adequate CO_2 tax schemes[1]. In essence, CO_2 taxes could thus provide short-term as well as long-term economic incentives to make consumption, production, and investment choices less carbon intensive without adversely affecting economic performance.

[1] Goulder (1995) differentiates between strong, intermediate, and weak double dividend claims. A strong double dividend claims that the substitution of a *typical* distortionary tax (e.g. labor tax) with a revenue-neutral environmental tax leads to zero or negative gross costs (measured as reductions in individual welfare). The intermediate double dividend differs from the strong double dividend only insofar as that it involves *a* (and not a typical) distortionary tax that is substituted. And the weak double dividend claims that reductions in the marginal rates of a distortionary tax will achieve cost-savings relative to a case where tax revenues are used for lump-sum payments.

Figure 1: Sectoral shares of GHG emissions in Austria in 2015.



Source: (Umweltbundesamt, 2017a)

Furthermore, the distributional impacts of CO_2 (and environmental/energy) taxes on different household income groups have been a focus of many analyses (Callan et al., 2009; Felder and van Nieuwkoop, 1996; Poterba, 1991; Wang et al., 2016; Wier et al., 2005), but still remain a much discussed topic, especially since differences between countries are high (Flues and Thomas, 2015; Kosonen, 2012). Nevertheless, most empirical findings for high-income countries suggest that a uniform CO_2 tax is likely to have a regressive impact as lower income households usually spend a higher share of their income on CO_2 intensive commodities (Wang et al., 2016). The impact is typically much more regressive with respect to heating or electricity, but not so much for mobility. Furthermore, different reactions to price changes may exacerbate or mitigate these impacts (Wadud et al., 2009)[2]. Numerous tax recycling and compensation measures can be employed to counteract potential negative distributional impacts, which will play a crucial role in the political feasibility of implementing a CO_2 tax (Baranzini et al., 2017; Felder and Schleiniger, 2002a). For example, distributional concerns are argued to have played a role in preventing the introduction of a CO_2 tax in Ireland in 2004 (Callan et al., 2009) in Washington, USA, (Roberts, 2016) and many others (see Wang et al., 2016 for more references). And the established CO_2 tax recycling scheme in British Columbia

[2] For example, middle-income households who depend on commuting to work by car may respond less strongly to fuel price increases (i.e. they have lower price elasticities) than others, and thus may face a higher tax burden.

allocates a substantial proportion to low income households (Murray and Rivers, 2015) as well as rural households (Beck et al., 2016). We therefore put specific focus on the distributional aspects of CO_2 taxes and possible tax recycling schemes.

As a CO_2 tax for non-ETS sectors could have wide-ranging macroeconomic impacts and feedbacks, which are seen as crucial in determining the overall distributive impacts (Dissou and Siddiqui, 2014; Wang et al., 2016)[3], we apply the macroeconomic Input-Output (IO) model DYNK[AUT] for Austria which specifically considers energy demand (both for industries and private households) as well as different household income groups. Previous versions of the model have already been applied in this area (Kratena, 2015; Sommer and Kratena, 2017).

1.2 Previous studies

Previous studies with focus on distributive impacts of CO_2 taxes can be broadly categorized into three types: (1) empirical studies based on household consumption surveys or applying micro-simulation models; (2) studies that combine static input-output (IO) models with household data or micro-simulation models, and (3) studies that simulate macroeconomic feedbacks, e.g. computable general equilibrium (CGE) models or macroeconomic IO-models[4]. These studies differ with respect to indicators used and effects considered. While the first two approaches usually measure the distributive impact of the tax burden relative to income or expenditure, macroeconomic studies often measure the distributive impact as changes in equivalent variation (EV – a typical welfare indicator in CGE studies)[5], but also as changes in household expenditure and income. Regarding the effects captured, empirical studies can only address direct price changes, while the combination with static IO-models allows capturing also indirect price changes (price transmission from industries taxed). Macroeconomic models naturally consider macroeconomic feedbacks and can thus further account for changes in production structures and factor incomes (labor and capital). Especially the latter effect is an important driver of distributive impacts in macroeconomic studies. Changes in consumption patterns can be captured in all three approaches, but some empirical studies keep consumption patterns constant. Among the three categories only macroeconomic studies provide additional information on macroeconomic indicators (GDP, employment, welfare) as well as environmental indicators. Our list is not exhaustive and concentrates on high-income countries. With respect to studies on Austria, we also include macroeconomic studies that do not explicitly consider distributive impacts in the following survey. For a more extensive review on distributional impacts see Wang et al. (2016) as well as Callan et al. (2009) for older studies.

[3] The same reasoning can of course be applied to environmental impacts.
[4] We define the difference between static and macroeconomic IO-models in that the latter can at least account for changes in production input factors such as capital, labor, energy or commodities.
[5] EV is, simply put, the change in income that is equivalent to the change in utility due to price changes, i.e. how much households would be willing to pay so that the price change would not take place.

1.2.1 Empirical studies

Callan et al. (2009) provide a review of macroeconomic and micro-simulation studies published between 1991 and 2008. Moreover, they conduct a micro-simulation analysis of CO_2 taxes in Ireland. Their review focuses mostly on high-income countries and the studies reviewed indicate that distributional CO_2 tax impacts can differ considerably but are found to be regressive in most countries. Their own model simulations also find regressive impacts for Ireland and show that increased welfare transfers can mitigate negative impacts for lower income households whereas labor tax cuts are better suited for compensating middle to high income households.

A review by Kosonen (2012) with specific focus on Nordic countries shows that the distributive impacts depend on the income concept used (e.g. annual income vs. life-time income, i.e. annual expenditure[6]) as well as on the use of tax revenues, and differ with respect to CO_2-intensive commodities, such as heating, electricity or mobility. While taxing heating fuels and electricity in the household sector is found to have a regressive effect, independent of the income concept used, taxing transport fuels is not always found to be regressive, especially in relation to annual expenditure. A recent OECD study by Flues and Thomas (2015), based on European Household Consumption Surveys, corroborates the findings by Kosonen (2012). It also provides data on the distributional impacts of CO_2 taxes in European OECD countries. Findings for Austria suggest that, if tax incidence is measured as percentage of total expenditure, a CO_2 tax will be regressive for heating and electricity, but rather proportional or inverted U-shaped for transport fuels, i.e. middle income groups are affected most strongly. If tax incidence is measured as percentage of net income, a CO_2 tax is always regressive.

1.2.2 Studies that combine IO models with household data and/or models

The impact of a CO_2 tax in Denmark has been investigated by Wier et al. (2005) by combining a static IO model with household characteristics. The authors account for both direct CO_2 taxes for electricity, heating oil and natural gas and indirect[7] commodity taxes for households. They show that CO_2 taxes are regressive in Denmark, measured as tax payments relative to annual disposable income, tax payments relative to total expenditure as well as for Gini-based indices. Indirect CO_2 taxes are less regressive than direct CO_2 taxes. Comparing CO_2 taxes with other types of levies shows that CO_2 taxes are more regressive than VAT or the average Danish levy while petrol taxes are progressive. Furthermore, tax burdens are higher in rural areas due to higher transport and heating demand. A similar approach is taken by Kerkhof et al. (2008) for the Netherlands. They also find a regressive impact of direct and indirect CO_2 taxes on household income groups. A comprehensive GHG tax is also regressive.

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[6] Typically, expenditure is used an approximate indicator for life-time income (see discussion in section 5.1).

[7] I.e. consumer price increases due to taxes levied on industry production.

García-Muros et al. (2016) use a static IO model in combination with a micro-simulation model for households (which includes the AIDS-approach to model changes in demand) to assess distributive impacts of local pollution as well as CO_2 taxes in Spain using EV well as Gini-based indices. They find proportional impacts for a CO_2 tax and regressive impacts for a local pollution tax, as the latter affects prices for food and energy more than a CO_2 tax. Again, a reduction in labor costs alleviates welfare losses and regressivity.

1.2.3 Macroeconomic studies

1.2.3.1 Distributional impacts in high-income countries

An early study by Felder and van Nieuwkoop (1996) analyzes the impact of CO_2 taxes (12 or 36 Swiss Franc per tCO_2) in Switzerland with a CGE model that accounts for six different household income groups. Taxes are recycled either by decreasing marginal tax rates on labor or via lump sum payments to households. They find substantial decreases in CO_2 emissions, increases in employment if labor taxes are reduced and small but positive impacts on GDP (with tax recycling). Typically for a CGE study they find a (strong) double dividend (Goulder, 1995), i.e. cost savings by substituting a typical distortionary tax (i.e. labor taxes) with a revenue-neutral environmental tax. Reducing labor taxes is also economically more efficient than lump sum payments (weak double dividend). Consumer welfare, measured as equivalent variation (EV), increases slightly with reduced labor taxes but decreases marginally with lump sum payments. However, lump sum payments redistribute welfare from the highest to the lowest income group, whereas labor tax reductions have the opposite effect.

Barker and Köhler (1998) apply an macroeconomic IO model to assess the distributional impacts of a CO_2 tax in eleven EU-MS (excl. Austria) for different expenditure household groups. They integrate CO_2 taxes via increases in excise duties and provide scenarios from 1990 to 2010. Changes in excise duty taxes are calibrated so that CO_2 emissions are reduced by 10% compared to the baseline in 2010. They find small positive GDP impacts even without recycling due to positive changes in net trade balances, but negative impacts on employment. With reductions in labor costs both GDP and employment increase by slightly more than 1%. Furthermore, although all households benefit with respect to real personal income from the recycling schemes, CO_2 taxes are regressive in most countries if labor cost reductions (i.e. low income households benefit less) are provided, but not if households receive lump sum payments.

Felder and Schleininger (2002a) analyze the ratio between change in EV and change in government transfers as indication of the political feasibility of different CO_2 tax schemes. They apply a similar model as in Felder and van Nieuwkoop (1996) but introduce a broader range of CO_2 tax schemes (e.g. uniform tax rates vs. industry specific tax rates and rebates). They find that while uniform taxes and tax rebates perform better economically (as they do not distort factor price ratios between sectors), they perform less well with respect to equity (as they redistribute welfare from energy-intensive to labor-intensive sectors). They conclude that from the viewpoint of political feasibility the best solution is to introduce uniform taxes but differentiated labor cost subsidies across industries.

Rausch et al. (2011) study the distributional impacts of a CO_2 tax for the USA with a CGE model that integrates a micro-simulation model for households. Similar to previous macroeconomic studies they also find that how tax revenues are recycled affects efficiency and equity, with labor tax cuts leading to regressive effects on welfare (measured as EV) and lump sum payments leading to progressive impacts. Their study provides three additional interesting findings. First, differences in other factors than income can be substantial across households, such as region or race (e.g. regions with high energy intensity see larger reductions in wages; black people show a higher share of expenditure for electricity and gas). Second, there is little evidence in their data and model that distributional impacts change if proxies for life-time income are used to assess welfare impacts. And third, without revenue recycling the tax burden is found to be proportional, although there are large differences between use (expenditure) and source (income) effects. Only looking at expenditure reveals regressive effects, while income shows progressive impacts. This is because real capital income decreases with a CO_2 a tax (which affects high income groups more), while (fixed) real government transfers increase (which affects low income groups more).

The impact of changes in factor incomes on equity is further detailed in Dissou and Siddiqui (2014). They show that, without tax recycling, the composite effect of changes in consumer price impacts (likely regressive) and factor incomes (likely progressive) may lead to an inverted U-shape impact on the Gini coefficient, i.e. inequality decreases at low levels of carbon taxes but starts to increase at higher levels (when price effects become stronger than income effects). Net impacts are thus context dependent and difficult to generalize.

A CGE model simulation of CO_2 taxes in British Columbia, Canada, by Beck et al. (2015) looks at distributional, macroeconomic, and GHG impacts in the first implementation period of the tax policy in this region (2008-2012). In contrast to most other studies, they find a progressive impact on welfare (EV) across household income groups even without recycling schemes. This is explained by very low heterogeneity in expenditure patterns across income groups in this region (which is almost perfectly proportional for CO_2 intensive commodities) but high heterogeneity in income patterns. Similar to Rausch et al. (2011) their model shows declines in real wages (more strongly affecting high-income groups) but increases in real transfers (from which low-income groups benefit more). This highlights the importance of macroeconomic effects (through changes in factor incomes) on overall tax incidence. Tax recycling as implemented in British Columbia (i.e. corporate income tax rate cuts for businesses as well as income tax cuts for low-income households) further enhances the progressivity of the CO_2 tax. Overall welfare (EV) decreases in all scenarios, but less with tax revenue recycling. GHG emissions are reduced by ca. 9% (assuming a \$30/t CO_2 tax).

Landis and Heindl (2016) analyze the distributional impact of the 2020 renewable energy and emission targets in the European Union with the CGE model PACE. They investigate distributional impacts between MS (incl. Austria) and five income groups within each MS. Their results show that impacts on households are regressive in most MS if taxes are not recycled, measured as changes in consumption compared to the baseline. With lump sum payments for households, also in the case of taxing non-ETS industries, impacts become progressive. Their findings for Austria indicate that, without recycling, the lowest income quintile faces the largest decrease in consumption, although impacts from the second-lowest to the highest income quintile are progressive. Recycling via existing transfer schemes leads to progressive impacts for Austria.

1.2.3.2 Studies with specific focus on Austria

The – to our knowledge – first macroeconomic assessment of CO_2 taxes in Austria has been simulated by Breuss and Steininger (1995) with a CGE model. They assess the impact of different recycling schemes, i.e. labor cost reductions vs. lump sum payments, and calibrate tax rates to reach a reduction of 37% (2005 vs. 1990). Compared to a reference scenario for the period 1990-2005 they find decreases in real GDP without recycling (ca. -1%) and hardly any impacts with uniform wage tax compensation. Negative impacts on real GDP are enhanced if wage taxes are differentiated between sectors (in order to increase competitiveness). A mixed recycling scheme that includes differentiated wage tax cuts and investment stimulations leads to lower short-term real GDP impacts and positive impacts in the long-term.

Kratena and Schleicher (1999) also investigate the impacts of policy measures on GHG emissions in Austria with a macroeconomic model (their modeling approach can be seen as an early version of the model applied for this analysis; see section 2.1). However, they do not assess the implementation of CO_2 taxes but the impact of (exogenously provided) investments in technical CO_2-reduction measures have on GHG emissions. The (additional) investments necessary to achieve these reduction targets naturally lead to increases in GDP, private consumption, investments, and employment.

A study on intertemporal welfare costs of different CO_2 recycling schemes in Austria has been conducted by Farmer and Steininger (1999) with a CGE model. Additional tax revenues can be used for reaching fiscal stock criteria or for reducing tax burdens to producers or consumers. Reaching a lower deficit/GDP ratio has higher welfare costs (measured in EV) than reimbursing producers or consumer for the increase in prices.

More recent macroeconomic IO studies on CO_2 taxes in Austria were conducted by Schneider et al. (2010) and Baresch et al. (2014). Both studies used the macroeconomic IO model MOVE/MOVE2 to model impacts of a CO_2 tax. MOVE bears similarities to our DYNK model (e.g. econometrically estimated behavioral functions for industry output and specific models on energy, emissions, and households). Without tax recycling (i.e. taxes are used for budget consolidation) macroeconomic impacts are moderately negative (GDP, consumption, investments, employment), and lower income households seem to lose more jobs than higher income households. Reductions in CO_2 emissions are quite considerable already in the first year. Tax recycling measures, such as lower labor taxes (Schneider et al., 2010) or lump sum payments for households together with investments in energy efficiency (old building restorations) (Baresch et al., 2014), can mitigate negative macroeconomic impacts. However, as both studies only use a fraction of total CO_2 tax revenue (75% in Baresch et al. (2014) and ca. 43% in Schneider et al. (2010)), small negative net impacts on GDP, consumption, investment, and employment remain.

The project KONSENS focused on the introduction of energy policy measures aimed at private households in Austria which included, inter alia, the impact of CO_2 taxes on mobility and heating (Stocker et al., 2011). The macroeconomic IO model e3.at was used to model impacts for the period 2010 to 2020 (Großmann et al., 2011). It has similar features as our DYNK[AUT] model and MOVE (see above). Macro-economic impacts on GDP, employment, and income are positive but negligibly small if tax revenues are used to either reduce the income tax or social contributions (Wolter et al., 2011). CO_2 emissions are reduced but only by ca. 0.2%. According to the authors low income households benefit less from reductions in income tax or social contributions than high income households.

1.2.4 Summary

Impacts of CO_2 taxes in the literature are manifold and depend, inter alia, on consumption and income patterns of households, the structure of the economy, macroeconomic feedbacks (e.g. factor incomes), price transmission of industries taxed, tax design (especially tax recycling), as well as the modeling approach and indicators used, and impacts will differ in the short- and long-term.

Overall, many studies find a regressive distributional impact on household income groups for high-income countries, usually measured as tax burden with respect to income or expenditure (empirical and IO studies) or EV in CGE studies. However, differences exist with respect to the concept of income used (annual or lifetime) and the type of commodities (or fuels) taxed. Taxing heating fuels and electricity is usually quite regressive, while taxing transport fuels is often proportional or inverted-U-shaped (i.e. middle income groups bear the highest burden). Using expenditure as a point of reference (as it is typically used as an approximate indicator for life-time income) leads to less regressive impacts compared to income. Moreover, macroeconomic feedbacks through factor incomes also seem to dampen regressive impacts. Finally, virtually all studies agree that potential negative distributional effects can be mitigated by tax recycling, although trade-offs exist between efficiency and equity, i.e. labor tax cuts are usually more efficient (weak double dividend) while lump sum payments perform better in terms of equity.

With respect to Austria, initial CGE studies in the late 1990s assessed the impacts of CO_2 taxes on GDP, employment, and GHG emissions, but they did not analyze distributive impacts (Breuss and Steininger, 1995; Farmer and Steininger, 1999). Two more recent macroeconomic IO studies (Baresch et al., 2014; Wolter et al., 2011) began to additionally focus on distributional impacts. While their results highlight impacts on employment (Baresch et al., 2014) or income (Wolter et al., 2011) across household groups, they did not report effects on the tax burden relative to income or expenditure, or changes in consumption across household groups. Wolter et al. (2011) further only focused on taxing households, but not industry and service sectors. Finally, two very recent studies provide results on tax burdens relative to income and expenditure (Flues and Thomas, 2015), as well as changes in expenditure (Landis and Heindl, 2016) for Austria, but no assessment or information on macro-economic indicators or GHG emissions is provided.

We therefore complement the literature by providing a thorough macroeconomic and comprehensive assessment of CO_2 taxes in Austria. Beside standard macroeconomic indicators (GDP, value added, and employment) and CO_2 emission impacts, we will provide results on a common range of indicators used in the literature to assess distributive impacts, i.e. tax burden relative to income and expenditure as well as changes in income and expenditure across household income groups. By applying the macroeconomic IO model DYNK[AUT] with its specific focus on energy demand and household income groups we can account for many effects considered important in the literature, i.e. direct and indirect price impacts, different consumption and income patterns across household income groups, changes in household consumption patterns and industry production factor inputs, labor market impacts, and changes in factor incomes.

2 Method

2.1 The DYNK[AUT] model in a nutshell

For this analysis of CO_2 tax schemes in Austria we apply the macroeconomic model DYNK[AUT]. It is a macroeconomic Input-Output model with recursive dynamic elements based on an earlier DYNK version for the European Union (Sommer and Kratena, 2017)[8]. The model draws on New-Keynesian (i.e. long-run full employment equilibrium and institutional rigidities) as well neo-classical economic theory (i.e. theory of firm, almost ideal demand system) and can be considered a hybrid form between CGE and static IO models. Core elements of DYNK[AUT] are already described in Sommer and Kratena (2017); therefore only the most important aspects are reiterated here, such as the integration of household income groups as well as the modeling of energy demand and the implementation of CO_2 taxes (see sections 2.2 and 2.3).

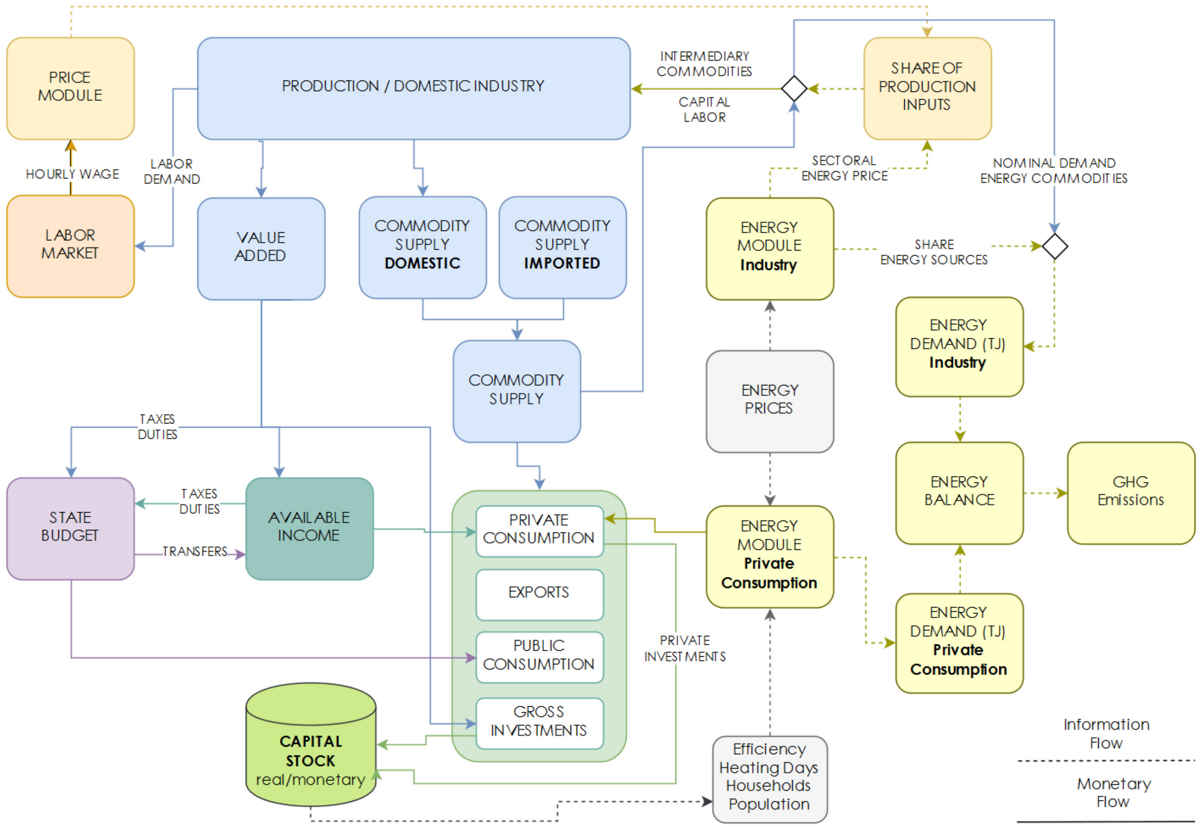
The input-output core of DYNK[AUT] describes the interlinkages between 62 sectors and final users (e.g. private consumption, gross fixed capital formation, public consumption) in Austria. Static input-output relationships are extended by the incorporation of econometrically estimated behavioral functions for industry & service sectors, private households, and the labor market.

[8] Both models are part of the macroeconomic model family FIDELIO (see Kratena et al. (2013, 2017) for an extensive documentation of core assumptions and theory). This model family also includes the global ADAGIO model (Kratena and Streicher, 2014).

The model includes $KLEM^mM^d$ trans-log production functions for each sector to estimate the share of production inputs needed for one unit of sector output (i.e. unit cost). Production inputs are differentiated between capital (K), labor (L), energy commodities (E), imported material commodities (M^m) and domestic material commodities (M^d). If input prices change, so will the shares of production inputs, depending on own-price as well as cross-price elasticities. This ultimately affects the unit cost of the sector output, which itself will have feedback effects on the rest of the economy. In the long-term factor-biases will also affect input shares (e.g. trends in capital shares) and total factor productivity (TFP) affects sectoral growth. An additional nested trans-log production function estimates the shares in energy sources as inputs for energy commodities (the E in $KLEM^mM^d$). We thereby differentiate between five aggregate energy sources: oil, gas, coal, electricity & heating, and renewables. Fuel prices are given exogenously. Commodity consumption of private households is modeled endogenously for 45 consumption categories (COICOP). The model differentiates between (i) investments in durable commodities such as vehicles, housing, and appliances, (ii) non-durable commodities via an almost ideal demand system (AIDS) and (iii) energy service demand (electricity, heating and private mobility). The labor market sub-module determines hourly wages for each sector, which depend on the distance to the natural unemployment rate, the working hours per employee, the previous year's consumer price index, the previous year's sectoral (or overall) labor productivity, and the previous year's hourly wage. DYNK[AUT] also accounts for household income and wealth, changes in gross fixed capital formation (depending on changes in net surpluses for each sector), as well as government expenditure and revenue. Finally, DYNK[AUT] includes two energy modules which capture energy demand by households and industries (see section 2.3). These modules reproduce the energy balances provided by Statistik Austria and provide energy related CO_2 emissions for industry sectors and households. CO_2 emissions captured by DYNK represent ca. 72% of all GHG emissions (i.e. 57 vs. 80 million tCO_2eq in the year 2012) and 71% of all non-ETS emissions (i.e. 35 vs. 50 million tCO_2eq in the year 2012) in Austria.

An overview of these linkages can be seen in Figure 2. DYNK[AUT] has now been coded in GAMS with most econometric estimates conducted in EViews and some data adjustments and graphical output done in the statistic environment software R.

Figure 2: A schematic overview of DYNK[AUT].



Major data sources for DYNK are Statistik Austria (make and use tables, government expenditure and revenues, employment, energy balances, consumption survey), the World Input-Output Database WIOD (to estimate production functions), EUROSTAT (household income and wealth, government debt, household consumption by quintiles), EU-SILC (household income by quintiles), and the IEA (energy prices).

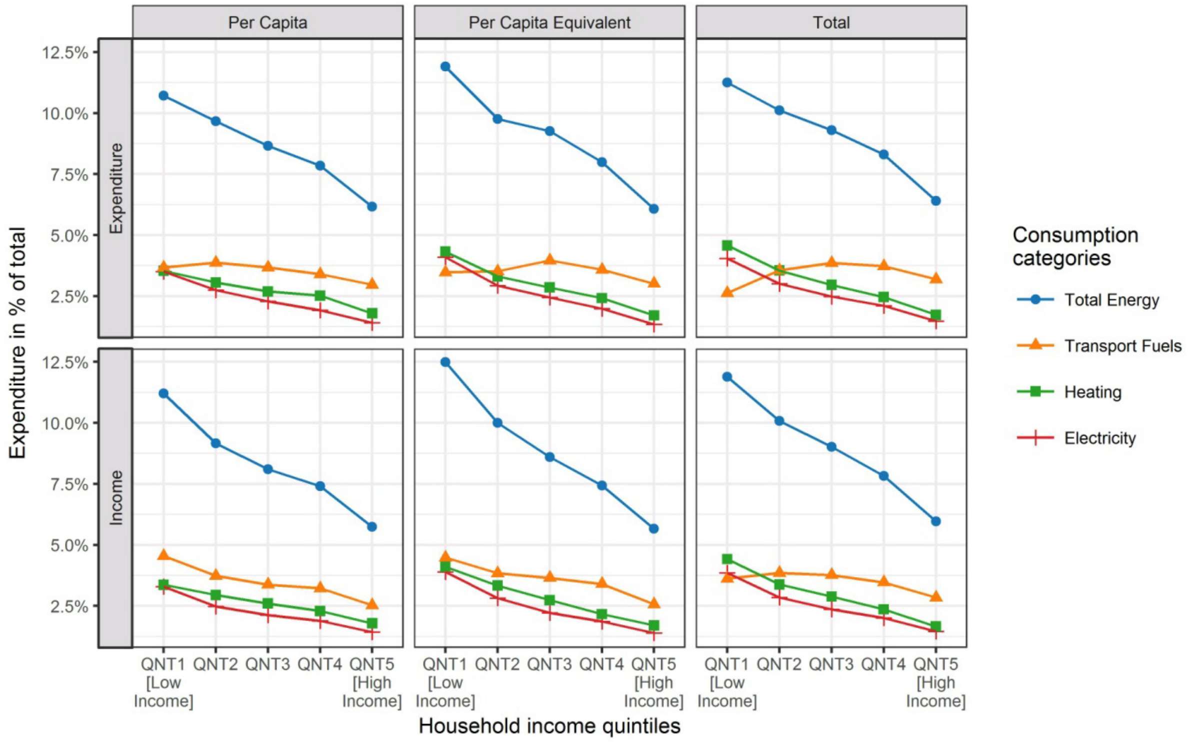
2.2 Household income groups in DYNK[AUT]

Data on household income groups have been specifically prepared for this analysis and incorporated in DYNK[AUT]. We use data from (i) the Austrian consumption survey 2009/2010 (Statistik Austria, 2011) and (ii) EU-SILC (Statistics on Income and Living Conditions) 2010 in order to obtain household income quintiles (i.e. five income groups) for our modules on household income, consumption, and final energy demand. The classification of income groups is based on income after taxes and the EU equivalence scale. In the literature on analyzing the distributive impact of energy, environmental, or CO_2 taxes, one finds either net disposable income and/or total expenditure as basis for the classification of household groups (see section 5.1 for a discussion). In our case an income classification on expenditure basis was not possible, as we had to merge the consumption survey with EU-SILC, and the latter does not provide data on total expenditure[9]. To ensure consistency with EUROSTAT values for household income we apply a typical RAS procedure to the EU-SILC data (i.e. biproportional scaling, see Miller and Blair (2009)). Shares in stocks such as vehicles, housing, and appliances are approximated by the respective shares of investment for the COICOP categories purchase of vehicles (07.1), actual and imputed rents (04.1 and 04.2), and household appliances (05.3). Information on how energy relevant data is differentiated by quintiles is provided in the next section (2.3.1).

Data from the Austrian consumption survey indicates that low income households in Austria spend a larger share of their income or expenditure on total energy consumption, independently of the type of classification. This can be used as an initial proxy for the likely CO_2 tax burden. Figure 3 illustrates this for six different classifications, i.e. total, per capita and per capita equivalent values of net income and total expenditure, respectively. Expenditure on total energy, heating, and electricity is considerably regressive in all cases. With income as basis regressive impacts are slightly stronger for each level. Differences between measurement values, however, are often stronger than between income and expenditure. With respect to total energy expenditure per capita equivalent values provide the most regressive picture. Transport fuels show the strongest variations. Here, the tax burden is likely to be almost progressive for total expenditure and considerably regressive for per capita net income.

[9] The fit between the consumption survey and SILC is satisfactory at our aggregate level, although some small differences exist especially with regard to the lowest and highest income quintiles (see Figure 17 in appendix 8.1).

Figure 3: Household expenditure on energy in Austria 2009/2010 with respect to income or expenditure and three different measurement classifications.



Note: QNT1 is the lowest income quintile and QNT5 the highest. The classification used in the DYNK[AUT] model is income and per capita equivalent. Source: Austrian Consumption Survey 2009/2010.

2.3 Energy demand and CO_2 taxes in DYNK[AUT]

2.3.1 Private households

2.3.1.1 Data

The Austrian Energy Balances (Statistik Austria, 2017a) and the Useful Energy Analysis (Statistik Austria, 2017b) are used to derive physical energy demand (in TJ) at aggregate household level by energy use category (appliances, heating, mobility) and energy source (electricity, coal, heating oil, gas, biomass, heat pumps, district heating, wood, diesel and petrol). Data on efficiencies are taken from the ODYSSEE data base [10] (appliances) as well as from previous project cooperation[11] with the Energy Economics Group (EEG, TU Vienna; INVERT/EE-Lab for data on heating) and the IVT (TU Graz; NEMO – Network Emission Model for mobility). Data on prices are taken from Statistik Austria (electricity and heating) as well as the fuel price monitor of the Austrian Ministry

[10] http://www.odyssee-mure.eu/project.html (accessed 2017-12-07)

[11] In this model version data sets based on the joint project „Monitoring Mechanism 2017" are implemented. The project is funded by The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management and operated by the Environment Agency Austria (the project report is forthcoming in 2018).

of Science, Research and Economy. Data on stocks are, again, based on the ODYSSEE data base, data by the EEG (heating), the IVT (vehicles), and Statistics Austria (total vehicles, population, households)[12]. Data on population and households are provided by Statistics Austria and data on heating degree days are taken from the Austrian Central Institute for Meteorology and Geodynamics (ZAMG).

Energy demand patterns of the five household income groups have been differentiated approximately with data from the Austrian consumption survey (Statistik Austria, 2011). Shares in energy demand for appliances are based on consumption shares for the COICOP category housing electricity (04.5.1). For heating they are based on all sub-groups of category 04.5 (Housing – electricity, gas and other fuels), which further includes gas (04.5.2), liquid fuels (04.5.3), solid fuels (04.5.4), further differentiated into wood (04.5.4.1) and coal (04.5.4.2), district heating (04.5.5), and other sources (04.5.6). The share of physical vehicles is derived from data on vehicle ownership from the consumption survey. Although this information does not provide data on the propulsion technology, different shares in diesel and petrol can be approximated based on data on petrol and diesel consumption (07.2.2.1 and 07.2.2.2). Kilometers driven – another important parameter for calculating mobility service energy demand – is differentiated for each quintile according to their share in the COICOP category 07.2.2, i.e. fuels and lubricants for personal transport equipment.

2.3.1.2 Service energy demand

Private consumption of energy is modeled as demand for service energy, i.e. energy flows divided by the efficiency of the energy service provided. By linking the efficiency of the durable stock (vehicles, appliances, housing) to energy demand we can thus account for possible rebound effects in efficiency improvement (Binswanger, 2001; Khazzoom, 1980; Sorrell, 2009). Service energy demand in DYNK[AUT] is simulated for (i) private mobility (i.e. for vehicles with diesel or petrol propulsion technologies), (ii) appliances (i.e. electricity), and (iii) heating (with an exogenously determined fuel mix). Details on the behavioral equations and econometric estimations are provided in appendix 8.2, and a general description is provided here.

Service energy demand for diesel or petrol vehicles (see equation E1 in appendix 8.2) is affected by changes in the service price (i.e. diesel or petrol fuel prices divided by the efficiency of the diesel or petrol vehicle stock) and changes in the number of vehicles per person. The service price elasticities (γ) are -0.25 for petrol and -0.12 for diesel. The stock elasticities (ξ) are -0.53 for petrol and -0.44 for diesel[13]. Demand for electric vehicles is considered in the model, but currently depends solely on exogenous assumptions. CO_2 taxes will thus affect service energy demand for private mobility directly through changes in fuel prices and indirectly through macroeconomic feedbacks on investments in the vehicle stock. Consumption for public transportation is also

[12] The nominal stock development is calibrated to correlate with the consumption expenditure of private households. The expenditure data was taken from the Input-Output-Tables on COICOP Consumption (Statistik Austria).

[13] The elasticity for an additional vehicle per capita should be negative, as one may assume that the kilometers driven will decrease for each car.

accounted for in the model, albeit currently only in monetary terms, and depends, inter alia, on a cross-price elasticity for private mobility (i.e. 0.4 taken from Holmgren (2007)).

Service energy demand for appliances per household follows a similar pattern as private mobility (see equation E2 in appendix 8.2). We consider electricity as the only energy source used to operate appliances. Changes in service energy demand for appliances depend on changes in the service price for appliances (i.e. the electricity price divided by the efficiency of the appliance stock) and changes in the real stock of appliances. The service price elasticity (γ) is -0.25 and the real stock elasticity (ξ) is 0.49. CO_2 taxes will thus affect service energy demand for household appliances only indirectly, i.e. either through changes in the electricity price or through changes in the real stock of appliances.

Household service energy demand for heating (see equation E3 in appendix 8.2) depends on an aggregate service price for heating[14] and the number of heating degree days. Households are found to react very inelastic to changes in the service price, i.e. the service price elasticity is -0.07, and more elastic to changes in heating degree days with an elasticity of 0.48. As the aggregate price is different for the household income groups considered (due to different heating fuel shares), households will react differently since they will face different price changes. CO_2 taxes will affect service energy demand for heating only directly (through the aggregate heating price) and not indirectly. In the current version of DYNK[AUT] we keep heating efficiencies constant and do not simulate investments in heating technologies endogenously.

The available data did not allow for quintile differentiated estimations regarding elasticities or to extract differences in the efficiency of stocks between income groups (e.g. vehicles, appliances). Wadud et al. (2009), however, show that both elasticities and efficiencies may indeed differ between household income groups. We therefore provide some sensitivity analyses for quintile differentiated elasticities (see section 4.6.2). Differences in efficiencies are not a major concern in our current simulations, as we only consider short-term impacts and currently cannot model the impact of investments on stock efficiency.

2.3.1.3 Integrating service energy demand into the macroeconomic model and CO_2 pricing

Physical energy demand (in TJ) is derived by dividing service energy by efficiency. With respect to heating exogenously determined fuel shares determine the energy demand for different fuel types (see equation E4 in appendix 8.2). As noted above, energy demand of appliances is restricted to electricity. For private mobility we differentiate between diesel, petrol and (exogenously determined) electricity[15]. From the data on final energy

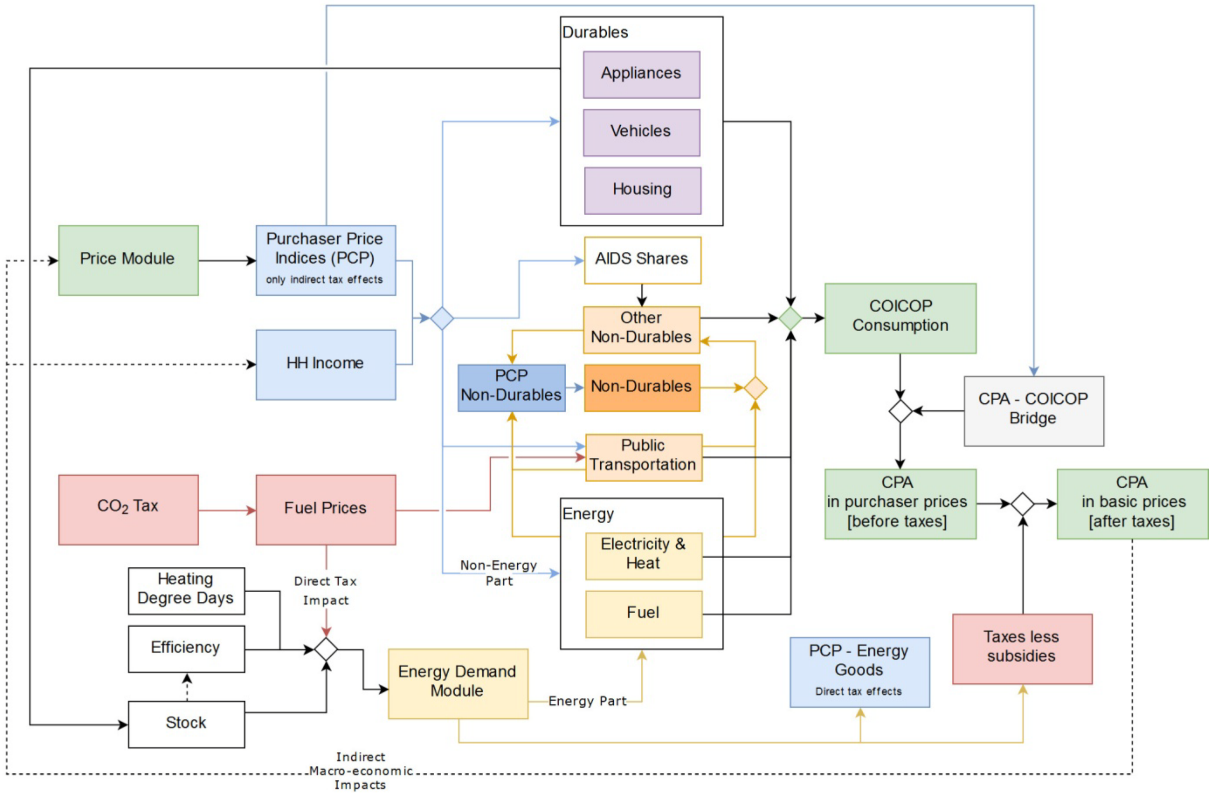
[14] The aggregate price for heating is weighted according to the shares of heating fuels and their respective prices for each household income group.

[15] Data and trend on electric vehicles is taken from the Monitoring Mechanism project, see footnote 11.

consumption we can then calculate CO_2 emissions by applying CO_2 emission factors for each fuel category (Umweltbundesamt, 2017b).

In order to integrate data on energy demand into the macroeconomic model, we multiply physical fuel demand (in TJ) by the respective fuel prices (in €/TJ) to get nominal consumption values in million €. To allow for a consistent integration we further split the COICOP consumption categories operation of personal transport equipment (07.2) and housing – electricity, gas and other fuels (04.5) into an energy part (i.e. the nominal consumption values from the energy module) and a non-energy part (where changes are calculated in the consumption module). By splitting we avoid to overestimate changes in energy fuel prices in these consumption categories. A CO_2 tax thus directly affects private households by increasing the price for fuels and thus the respective service prices in service energy demand equations (E1 to E3 in appendix 8.2). CO_2 tax revenues are calculated in the energy module and are direct input to the taxes less subsidies variable, which further affects government revenues. Because of this consistent integration DYNK[AUT] can account for macroeconomic feedbacks due to changes in private consumption (e.g. sector outputs, factor incomes, government revenues) and how this in turn affects stocks (e.g. vehicles purchased) and thus service energy demand. See Figure 4 for a schematic overview on how energy demand and CO_2 pricing is integrated into the modeling of private consumption in DYNK[AUT].

Figure 4: Modeling consumption, energy demand and CO_2 taxes for private households in DYNK[AUT].



2.3.2 Industry sectors

The energy demand by industry sectors is based on data on final energy consumption (Statistik Austria, 2017a). The 62 NACE sectors are aggregated to the 18 sectors differentiated in the Austrian Energy Balances. Based on real energy input in basic prices (i.e. the E in KLEM^{m}M^d in basic prices and divided by its price index; see also section 2.1) and the respective energy intensity (TJ/€m) for each sector we derive aggregate energy demand in TJ. Physical energy demand (in TJ) of the industry sectors differentiated by fuel is obtained by multiplying total energy demand by the (endogenously modeled) real shares of fuel inputs for sector energy input (E), i.e. coal, oil, gas, electricity & heating, and renewables. Based on official CO_2 emission factors (Umweltbundesamt, 2017b) fuel energy demand is converted to CO_2 emissions from which CO_2 tax revenues can be calculated (if CO_2 taxes are applied).

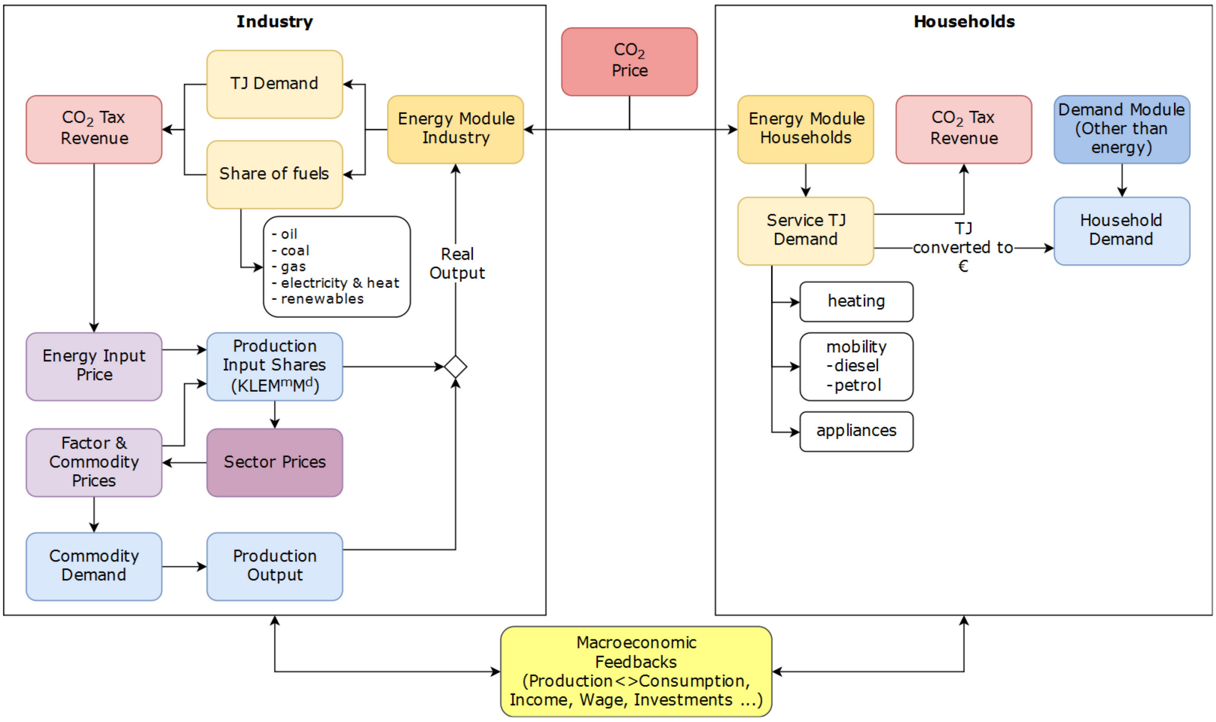
In our model the input factor energy (E) is, due to the aggregate level of the supply and use tables, only an approximation of real physical energy input[16]. The price index for E is nonetheless derived from exogenous fuel prices and the respective fuel shares obtained in the model. In order to avoid overestimating the price effect of CO_2 taxes on the

[16] It is the sum of the CPA (Classification of Product by Activity) categories mining and quarrying (05), manufacture of wood (16), manufacture of coke & refined petroleum products (19), and electricity, gas, steam and air conditioning supply (35).

aggregate energy input price[17] we model the impact as follows: First, fuel prices (in purchaser prices) are adjusted exogenously according to the impact of the CO_2 tax rates on fuel prices. This will affect the fuel shares of the industries. Second, based on the CO_2 emissions derived we calculate the CO_2 tax revenue from industries and transfer them to the taxes less subsidies variable. Third, we calculate the aggregate energy price (in purchaser prices) based on changes in the taxes less subsidies rates. This ensures that the price effect accounts for the non-energy commodities that are also part of E. We can thus account endogenously for the impact that CO_2 prices have on the aggregate energy price and thus on the aggregate energy input (E) of industry sectors.

Impacts on the competitiveness of domestic industries are captured by (i) the impact on the share of imported material goods (M^m) as an input for sector production and (ii) through the incorporation of Armington elasticities for private consumption. Exports are exogenously given. However, since exports are provided in nominal values, this implicitly assumes a unit elastic demand on real exports (i.e. if domestic prices increase by 1%, real exports will decrease by 1%).

Figure 5: CO_2 price impact chains in DYNK[AUT].



Hence, although we do not model energy demand first-hand for industry sectors (i.e. only as a derivative of real energy input), we can simulate the impacts of CO_2 taxes endogenously through their impact on taxes less subsidies and thus commodity prices in

[17] Since E consists of energy and non-energy commodities, a 1:1 transmission of CO_2 prices would lead to higher price effects as (the much smaller) changes in prices for non-energy commodities are not taken into account.

purchaser prices (and finally the aggregate energy price index). Figure 5 illustrates these CO_2 impact chains (also for private households) and indicates that DYNK[AUT] accounts for all other macroeconomic feedbacks caused by CO_2 taxes (e.g. higher production costs increase sector prices which affect final uses which affect income).

3 Scenarios

Our scenarios aim at covering a reasonable range of tax rate variants and tax recycling schemes. The main focus of our scenarios is on energy-related CO_2 emissions generated in non-ETS sectors, i.e. mostly CO_2 emissions from energy consumption by private households, transport and service sectors[18]. We also provide three additional scenarios: (1) a floor price for ETS sectors; (2) an increase in the vehicle registration tax (NoVa) for vehicle purchase; and (3) policy scenarios until 2030. These scenarios address further design options for carbon taxes in Austria and give an indication of the effects of the introduction of a carbon tax in the mid-term. Most scenarios are counterfactual comparisons in the short term (i.e. one representative year) comparing scenario results with the model's current base year 2012, labeled *Base*. For our mid-term scenario we compare the scenario runs to a *Baseline* simulation until 2030.

3.1 CO_2 tax rates

Our CO_2 tax rate scenarios have two components: (1) an energy tax rate (which is converted into an implicit CO_2 tax rate based on the CO_2 content of the fuels) and (2) an explicit CO_2 tax rate. Current energy tax rates in Austria translate into implicit CO_2 tax rates ranging from €18/tCO_2 for coal to €195/tCO_2 for petrol in the year 2016[19]. We consider three tax rate scenarios (see Table 1 for an overview): (1) *Low* – which assumes an explicit €60/tCO_2 tax rate on top of current energy tax rates, (2) *Med* – which assumes an explicit €120/tCO_2 tax rate on top of energy-equivalized energy tax rates (i.e. the energy tax rate in €/TJ is the same for all fuels), and (3) *High* – which assumes that an explicit and uniform €315/tCO_2 tax rate across all fuels replaces current energy tax rates. The explicit CO_2 tax rates in the scenarios *Low* and *Med* are similar to current CO_2 tax levels in Finland and Sweden, respectively. In relative terms the changes in the tax structure would imply price increases of ca. 10% to 21% for petrol, 12% to 33% for diesel, 15% to 43% for oil, 31% to 148% for gas and 82% to 408% for coal. Notably, price increases for gas and coal will be much larger than for petrol and diesel as these fuels currently face much lower energy tax rates and thus also much lower implicit CO_2 tax rates.

[18] Other relevant GHG such as N_2O and CH_4, primarily emitted by the agricultural sector and waste management, are not accounted for.
[19] Calculations are based on EU Excise Duty Tables and can be downloaded here: http://cats.wifo.ac.at/wp/wp2.htm [accessed 2018-01-25]

Table 1: CO_2 tax price scenarios for Austria

Scenario Name	Explicit CO_2 tax (€/tCO_2)	Energy Tax	Implicit CO_2 tax rates for fossil fuels (€/tCO_2)				
			Petrol	Diesel	Oil[1]	Gas	Coal
Base	0	Current	195	147	40	31	18
Low	60	Current	255	207	100	91	78
Med	120	Equivalized	315	315	160	178	153
High	315	None	315	315	315	315	315

[1]Refers to heating oil.

3.2 CO_2 tax recycling

Our tax recycling scenarios include compensation measures typically applied in the modeling literature, as well as in actual CO_2 tax schemes, such as the one in British Columbia, Canada (Murray and Rivers, 2015). This includes, on the one hand, lump sum transfers to households, once with an equal per-capita transfer for all income groups (*RecH*) and once with an equal per-capita payment only for the three lowest income groups (*RecH [low]*). On the other hand, we consider a reduction of employers' social contributions for industry & service sectors affected by a CO_2 tax (*RecQ*), effectively lowering the cost of labor for these sectors. In many studies these two compensation schemes have been compared, i.e. recycling all CO_2 tax revenues either through lump sum transfers or through reductions in labor taxes. We focus on a reasonable compromise between these two alternatives, similar to the tax recycling scheme in British Columbia: CO_2 tax revenues from private households are transferred back via lump sum payments to households and CO_2 tax revenues from industry & service sectors are transferred back via uniform reductions of employers' social contributions to the sectors affected (labeled *RecQH* if all household receive lump sum payments and *RecQH [low]* if only the lowest three income groups are eligible for lump sum payments). The tax compensation scenarios are compared to a scenario were tax revenues are not recycled (*NoRec*), which implicitly assumes that the government uses the revenues for budget consolidation.

Table 2: CO_2 tax recycling scenarios for Austria

Scenario	Description
NoRec	No tax recycling
RecH	All CO_2 tax revenues are recycled via equal per-capita lump sum payments to all households (H)
RecH [low]	All CO_2 tax revenues are recycled via equal per-capita lump sum payments to the three lowest households (H) income groups (QNT1 to QNT3)
RecQ	All CO_2 tax revenues are recycled via uniformly reduced employers' social contribution for industry & service sectors (Q) affected
RecQH	CO_2 tax revenues from households (H) are recycled as in *RecH* CO_2 tax revenues from industry & service sectors (Q) are recycled as in *RecQ*
RecQH [low]	CO_2 tax revenues from households (H) are recycled as in *RecH [low]* CO_2 tax revenues from industry & service sectors (Q) are recycled as in *RecQ*

3.3 Additional scenarios

Due to persistently low CO_2 prices in the ETS (Edenhofer et al., 2017) we also simulate a short-term scenario with a CO_2 floor price for ETS sectors (Wood and Jotzo, 2011) in order to see how this would affect our modeling results. We thereby assume an ETS price of €7/tCO_2.

We primarily focus on short-term impacts as these can already show the most important macroeconomic mechanisms and feedbacks relevant to distributional impacts without depending on too many external assumptions. Nevertheless, we will provide some simulations for the mid-term, i.e. until 2030, in order to indicate how an incremental introduction of CO_2 prices until 2030 could contribute to achieving GHG mitigation targets for 2020 and 2030. These scenarios are compared to a baseline scenario that (i) forecasts past trends, e.g. sector energy efficiencies and exports; and (ii) relies on other forecasts, e.g. mid-term forecasts for the Austrian economy (Baumgartner et al., 2017), energy prices based on PRIMES (Capros et al., 2010), and assumptions on household energy efficiencies for heating and mobility from the "Monitoring Mechanism 2017" project (see footnote 11). Our baseline is thus quite similar (but not identical) to the "with existing measure" scenario in the "Monitoring Mechanism 2017" project. Notably, these mid-term scenarios do not assess how CO_2 prices could affect the efficiency of stocks, e.g. investments in low-carbon heating systems or more energy efficient production processes, since this was outside the scope of this study. Our results for these scenarios should therefore only be seen as lower bound that only takes into account short-term price elasticities.

Finally, the mid-term scenarios are accompanied by a scenario that looks at increases in the vehicle registration tax ("Normverbrauchsabgabe" – NoVA). In Austria the NoVA depends on the specific CO_2 emissions of the vehicle purchased. Based on an empirical study by Hackbarth and Madlener (2011), who apply a discrete choice model on survey data, we implement a scenario that investigates how a higher NoVA could affect vehicle purchase choices and how this would affect CO_2 emissions from private mobility. We thereby decrease the standard NoVA denominator[20] from 5 to 1.66. More information on the modeling of NoVA is provided in appendix 8.3.

4 Results

4.1 CO_2 emissions and energy

The range of short term (i.e. one year) impacts of our simulated CO_2 tax scenarios on energy related CO_2 emissions[21] in non-ETS sectors is illustrated in Figure 6 for the tax recycling scenario *RecQH* (i.e. lump sum transfers and lower labor taxes). Total non-ETS emissions decrease by 3% (*Low)* to 10% (*High)*. Impacts are lowest for households due to the very low (short-term) price elasticities estimated for service energy demand and range from -1% to -3%. This indicates that comfortable room temperatures as well as mobility (e.g. commuting by private cars) are basic necessities for households, which will not change considerably in the short term even if prices increase strongly. Industry & service sectors react more sensitive with decreases of up to 14% in the transport sector[22] and 20% in the service sector. The impact for overall non-ETS industry & service sector emissions lies between -6% and -17%.

There are some small but negligible rebound effects in the model due to compensation schemes as households have more income to spend, either explicitly due to the lump sum payments or implicitly due to lower commodity prices if labor costs are reduced (see Figure 18 in appendix 8.4.1). In addition, macroeconomic impacts on employment will also affect household incomes. For example, in the CO_2 tax rate scenario *High* emissions of households (+0.2%) and industry & service sectors (+1.2%) and respectively total non-ETS emissions (+0.6%) are slightly higher with tax compensation ($RecQH_{[low]}$) than without (*NoRec)*.

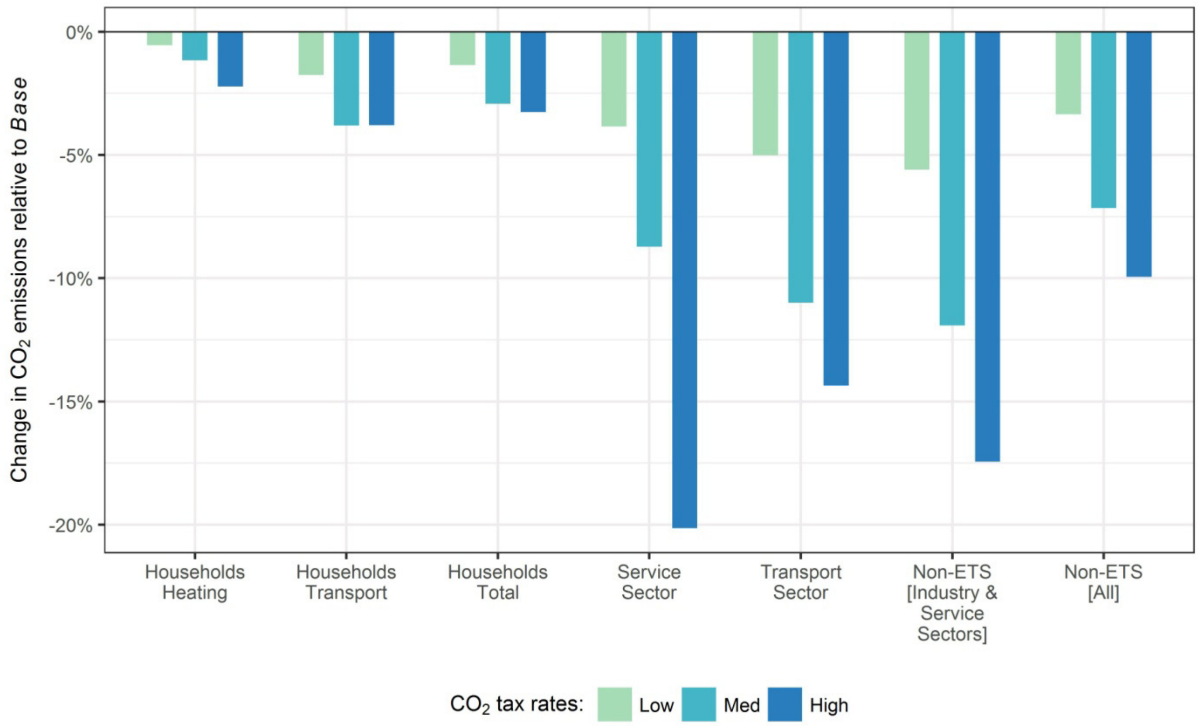
Higher fuel prices without tax compensation (*NoRec*) also increase real expenditure for public transportation between 4% (*Low*) to 9% (*Med*). Here, the upper bound is not found for the tax rate scenario *High* (+7%) as the impact on real expenditure for public transportation depends on the composite effect of changes in fuel prices, household income, and price changes for public transportation (due to macroeconomic feedbacks)[23]. Furthermore, rebound effects due to recycling of tax revenues are quite pronounced, as increases in income lead to decreased demand for public transportation (i.e. negative

[20] The standard NoVA calculation is (CO_2g – 90) / 5, although many exemptions are in place.
[21] In the remainder of text „emissions" will always refer to energy related CO_2 emissions.
[22] This measure implicitly includes also reductions in fuel tourism, i.e. haulers involved in international activities or consumers located near the border of a low taxing country fuel their vehicles in the Member State with the lowest prices. Due to comparably low tax rates, diesel and petrol are considerably cheaper in Austria than e.g. in Germany and Italy.
[23] The change in aggregate fuel price (diesel and petrol) is basically the same between *Med* and *High* (ca. +28%, see Table 1) but the price increase in public transportation is much stronger in *High* than in *Med*.

income elasticities). In the tax recycling scenario $RecQH_{[low]}$ increases in real expenditure for public transportation are reduced to 3% for *Low* and 7% for *High*.

Finally, introducing a CO_2 floor price for ETS industry sectors indicates a substantial potential to further decrease emissions (see Figure 19 in appendix 8.4.1). In the CO_2 tax scenario *Med & RecQH* CO_2 emissions in ETS sectors decrease by 1% without a floor price and by 12% with a floor price. This almost doubles the reduction of all energy related CO_2 emissions from 5% to 9%. Emissions in the non-ETS sectors are not affected much by the ETS floor price as the floor price only affects energy prices via the price of electricity (by ca. 5% to 6%) and indirect emissions are not taxed.

Figure 6: CO_2 emissions impact of the CO_2 tax rates (Tax recycling scenario: RecQH*).*

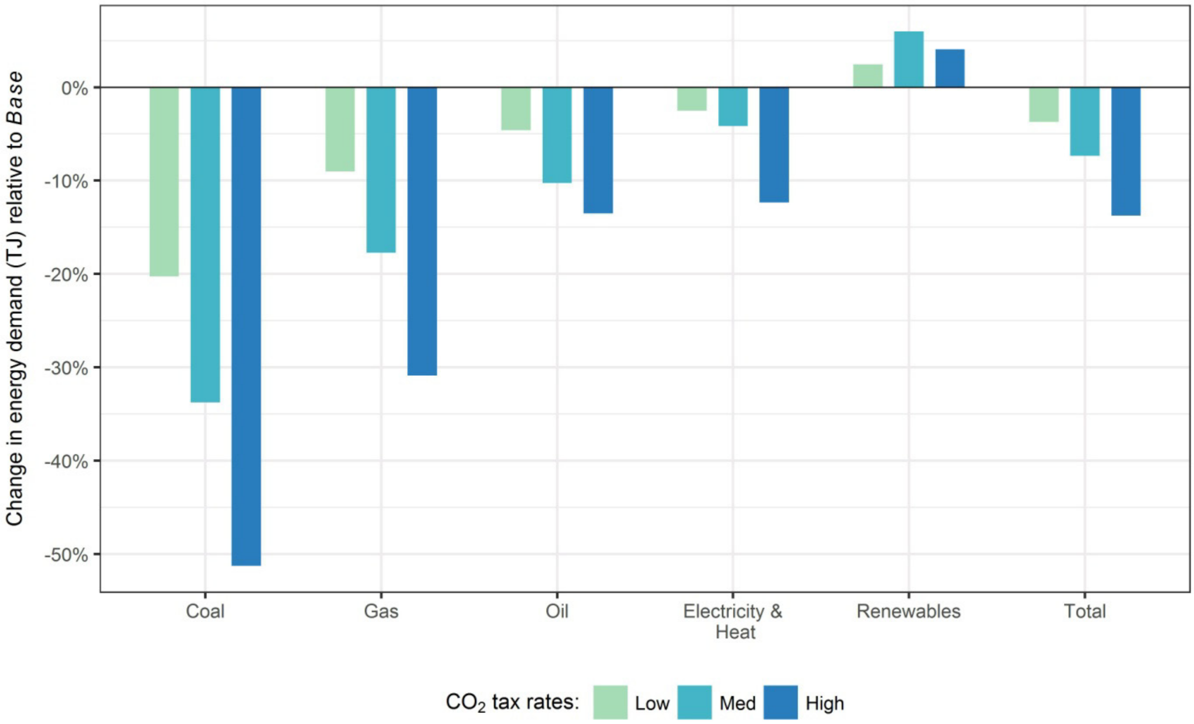


As DYNK[AUT] is a top-down model, it cannot provide detailed technical insights into how these changes arise. However, a look at the endogenously modeled changes in fuel demand for non-ETS industry & service sectors can provide some first clues (see Figure 7)[24]. Assuming tax compensation for both industries and households (*RecQH*) energy demand decreases most strongly for coal (-20% to -51%) and gas (-9% to -31%), followed by oil (-5% to -14%), and electricity & heat (-3% to -12%). Demand for renewables increases slightly by 2% to 6%. Note that the slower increase in renewables in *High* compared to *Med* conceals that their share still increases (15% in *High* compared to 14% in *Med*; see Figure 20 in appendix 8.4.1). These changes reflect the difference in

[24] As described in section 2.3 (aggregate) fuel demand shares are endogenously determined in the model, except for heating fuel shares in households.

relative fuel price changes due the introduction of CO_2 taxes. Total energy demand in non-ETS industry & service sectors (excl. households) decreases by 4% to 14%. The largest impact on CO_2 emissions from non-ETS industry & service sectors thus stems from reductions in overall energy demand, although shifts in fuel demand lead to slightly lower carbon intensity (tCO_2/TJ). Carbon intensity of non-ETS industry & service sectors decreases by 2% (*Low*), 5% (*Med*) and 4% (*High*). The decrease in carbon intensity is slightly lower in *High* than in *Med* as the aggregate oil price increases only slightly in most sectors from *Med* to *High*[25] while the gas price continues to increase significantly. This leads to lower gas shares and higher oil shares than in *Med* (see Figure 20 in appendix 8.4.1). As gas has a lower carbon content than oil, this explains the higher carbon intensity in *High* compared to *Med*. However, absolute CO_2 emission reductions are still higher in *High* than in *Med*.

Figure 7: Impact of CO_2 tax rates on non-ETS industry & service sector energy fuel demand (Tax recycling scenario: RecQH*).*



[25] In most sectors diesel contributes the largest share to aggregate oil demand and diesel prices are the same in *Med* and *High* (see Table 1). And even in sectors with a high share of gas oil or heating oil (e.g. Food & Tobacco) price increase remain much lower than for gas.

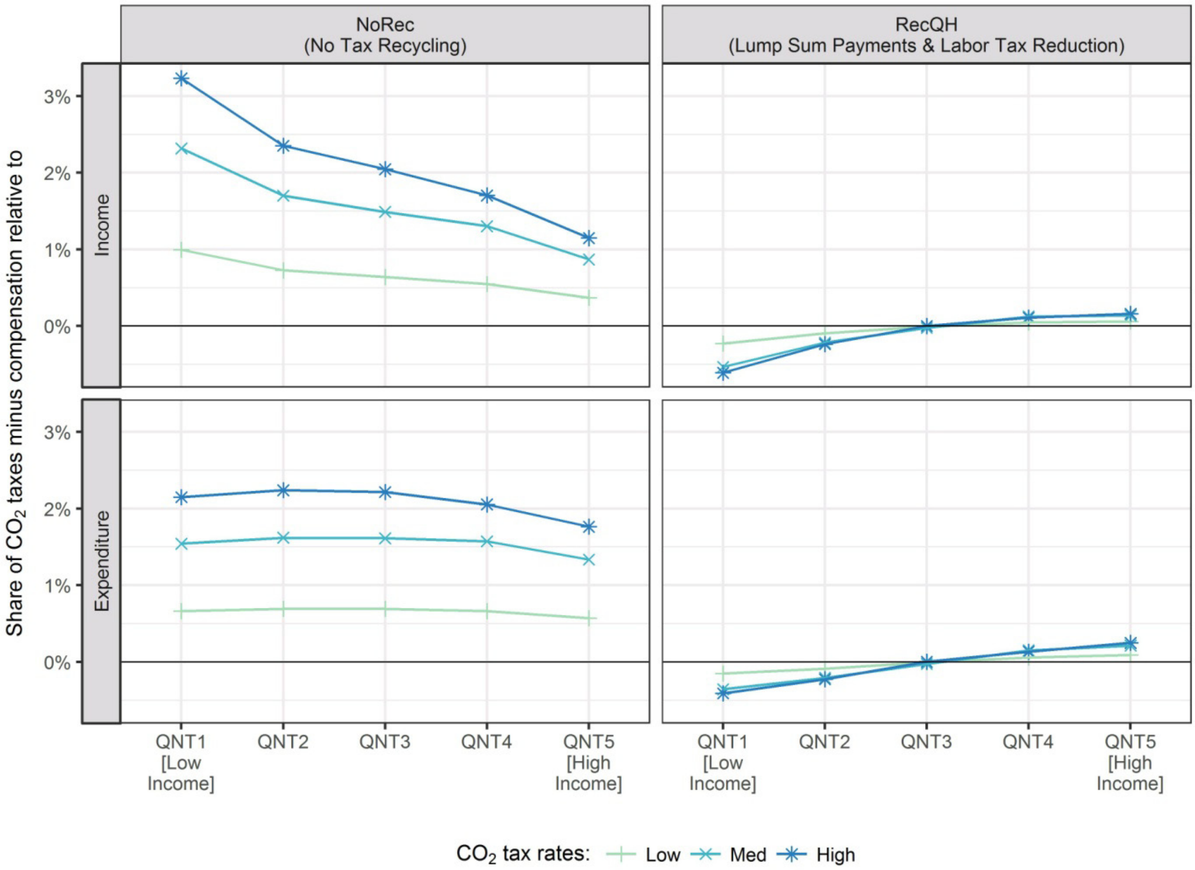
4.2 Distributional and tax impacts

The additional tax revenues from CO_2 taxes are quite substantial and range from almost €1.9b (*Low*) to €6.7b (*High*) for the tax recycling option *RecQH* (see Figure 21 in appendix 8.4.2). This would increase total tax revenue in Austria by 5% to 16%, respectively. Taxes paid by households make up more than 50% of total CO_2 tax revenue in all scenarios.

For assessing the distributive impact of CO_2 taxes on household income groups many indicators can be used (see section 1.2). We therefore provide results for a common range of indicators used in the literature, i.e. tax burden relative to household income or total expenditure, as well as changes in real household income and expenditure for all income groups.

Figure 8 illustrates outcomes for the indicators "tax burden relative to income" and "tax burden relative to expenditure" for our range of CO_2 tax rates without tax revenue recycling (*NoRec*) and tax compensation for both households and industry & service sectors (*RecQH*). In *NoRec* the household group with the lowest income spends between 1.0% (*Low*) to 3.2% (*High*) of their income on CO_2 taxes compared to only 0.4% to 1.1% for the household group with the highest income (see upper left graph in Figure 8). In absolute terms, annual CO_2 tax payments range between €108 to €349 per year and per capita in the lowest income and between €159 to €489 per year and per capita in the highest income quintile. The impacts become less regressive (slightly inverted U-shaped) if one looks at CO_2 taxes paid relative to total expenditure (see lower left graph in Figure 8). This is because (i) differences in expenditure between the household income groups are smaller than differences in income levels, and (ii) different relative price changes for transport and heating and their respective expenditure shares (see upper middle graph in Figure 3). As relative price increases in transport fuels are higher in *Low* and *Med* than price increases for heating (see Table 1), the inverted-U-shaped expenditure share of transport fuels dominates and impacts are almost perfectly proportional (ca. 0.7% in *Low*). However, impacts become slightly regressive in *High* as prices for heating are now higher than for transport fuels, and expenditure shares for heating are clearly regressive. Notably, if compensation measures in the form of lump sum payments are subtracted from CO_2 taxes paid, the CO_2 tax rate scenarios become progressive both relative to income and expenditure and lead to net increases for QNT1 and QNT2 (see both graphs on the right in Figure 8).

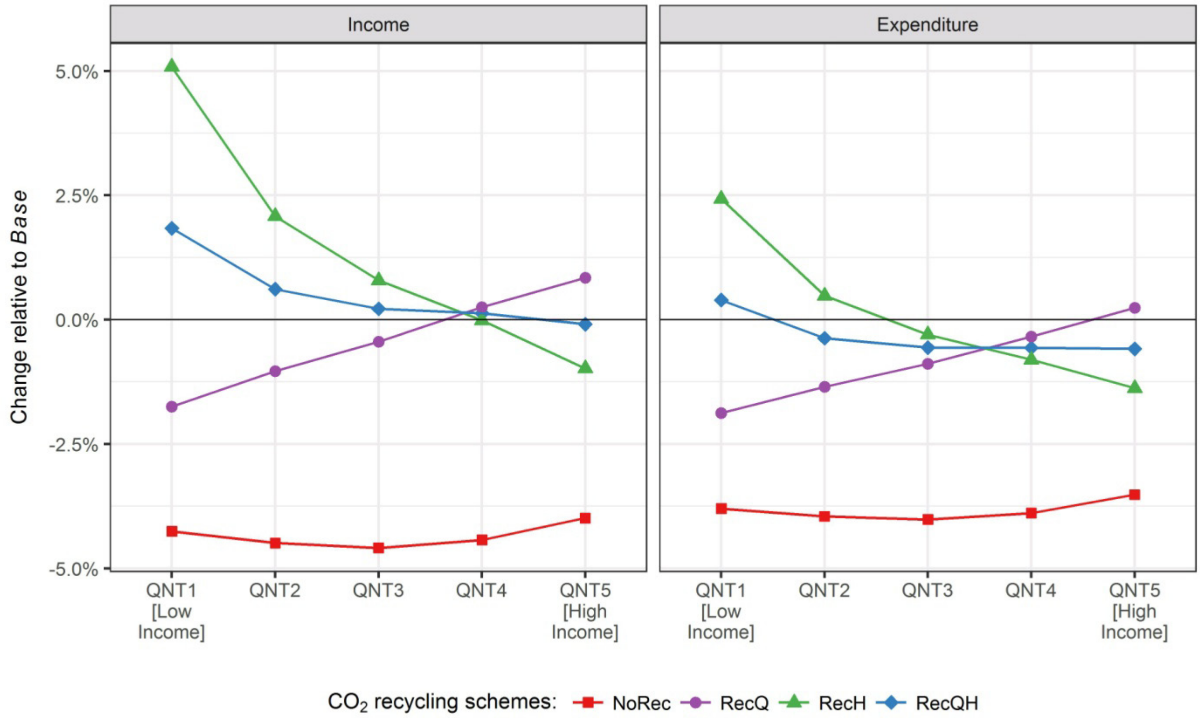
Figure 8: Tax burden impact on households.



Distributive impacts can also be shown with respect to overall changes in household income and expenditure. Figure 9 highlights these impacts for different tax compensation measures and the CO_2 tax rate scenario *High* in real values. Changes in incomes are similar to changes in expenditure, although a bit more pronounced and can differ in sign. Without tax recycling (*NoRec*) real expenditure decreases by ca. 4% for all household income quintiles. Differences between income quintiles are small in *NoRec*, but the middle income quintiles (QNT2 to QNT4) face slightly higher relative decreases for expenditure and income than the lowest and highest income quintiles. This mirrors somewhat the indicator "tax burden relative to expenditure". Three mechanisms explain these impacts. First, in DYNK[AUT] all households react similar to price changes. Hence relative changes in nominal expenditure will be (nearly) the same across all income groups in our model (see the sensitivity analysis in section 4.6.2 for simulation runs with differentiated reactions). Second, changes in real expenditure and income are driven by differences in consumer price indices. These in turn depend on commodity shares and will differ between income groups (see Figure 3). Therefore, real expenditure mirrors the indicator "tax burden relative to expenditure" (see Figure 8). Third, changes in nominal income are actually slightly progressive (see Figure 22 in appendix 8.4.2) as lower income households derive a larger share of their income from transfers (e.g. 42% in

QNT1 compared to 20% in QNT5) compared with higher income quintiles. Since transfers in our model are currently fixed (nominally) lower income quintiles are less affected by decreases in labor and capital incomes than higher income quintiles with respect to expenditure and income.

Figure 9: Changes in real household income and expenditure (CO_2 tax rate: High*).*

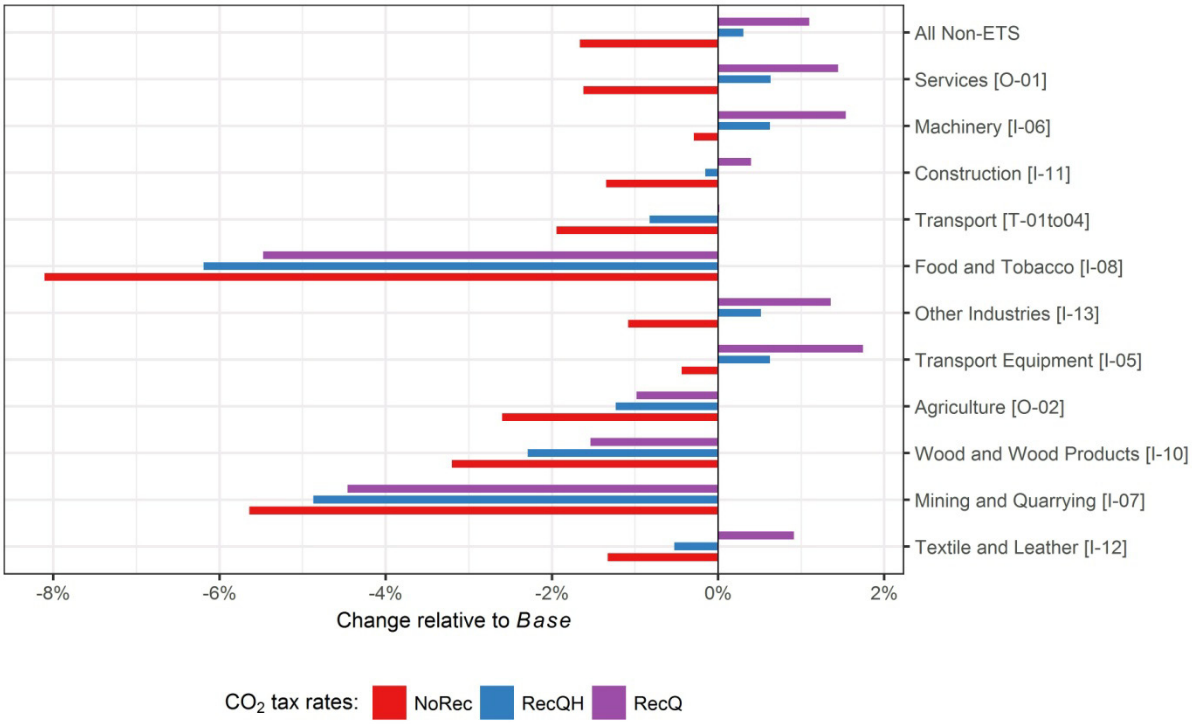


The model simulations further show that lump sum transfers benefit low income households more than labor tax reductions. Results for the CO_2 tax rate *High* are depicted in Figure 9. If taxes are solely recycled via a reduction of employers' social contributions (*RecQ*) real expenditure remains almost unchanged for the highest income quintile, but decreases by ca. 2% for the lowest income quintile. Lump sum payments (*RecH*, *RecQH*) lead to strong progressive tax burden impacts, increases in real expenditure for the lowest income quintile (in *RecH* also for the second lowest), and increases in real income for every income quintile except the highest. The positive distributive impact of lump sum payments (for all households) can be simply explained by the difference in CO_2 emissions and thus taxes paid between the income groups. Lower income households emit less CO_2 in absolute terms than the average household. Therefore, the per capita lump sum payments will be higher than the per capita CO_2 tax paid. This effect is of course amplified if lump sum payments are only eligible for households below a certain income threshold level (*$RecH_{[low]}$ and $RecQH_{[low]}$*, see Figure 23 in appendix 8.4.2).

4.3 Macroeconomic impacts

Impacts on the real value added of non-ETS sectors are shown in Figure 10 for the CO_2 tax rate scenario *High* and different CO_2 tax recycling schemes. Impacts differ substantially between sectors, depending on the importance of CO_2 intensive fuels as production input (e.g. initial share and substitutability). Sectors with significant reductions in value added are mining and quarrying, food and tobacco, wood and wood products, agriculture, and transport (i.e. land and water transport). Without tax compensation these sectors show decreases in real value added by 2% (transport) to 8% (food and tobacco) in the CO_2 tax scenario *High* (in *Low* these decreases are only 0.3% and 1.1%, respectively). At aggregate level the negative impacts on value added can generally be mitigated if labor costs are reduced, and the effect is naturally stronger for *RecQ* (all CO_2 tax revenue recycled via labor tax cuts) than for *RecQH* (CO_2 tax revenues recycled via labor tax cuts and lump sum payments for households). Notably, sectors with lower shares of labor input and substitution potential may still face negative impacts even with lower labor costs (e.g. transport, food and tobacco). However, these sectors contribute only little to overall non-ETS value added (ca. 8% in total).

Figure 10: Changes in real value added of non-ETS industry & service sectors (CO_2 tax rate: High*).*



Note: Sectors are ordered according to their share in total value added of non-ETS sectors (service sectors as an aggregate category already represent 74% of total non-ETS value added).

Increasing the price of CO_2 in ETS sectors via a floor price generally has more negative impacts on (real) value added of ETS sectors (see Figure 24 in appendix 8.4.3) than introducing a CO_2 tax in non-ETS sectors. This reflects the relatively higher importance of CO_2 intensive energy as input for sector production (a major reason why these sectors are included in the ETS). For example, the CO_2 tax rate *High* decreases value added in the energy sector by ca. 8% without tax compensation (*NoRec*) and by ca. 6% with tax compensation (*RecQH*). Overall ETS value added decreases by ca. 3% (*NoRec*) and 2% (*RecQH*). Tax compensation measures (i.e. lower labor costs) are less effective for these sectors due to the comparably lower relevance of labor costs and lower substitution potentials, although they reduce the negative impact by about half.

The GDP impact of the CO_2 tax rate *Med* and our tax recycling schemes is illustrated in Figure 11. Without compensation (*NoRec*) real GDP is negatively affected (-€3.5b or -1%). This decrease is primarily driven by significant reductions in private expenditure and lower investment (due to lower production output). Public expenditure also decreases, but only in real terms as nominal values are exogenously determined. Although one might expect that import shares increase with CO_2 taxes, the impact on net trade is actually positive (i.e. imports decrease stronger than exports). This is because commodities affected by the CO_2 tax, such as petrol and diesel, have a much higher import share than the average commodity. When they decrease substantially, net trade balances can be positively affected, even if import shares for all commodities increase. In addition, changes in import shares are generally quite low, as domestic output prices do not change considerably given that energy costs play only a minor role for most sectors. In scenario *High & NoRec* overall import shares (final and intermediate use) increase marginally from 33.2% to 33.5%.

Figure 11: GDP impacts (real values) (CO_2 tax rate: Med).

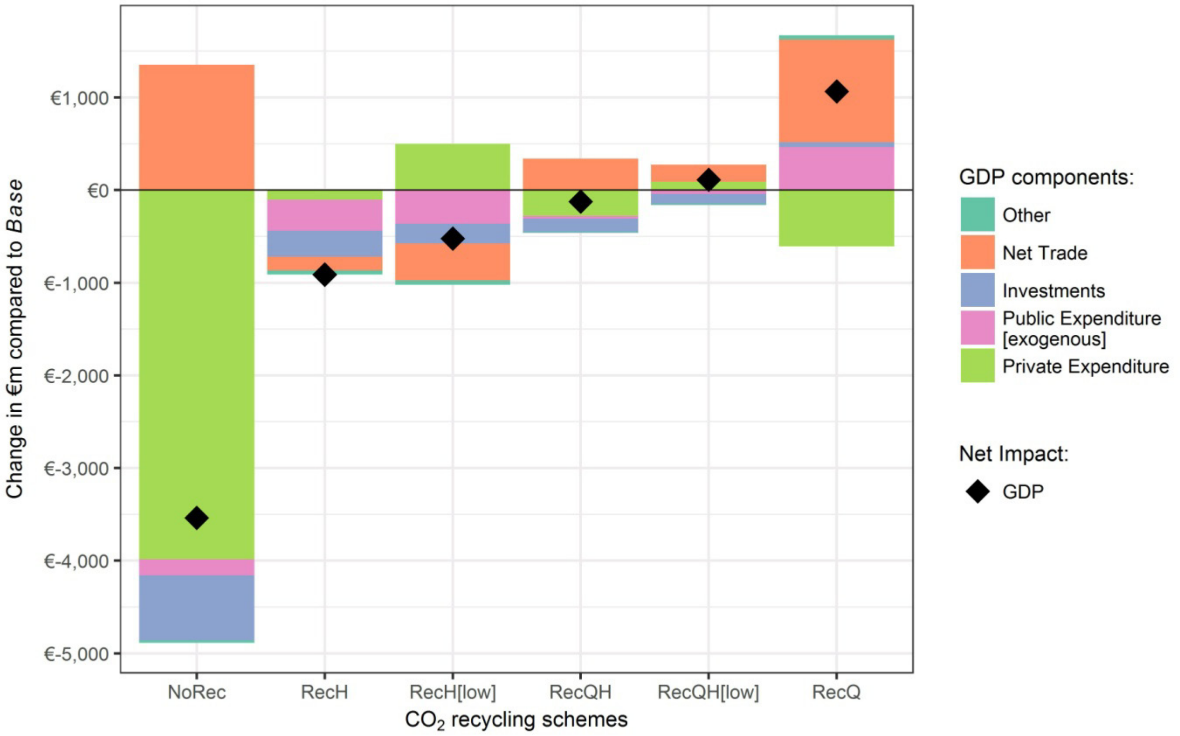
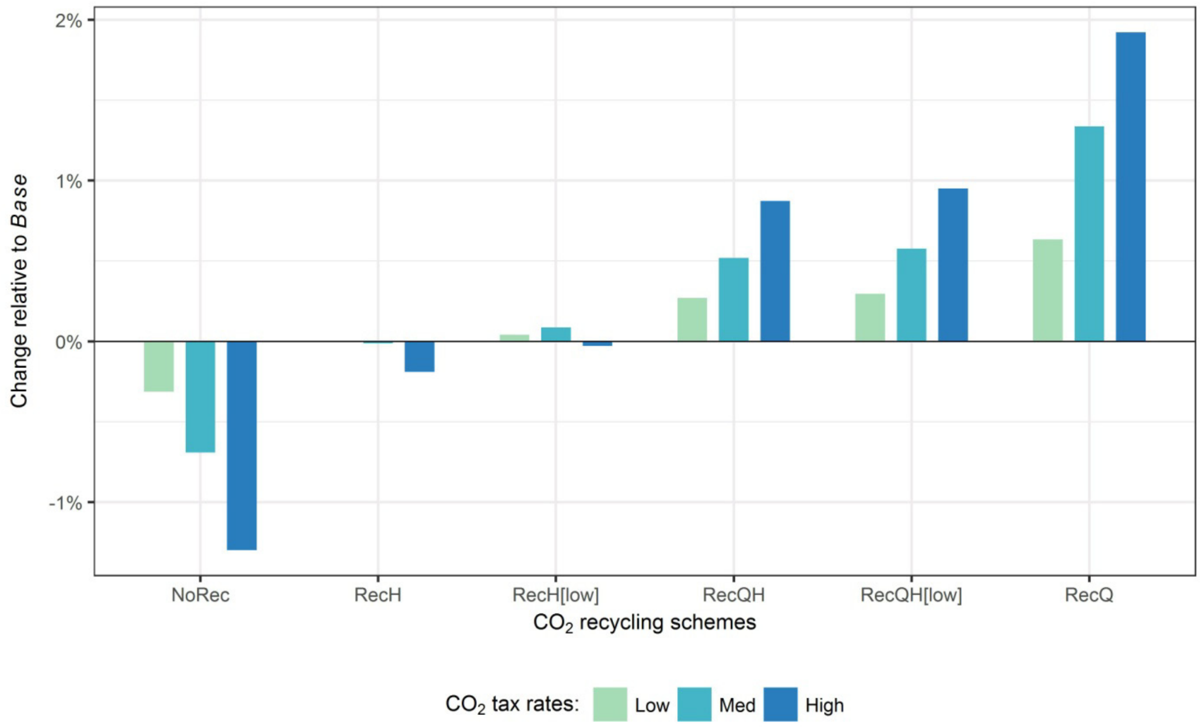


Figure 11 further illustrates that tax compensation schemes mitigate GDP impacts, although differences exist in magnitude and net impact sign. In *RecQH*, where both industry & service sectors as well as households are compensated, we only see small decreases in private expenditure and investments and net impacts are almost zero. These effects are enhanced if lump sum payments are only available for households with lower income (*RecQH*$_{[low]}$). In our model, all households react in the same way to relative changes in income (i.e. we cannot account for differences in marginal propensity to consume), this also means that households with lower income will face much higher relative increases in their income with per capita lump sum payments, especially if only QNT1-QNT3 receive payments. This will result in slightly higher increases in expenditure in the model even in the absence of accounting for differences in marginal propensity to consume between income groups. Our simulations further show that tax recycling via labor tax cuts only (*RecQ*) leads to better and even positive GDP impacts (+0.3%) than compared to tax recycling via lump sum payments only (*RecH* and *RecH*$_{[low]}$), where GDP impacts remain negative (-0.3% and -0.2%, respectively). Notably, GDP impacts are marginal in relative terms in all tax recycling scenarios, independent of the CO_2 tax rate. The total range of GDP impacts (see Figure 25 in appendix 8.4.3) is between -0.5% (*Low*) and -2.3% (*High*) if no compensation measures are provided (*NoRec*). With tax recycling GDP does not decrease more than 0.7% (*High & RecH*) and may even increase by 0.3% (*Med & RecQ*).

Impacts on employment (see Figure 12) are smaller but similar to relative changes in GDP. Without tax compensation (*NoRec*) employment (measured in full time equivalents

– FTE) decreases by -0.3% (*Low*) to -1.3% (*High*). In absolute terms this means a reduction in full time equivalent (FTE) jobs by ca. 10,000 to 41,000, respectively. By compensating industry & service sectors affected via a reduction in labor costs, employment may thus even increase by 0.3% (*Low* & *RecQH*) to 1.9% (*High* & *RecQ*), i.e. by 8,500 to 60,500 FTE jobs, respectively.

Figure 12: Employment (FTE) impacts.

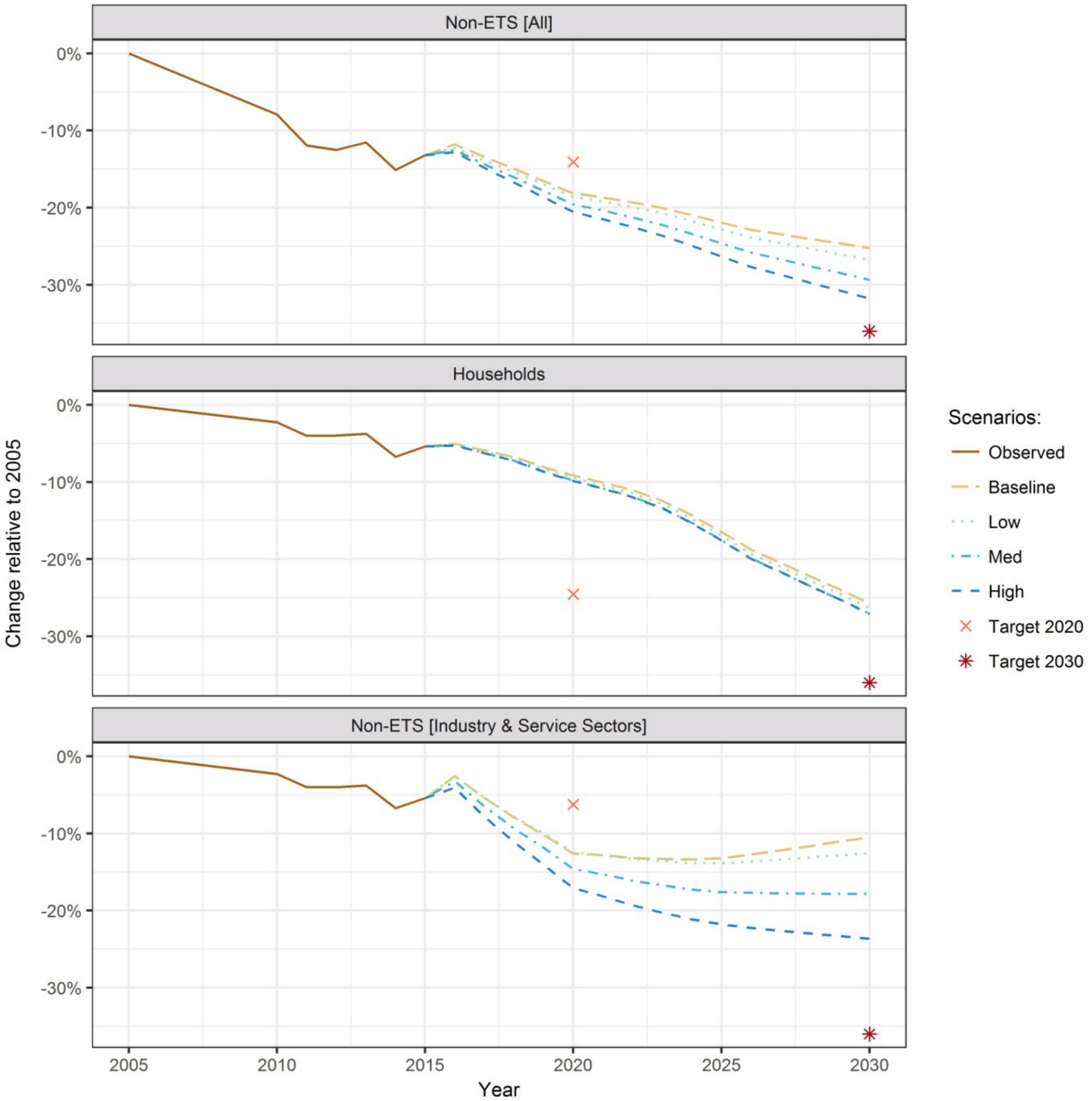


4.4 Scenarios until 2030

For our mid-term scenarios we simulate an incremental introduction of our CO_2 tax rates for the tax recycling scheme *RecQH* (lump sum payments and labor cost reductions). We assume that tax rates in these scenarios are implemented continuously, i.e. tax rates are increased linearly until the respective tax rates are reached in 2030. We further adjusted these tax rates for changes in the consumer price index in the baseline scenario until 2030 (i.e. they are adjusted for inflation).

Possible trajectories of total non-ETS CO_2 emissions are shown in Figure 13 (upper graph). It includes the observed trend of non-ETS GHG emissions between 2005 and 2015 as well as the mandatory 2020 target (Umweltbundesamt, 2017a) and the proposed 2030 target (i.e. -36%). We assume that the total GHG emission trend is identical to the CO_2 emission trend, as CO_2 is by far the most important greenhouse gas. Relative changes in CO_2 emissions in DYNK are then used to extrapolate possible trajectories from 2015 to 2030. *Baseline* scenario CO_2 emissions are considerably driven by economic growth (real GDP grows annually by ca. 1%), the forward projection of past energy intensity trends (€/TJ) in industry & service sectors (based on energy balances and IO data from 1995 to 2005), and exogenously assumed trends in household energy efficiencies (e.g. heating systems and vehicles). Although CO_2 emissions increase between 2014 and 2016 due to very low fossil fuel prices, we see a declining trend in total non-ETS CO_2 emission in the *Baseline* scenario already in 2017. This declining trend keeps emissions below the 2020 target, but is not enough to reach the proposed target for 2030 in the model. The CO_2 tax scenarios lead to lower emission trends, but also come short of the 2030 target (*High* leads to a reduction of ca. 32%).

Figure 13: Non-ETS CO_2 emission trends: observed (2005-2015) and modeled (2015-2030).



Note: CO_2 taxes are recycled as in *RecQH*. Emission reduction targets for 2020 are taken from Umweltbundesamt (2017a) and differentiated for sectors (-14% total, -6% for industry & service sectors, and -25% for households). The currently non-binding targets for 2030 (-36%) are not yet differentiated.

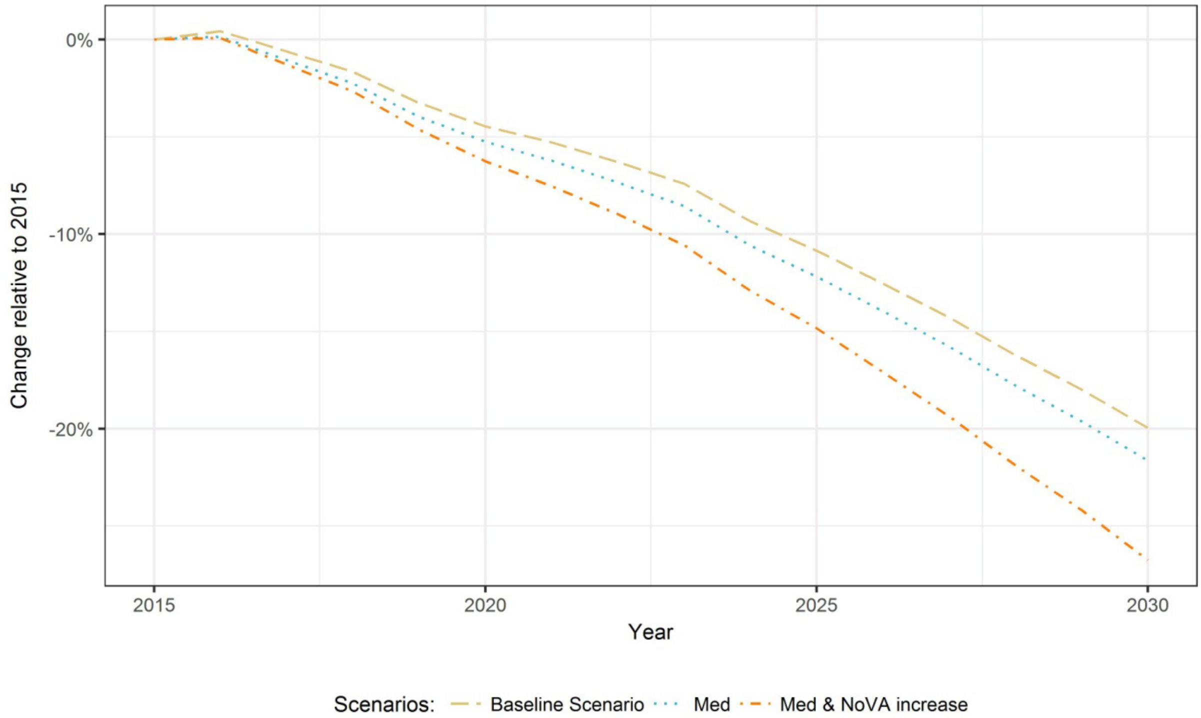
There are significant differences in the baseline trends between households and industry and service sectors (see middle and lower graph in Figure 13). For industry and service sectors in the baseline scenario we first see a decline in CO_2 emissions from 2016 to 2024 and increases thereafter. This is primarily driven by the exogenously determined trends in energy intensity. Total energy intensity first decreases (ca. until 2024), but from 2025 onward industry and service sectors with increasing energy trends (e.g. the transport sector) begin to dominate the total trend[26]. The CO_2 tax rates considered are high enough to counter the upward trend after 2024. For households, mid-term impacts are mostly driven by exogenous assumptions for the business as usual scenario (see footnote 11) on heating fuel shares and energy efficiency improvements for heating and mobility. These exogenous assumptions show (i) a strong decrease in oil heating which is substituted by increases in gas, biomass and district heating, and (ii) considerable improvements in energy efficiency for petrol and diesel vehicles. The impact of CO_2 tax rates is quite small compared to these driving forces, as we only consider short-term price elasticities and do not model the impacts of CO_2 tax rates on investment decisions. We thus caution that these results can only illustrate a lower bound of mid-term impacts of CO_2 tax rates.

4.5 Increasing the vehicle registration tax (NoVA)

The impact of an increase in the vehicle registration tax (NoVA) on vehicle stock efficiency and CO_2 emissions is simulated for the period 2015-2030. Increased revenues from NoVA are recycled as in *RecQH* (i.e. equal lump sum payments to all households). The impact on CO_2 emissions of an incremental increase in the NoVA (towards a denominator of 1.66 instead of 5) is shown in Figure 14 with respect to transport fuels (diesel & petrol). Compared to the CO_2 emissions in the CO_2 tax rate scenario *Med* an increase in the NoVA has a more significant impact than the CO_2 tax rate on diesel and petrol. Compared to the *Baseline* emissions in 2030 are only 2% lower in *Med*, but 8% lower with an additional increase in NoVA. An increase in the NoVA affects both the fuel efficiency of diesel and petrol vehicles (Figure 15), by increasing the share of more fuel efficient vehicles. The share of electric vehicles increases also but only marginally (from 10.7% in the *Baseline* in the year 2030 to 10.9% in the scenario *Med & RecQH* with NoVA increase). As shown by Hackbarth and Madlener (2011) other factors than purchase or fuel prices are much more important for the purchase decision of electric cars (e.g. battery recharge time, driving range, and fuel availability).

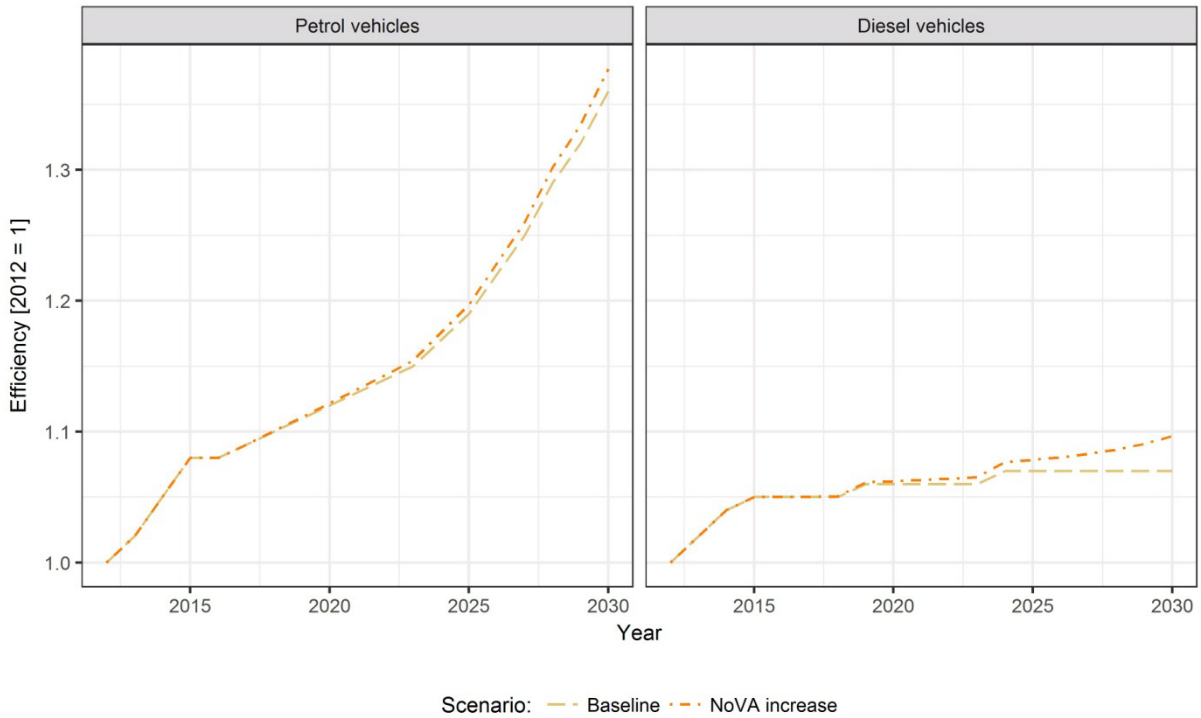
[26] As long as some sectors show increasing energy trends they will, at some point in the future, become dominant, as their relative contribution to overall energy demand will increase over time.

Figure 14: Petrol & diesel CO_2 emissions of households (2015-2030).



Note: CO_2 taxes as well as increased revenues from NoVA are recycled as in *RecQH*.

Figure 15: Fuel efficiency of petrol & diesel vehicles (2015-2030).



4.6 Sensitivity analyses

As in every model, many results depend on assumptions, system boundaries and uncertainty in model parameters. Here, we provide some sensitivity analyses for the most important drivers of our scenario results. We mainly concentrate on import and price elasticities.

4.6.1 Import shares

We ran our model estimations with two different Armington elasticities for private expenditure (see Table 10 in appendix 8.5)[27]. The default, used to obtain the results in section 3, are estimates taken from the FIDELIO2 model, which were derived in fixed-effects panel regressions based on WIOD data (Kratena et al., 2017). These are much lower than other reported Armington elasticities (e.g. Hertel et al., 2007; Németh et al., 2011). However, applying higher elasticities did not change the results significantly. Price changes in sector outputs remain too small to considerably affect import shares in private expenditure. Import shares slightly increase for the most relevant traded commodities (see Table 10 in appendix 8.5) but this does not alter the main results presented in section 3. For example, the highest reduction in GDP simulated in scenario *High & NoRec* increases only by 0.1 percentage points from -2.2% to -2.3% if Armington elasticities from Hertel et al. (2007) and Németh et al. (2011) are applied.

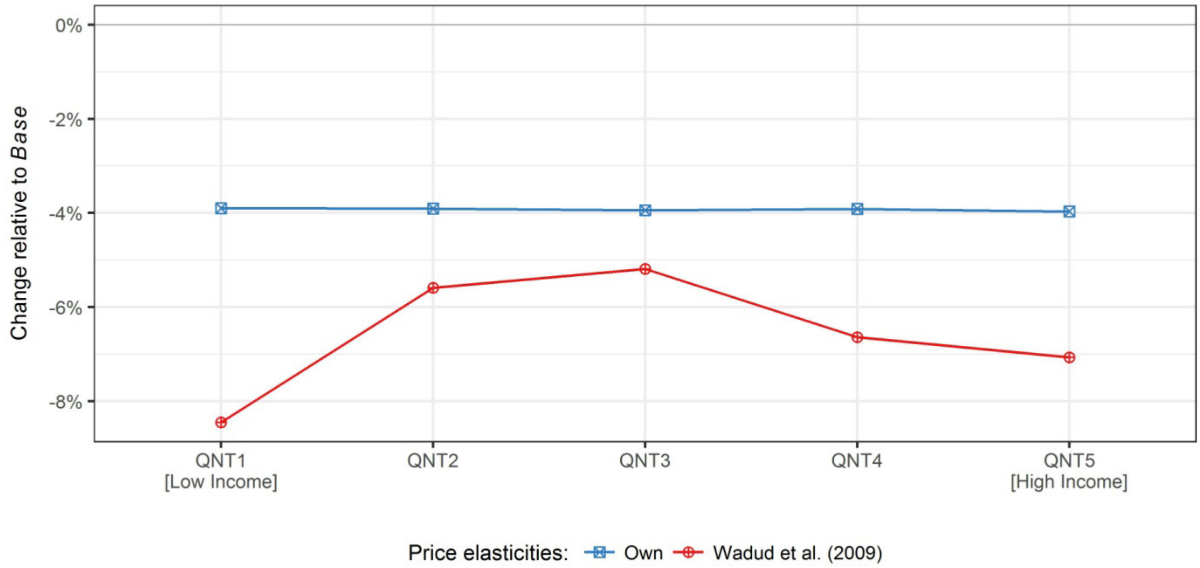
4.6.2 Service energy elasticities

In order to investigate the impacts of different price reactions we integrate quintile differentiated fuel demand equations as obtained in Wadud et al. (2009). Their estimations are based on US household data and may thus not be valid for Austria. However, their price elasticities show that household quintiles may react differently to changes in fuel prices, income, efficiency, and stocks. Income groups in the middle react more rigidly than the lowest and the highest income groups with respect to changes in fuel prices and income. This could reflect the higher dependence of middle income quintiles on private mobility (i.e. sub-urban or rural commuters), which could also be the case in Austria.

Figure 16 shows the difference in CO_2 emissions if quintile differentiated elasticities from Wadud et al. (2009) are applied in our model for the scenario *Med & NoRec*. Emission reductions are now generally higher simply due to higher elasticities, i.e. CO_2 emissions from all households decrease by 3% with our estimates and by 5% with Wadud et al. (2009) estimates. However, although QNT2 to QNT4 react less sensitively to price changes than QNT1 and QNT5, these differences are too small to really affect any of the distributive or macroeconomic indicators presented in section 4 (see for example Figure 26 in appendix 8.5.2 for tax burden relative to income). Hence, although differentiated reactions would certainly play an important role at the individual household level, they do not add much information to our aggregate macroeconomic indicators.

[27] We only use first nest elasticities (i.e. substitution between domestic and imported goods) and not second nest elasticities (i.e. substitution between different countries for imported goods).

Figure 16: *Difference in CO_2 emissions from transport fuels if household income quintiles react differently to changes in fuel prices for the scenario Med & NoRec.*



5 Discussion

5.1 Distributional impacts – Which indicator to use?

The distributive impacts of CO_2 taxes have been assessed based on many indicators in the literature (see section 1.2), most prominently as "CO_2 taxes relative to income and/or expenditure", but also with respect to changes in expenditure, income, welfare (EV), and equity indices such as the Gini coefficient.

Regarding "CO_2 taxes relative to income and/or expenditure" it is debated whether income or expenditure is a more reasonable indicator for measuring regressivity of tax incidence (Rausch et al., 2011; Wier et al., 2005). A distinct summary of arguments in favor of either can be found in Flues and Thomas (2015) and the discussion often refers to Poterba (1991). More often expenditure is recommended (Flues and Thomas, 2015; Kosonen, 2012; Poterba, 1991). Proponents argue that expenditure might be a better approximation for lifetime income[28] (e.g. an income based classification may include people with low transitional income in lower quintiles such as students or retired people; on the other hand frugal people with high income may fall into low consumption groups). In section 2.2 we provide results on consumption data for both classification types with respect to energy expenditures (Figure 3). We show that regressive impacts for Austria are not only influenced by the type of indicator (i.e. income or expenditure), but also by

[28] For example, our data suggests that the two lowest income groups (QNT1 & QNT2) currently have higher expenditure than income levels. According to the permanent income theory, this could reflect the expectation of receiving higher income the future or drawing on assets accumulated over time.

the type of measurement (i.e. total, per capita, or per capita equivalent). The latter effect is even more significant in our data, but is not discussed at all in recent reviews and publications (Flues and Thomas, 2015; Kosonen, 2012), except in Wier et al. (2005). We assume per capita equivalent to be the most reasonable measurement, as total levels put large households with low per capita income into higher income groups and per capita levels do not account for the cost-savings of sharing household goods (e.g. appliances, vehicles). We provide modeling results on both indicators (and the different measurements) in this study, but agree with Rausch et al. (2011) that the permanent-income hypothesis rests on strong assumptions (i.e. households know their full stream of lifetime income, or at the least the stream of income in the mid-term future).

Macroeconomic studies, such as ours, usually provide additional indicators, such as changes in expenditure and income, or, especially in CGE studies, changes in welfare indicators such as EV. Although changes in welfare across household incomes could probably be regarded as a better distributive indicator than changes in real expenditure or real income, it still rests on strong assumptions regarding the utility function of households, which ultimately will remain unknown. Another important issue with regard to welfare effects is how changes in expenditure, income, or utility should be weighed across household income groups. Implicitly all households have received similar weights in the studies reviewed. But a society may value changes in low income households more than changes in high income households, which can be seen in the discussions surrounding the implementation of CO_2 taxes (Callan et al., 2009; Roberts, 2016; Wang et al., 2016). Surprisingly, this issue remains ignored in all studies reviewed here and should receive more attention in the future.

5.2 Comparison with other studies and findings

5.2.1 CO_2 emissions

Our short-term impacts on CO_2 emissions are difficult to compare with other studies, as these often focus on different countries, different time periods, different CO_2 tax schemes, and use different methods to estimate energy demand. Our impacts are probably on a lower bound with respect to other studies, especially compared to CGE models (e.g. Beck et al., 2015; Breuss and Steininger, 1995; Felder and Schleiniger, 2002b; Rausch et al., 2011). This is not surprising as macroeconomic IO models are by nature and design more rigid than CGE models. Compared to other macro-economic IO models reviewed, we find our results to be close but lower than in the MOVE model (Baresch et al., 2014; Schneider et al., 2010), and – with respect to private households – higher than in e3.at (Wolter et al., 2011). And even though these models seem similar, a comparison remains difficult due to different CO_2 tax schemes and behavioral estimations in the model (for which detailed information is often not available).

5.2.2 Macroeconomic impacts

Similar to CO_2 emission macroeconomic impacts are also difficult to compare with other studies. Nonetheless, comparable to our results, both CGE (Breuss and Steininger, 1995;

Farmer and Steininger, 1999) and macroeconomic IO models (Baresch et al., 2014; Schneider et al., 2010; Wolter et al., 2011) find quite small negative impacts without tax recycling in Austria. Negative impacts are slightly higher in macroeconomic IO models than in CGE models. Some studies for other countries find small positive impacts of CO_2 taxes without revenue recycling (Barker and Köhler, 1998; Felder and van Nieuwkoop, 1996). Barker and Köhler (1998) explain this due to positive changes in net trade balances in some of the EU-MS considered in this study (as many fossil fuel commodities have high import shares). This mechanism can also be seen in our results (see Figure 11) but it is not strong enough to change the sign of impact. Beck et al. (2015) find small but negative welfare impacts for British Columbia, Canada, even with tax recycling. A common finding across all studies, including ours, is that compensation schemes usually lead to better macroeconomic results and that labor tax cuts have positive effects on employment.

5.2.3 Distributive impacts

Our data on transport fuel expenditure (measured in per capita equivalent, see Figure 3) are quite similar to the fuel tax impact reported in Flues and Thomas (2015, p. 21) for Austria, i.e. regressive for income and inverted-U-shaped for expenditure. This reflects that both studies use the same underlying data sets (official consumption surveys). Moreover, the actual model results for the indicator "CO_2 taxes relative to income and/or expenditure" are quite typical for a high-income country and similar to results for Denmark (Wier et al., 2005) and the Netherlands (Kerkhof et al., 2008). Baresch et al. (2014) do not provide impacts on tax burden, but can show that employment effects are most adverse for low income households in Austria. Wolter et al. (2011) can show that tax compensation via income tax or social contributions benefits high income households more in Austria. This is quite similar to our findings.

Overall welfare impacts of implementing CO_2 taxes without revenue recycling, in our study measured as changes in real expenditure and real income, are in the range of other macroeconomic results. Barker and Köhler (1998) find a more regressive impact for EU-MS with respect to real expenditure. However, a more recent study by Landis and Heindl (2016) that includes Austria provides similar results with respect to changes in expenditure. Impacts on EV in Rausch et al. (2011) for the US also come quite close to our indicators (i.e. rather proportional without tax revenue recycling) while Beck et al. (2015) find progressive impacts for British Columbia. A common finding across all studies, ours included, is that compensation measures can mitigate any potential regressive impacts.

5.2.4 Efficiency, equity and the double dividend

A prominent theme in previous macroeconomic studies has been the trade-off between efficiency and equity and the double dividend effect. The consensus seems to be that while income/labor tax cuts are more efficient than lump sum payments (i.e. the weak double dividend), lump sum payments perform much better with respect to equity. A conceptual proof for this can be found in Klenert and Mattauch (2016) and our model results also indicate (i) both a strong double dividend, i.e. increases in macroeconomic indicators and decreases in emissions with uniform labor tax cuts (no lump sum payments for households), as well as a weak double dividend, i.e. labor tax cuts are more efficient than lump sum payments (see Figure 25 in appendix 8.4.3), and (ii) more equitable impacts with lump sum payments than with labor tax cuts (see Figure 9 in section 4.2). Results in Baresch et al. (2014) further indicate that recycling only a proportion of total tax revenue might not be enough to reach a strong double dividend (i.e. positive net impacts on GDP/employment). Finally, a combination of both labor tax cuts and lump sum payments (i.e. our *RecQH* recycling scenario) seems to be a reasonable trade-off between equity and efficiency.

5.3 Further issues

As with many other studies, we only considered the economic cost impacts of CO_2 taxes on traditional macroeconomic indicators. While it is implicitly assumed that CO_2 tax rates are needed to account for an environmental externality caused by the emissions of CO_2 we did not provide any information on the benefit side of the equation. While it is a tedious if not impossible task to put a precise figure on the environmental and/or social cost of externalities, one can safely assume that small negative impacts on macroeconomic indicators such as GDP or EV are likely to be offset if these externalities are accounted for, especially if environmental co-benefits of GHG mitigation are considered (Deng et al., 2017; García-Muros et al., 2016). For example, poor workers may profit much more from reductions in local air pollution (an often cited co-benefit of CO_2 mitigation) than others (Wang et al., 2016). Furthermore, Felder and Schleiniger (2002b) show that taxing local externalities might even have a stronger impact on CO_2 emission reductions than a CO_2 tax alone (due to co-dependencies of many externalities such as clean air or absence of noise). They also account for some approximate economic measures of environmental benefits and show that they can outweigh decreases in traditional economic welfare indicators such as EV.

Finally, impacts might differ strongly in the mid- and long-term, if investment decisions (e.g. heating systems, vehicles) or modal switches are taken into account (which our model currently does not). We do aim to include these impacts in future studies, but would rather leave the modeling of investment decisions to technical bottom-up economic models[29]. Furthermore, a model linkage with micro-simulation models would allow us to assess the social impact of the introduction of a carbon tax across a wider range of household factors (e.g. education, gender). Integrated modeling frameworks (Laniak et al., 2013) could provide much more detailed insights into the social and environmental impacts of CO_2 taxes while still accounting for macroeconomic feedbacks.

[29] These are much better suited to assess such consumption and investment choices for e.g. mobility (Pfaffenbichler et al., 2008), energy (Schmidt et al., 2011) or land use (Kirchner et al., 2016). Additionally, we would like to combine our model with micro-simulation models (e.g. Ederer et al., 2017).

6 Summary and conclusion

We provide a macroeconomic assessment of distributive, macroeconomic, and CO_2 emission impacts of CO_2 taxes in Austria. Our simulations indicate significant reductions in CO_2 emissions already in short-term as well as mid-term, at least for industry & service sectors. Scenario simulations until 2030 show that mitigation targets in the mid-term future are not met. However, we did not model the impacts of CO_2 taxes on stock efficiencies (though investments in low carbon technologies) and it is likely that CO_2 taxes will provide incentives to invest in low-carbon or carbon-neutral technologies in the mid- and long-term. This should be assessed in combination with technical economic bottom-up models in future studies. The distributional impacts depend on the indicator used and the recycling mechanisms considered. Without compensation measures regressive impacts are shown for tax burden in relation to income, but rather proportional impacts are found for changes in real income and real expenditure as well as for tax burden in relation to expenditure. Compensation measures in the form of lump sum payments for households and labor tax cuts for industry sectors affected can mitigate potential regressive tax impacts, competitiveness issues for industries, as well as negative macroeconomic impacts. Labor tax cuts also boost employment. Recycling CO_2 tax revenues both via reductions in labor costs for businesses and lump sum payments for households could be a reasonable trade-off between economic efficiency and social equity.

Our modeling results thus provide many arguments that carefully designed CO_2 tax policies can play an important part in achieving GHG emission targets for non-ETS sectors in Austria with potentially positive distributive and macroeconomic impacts. The case for CO_2 taxes is further amplified if one would account for the positive benefits and co-benefits of mitigating CO_2 emissions.

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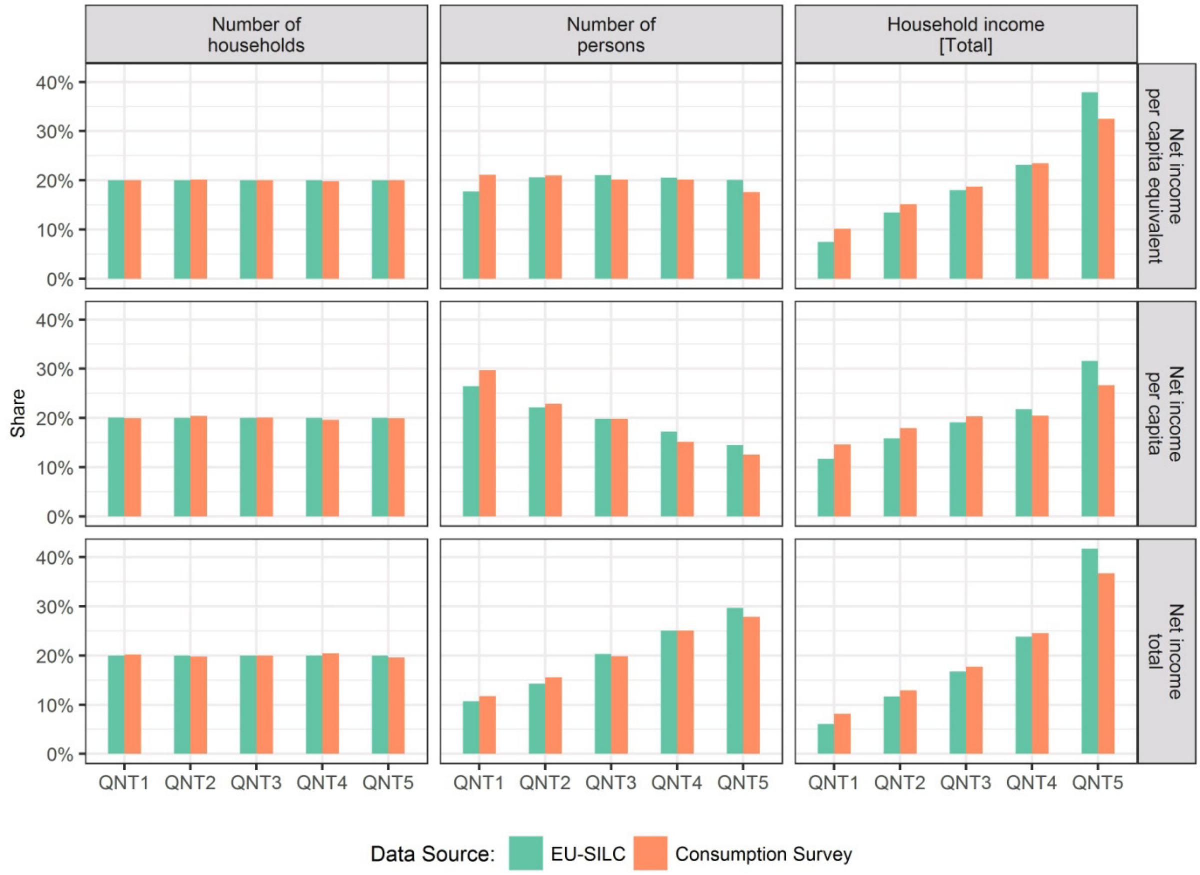
8 Appendix

8.1 Household income quintiles

Figure 17: Comparison of EU-SILC and Consumption Survey data and three different measurement levels of net income (total, per capita and per capita equivalent).



Note: The somewhat unequal distributions of households in the consumption survey (see figures on the left) are due to many households reporting the exact same income after taxes.

8.2 Service energy demand households

Behavioral Equations:

$$\log\left(\frac{S_{\text{mob},fm,h}}{VEH_{fm,h}}\right) = \mu_{\text{mob},fm,h} + \gamma_{\text{mob},fm} * \log\left(\frac{p_{\text{mob},fm,h}}{e_{\text{mob},fm}}\right) + \xi_{\text{mob},fm} * \log\left(\frac{VEH_{fm,h}}{pop_h}\right) \quad \text{(E1)}$$

$$\log\left(\frac{S_{\text{app,elec},h}}{hh_h}\right) = \mu_{\text{app,elec},h} + \gamma_{\text{app,elec}} * \log\left(\frac{p_{\text{app,elec},h}}{e_{\text{app,elec}}}\right) + \xi_{\text{app,elec}} * \log\left(\frac{K_{\text{app},h}}{hh_h}\right) \quad \text{(E2)}$$

$$\log\left(\frac{S_{\text{heat,tot},h}}{hh_h}\right) = \mu_{\text{heat,tot},h} + \gamma_{\text{heat,tot}} * \log\left(\frac{p_{\text{heat,tot},h}}{e_{\text{heat,tot}}}\right) + \vartheta_{\text{heat,tot}} * \log(hdd) \quad \text{(E3)}$$

$$S_{\text{heat},fh,h} = S_{\text{heat,tot},h} * fhshare_{fh,h} \quad \text{(E4)}$$

Table 3: Indices used in equations E1 to E4

Set Symbol	Description	Items
u	Energy use categories	heating [heat], appliances [app], mobility [mob]
f	Energy fuel categories	total [tot], diesel, petrol, electricity [elec], coal, oil, gas, biomass [bio], heat pumps [hpump], district heating [dheat], wood
$fm\ (\subset f)$	Private mobility fuel types	diesel and petrol
$fh\ (\subset f)$	Heating fuels	elec, coal, oil, gas, bio, hpump, dheat, wood
h	Household income groups	QNT1*QNT5

Note: In the equations indices in italics refer to sets or sub-sets and indices in non-italic refer to unique items.

Table 4: Activity variables used in equations E1 to E4

Symbol	Description
$S_{u,f,h}$	Service energy (in TJ) for energy use (u), energy fuels (f) and households (h)
$VEH_{fm,h}$	Number of vehicles per fuel type (fm) and households (h)
$K_{\text{app},h}$	Real stock of appliances (in €m) per household (h)

Table 5: Exogenous parameters used in equations E1 to E4

Symbol	Description
$\mu_{u,f,h}$	Constant differentiated for selected energy use (u), energy fuels (f) and households (h)
$\gamma_{u,f}$	Service price elasticities differentiated for selected energy use (u) and energy fuels (f)
$\xi_{u,f}$	Stock elasticities differentiated for selected energy use (u) and energy fuels (f)
$\vartheta_{\text{heat,tot}}$	Heating degree elasticity for total heating service energy demand
$p_{u,f,h}$	Price index differentiated for energy use (u), energy fuels (f), and households (h) Note: Households face different fuel prices only at aggregate levels (e.g. heating) due to different fuel shares in the energy use categories.
$e_{u,f}$	Efficiency index differentiated for energy use (u) and energy fuel (f)
pop_h	Persons per household groups (h)
hdd	heating degree days
$fhshare_{fh,h}$	Share of fuels used for heating (fm) and per household (h)

Table 6: *Estimation Results for Service Energy Demand for Petrol*

	Coefficient	Std. Error	t-Statistic	Prob.
μ	-3,749979	0,07251	-51,71648	0
γ	-0,248896	0,055786	-4,461645	0,0002
ξ	-0,533912	0,118087	-4,521332	0,0001
R-squared	0,945474	Mean dependent var		-3,277074
Adjusted R-squared	0,94093	S.D. dependent var		0,137984
S.E. of regression	0,033536	Akaike info criterion		-3,847941
Sum squared resid	0,026992	Schwarz criterion		-3,703959
Log likelihood	54,94721	Hannan-Quinn criter.		-3,805128
F-statistic	208,0766	Durbin-Watson stat		0,793781
Prob(F-statistic)	0			
Method: Least Squares (Marquardt - EViews legacy)				
Included observations: 27 (1990-2016)				

Table 7: *Estimation Results for Service Energy Demand for Diesel*

	Coefficient	Std. Error	t-Statistic	Prob.
μ	-3,552426	0,04524	-78,52386	0
γ	-0,119403	0,029131	-4,098795	0,0004
ξ	-0,441146	0,070009	-6,301252	0
R-squared	0,944146	Mean dependent var		-3,192313
Adjusted R-squared	0,939491	S.D. dependent var		0,094007
S.E. of regression	0,023124	Akaike info criterion		-4,591423
Sum squared resid	0,012834	Schwarz criterion		-4,447441
Log likelihood	64,98421	Hannan-Quinn criter.		-4,54861
F-statistic	202,8448	Durbin-Watson stat		0,701165
Prob(F-statistic)	0			
Method: Least Squares (Marquardt - EViews legacy)				
Included observations: 27 (1990-2016)				

Table 8: *Estimation Results for Service Energy Demand for Appliances*

	Coefficient	Std. Error	t-Statistic	Prob.
μ	2,033375	0,068967	29,4834	0
γ	-0,248554	0,069743	-3,563866	0,0022
ξ	0,493865	0,044491	11,10041	0
R-squared	0,87883	Mean dependent var		2,761352
Adjusted R-squared	0,865367	S.D. dependent var		0,099094

S.E. of regression	0,03636	Akaike info criterion		-3,659132
Sum squared resid	0,023797	Schwarz criterion		-3,509915
Log likelihood	41,42089	Hannan-Quinn criter.		-3,626748
F-statistic	65,27574	Durbin-Watson stat		0,73661
Prob(F-statistic)	0			
Method: Least Squares (Gauss-Newton / Marquardt steps)				
Included observations: 21 (1995-2015)				

Table 9: Estimation Results for Service Energy Demand for Heating

	Coefficient	Std. Error	t-Statistic	Prob.
μ	-7,091363	0,396639	-17,87863	0
γ	0,478419	0,050883	9,402375	0
ϑ	-0,066055	0,038068	-1,735193	0,0846
R-squared	0,991992	Mean dependent var		-3,351803
Adjusted R-squared	0,990641	S.D. dependent var		0,538363
S.E. of regression	0,052083	Akaike info criterion		-2,935542
Sum squared resid	0,450293	Schwarz criterion		-2,448789
Log likelihood	315,2154	Hannan-Quinn criter.		-2,738461
F-statistic	734,3695	Durbin-Watson stat		1,390494
Prob(F-statistic)	0			
Method: Panel Least Squares				
Total panel (balanced) observations: 195 (2000-2012; 15 Cross-Sections)				

8.3 Modeling of vehicle registration tax (NoVA) changes

For the modeling of increases in the vehicle registration tax (NoVA) we apply a modified version of the discrete choice models of Hackbarth and Madlener (2011). They applied a stated preference discrete choice experiment based on a nationwide survey of potential car buyers in Germany with specific focus on alternative fuel vehicles, such as electric cars. Vehicle attributes considered in the experiment included, inter alia, purchase price, fuel efficiency, and CO_2 emissions. We use the estimated parameter on price elasticity from the multinominal logit model and implemented the price reaction in our model. Based on data from the European Environment Agency (EEA, 2016) we calculated shares of low, medium, and high fuel efficient petrol and diesel vehicles as well as electric vehicles for Austria for our base year 2012. Prices for car purchase were taken from Statistics Austria and Eurostat. We then simulated how changes in the NoVA would affect vehicle type shares through its impact on purchaser prices. For sake of simplicity we kept all other attributes constant. The calculations were computed exogenously in spreadsheets (i.e. ex-ante to DYNK simulations) and results on vehicle shares, fuel efficiency, CO_2 emissions and CO_2 tax revenues were transferred to DYNK. Due time and resource constraints a full integration into DYNK was not feasible within this study.

8.4 Results

8.4.1 CO_2 emissions and energy

Figure 18: Rebound effect of tax recycling scenarios (CO_2 tax rate: High*).*

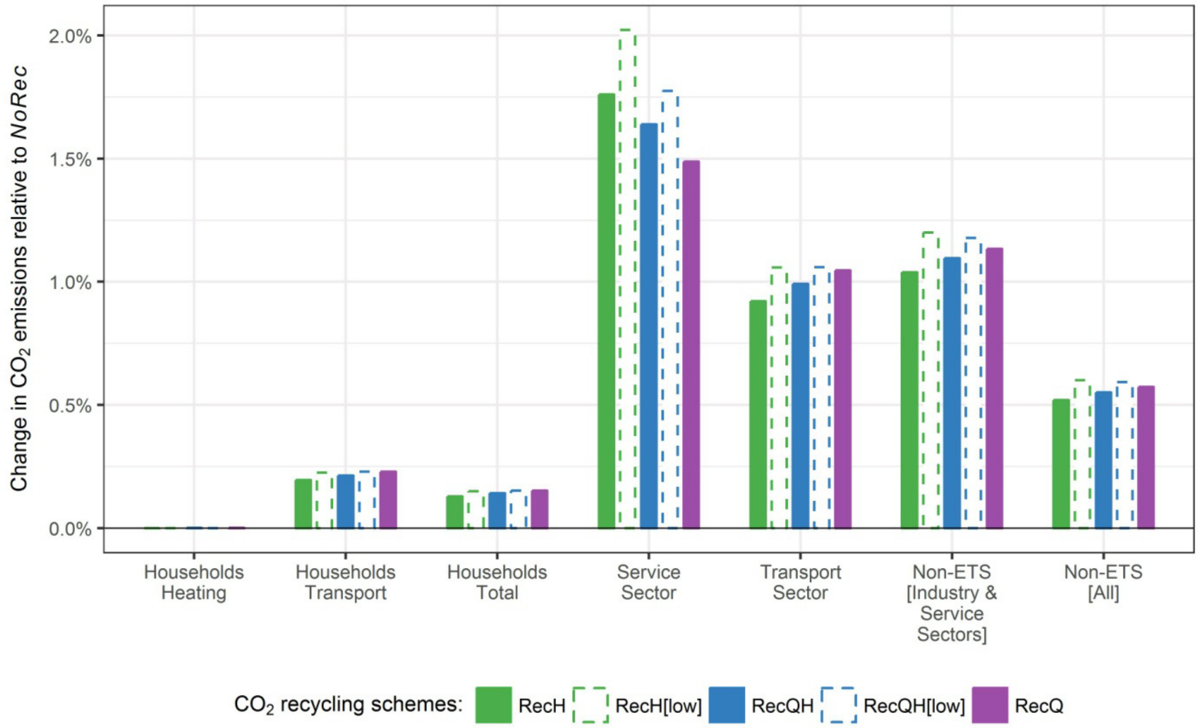


Figure 19: Change in CO_2 emissions with and without a floor price for ETS industry sectors in the CO_2 tax scenario Med & RecQH*.*

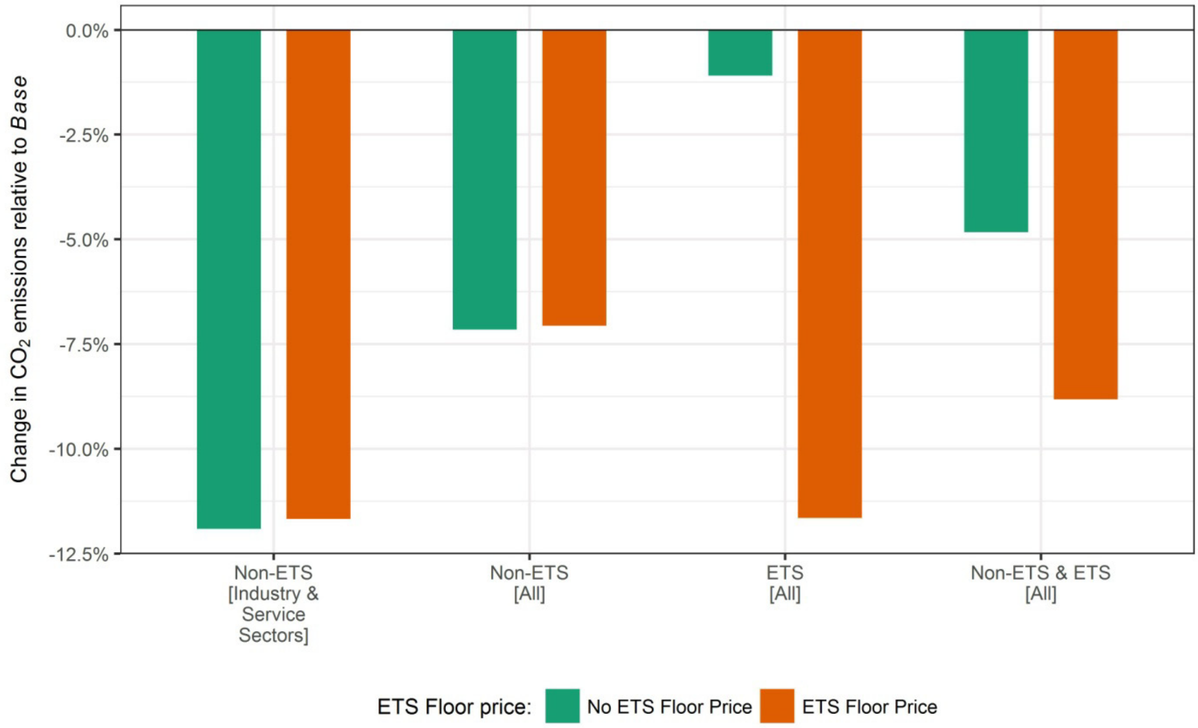
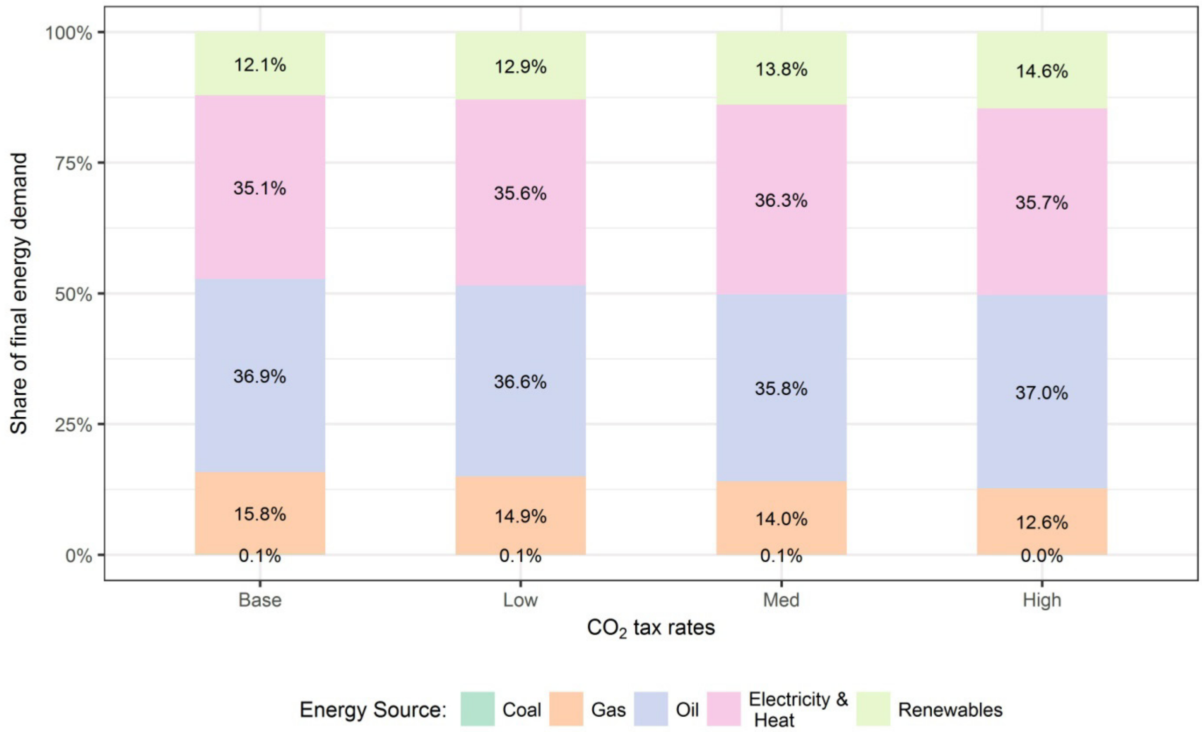


Figure 20: Energy fuel demand shares of non-ETS industry & service sector (Tax recycling scenario: RecQH*).*



8.4.2 Distributional impacts

Figure 21: CO_2 tax revenues (Tax recycling scheme: RecQH*).*

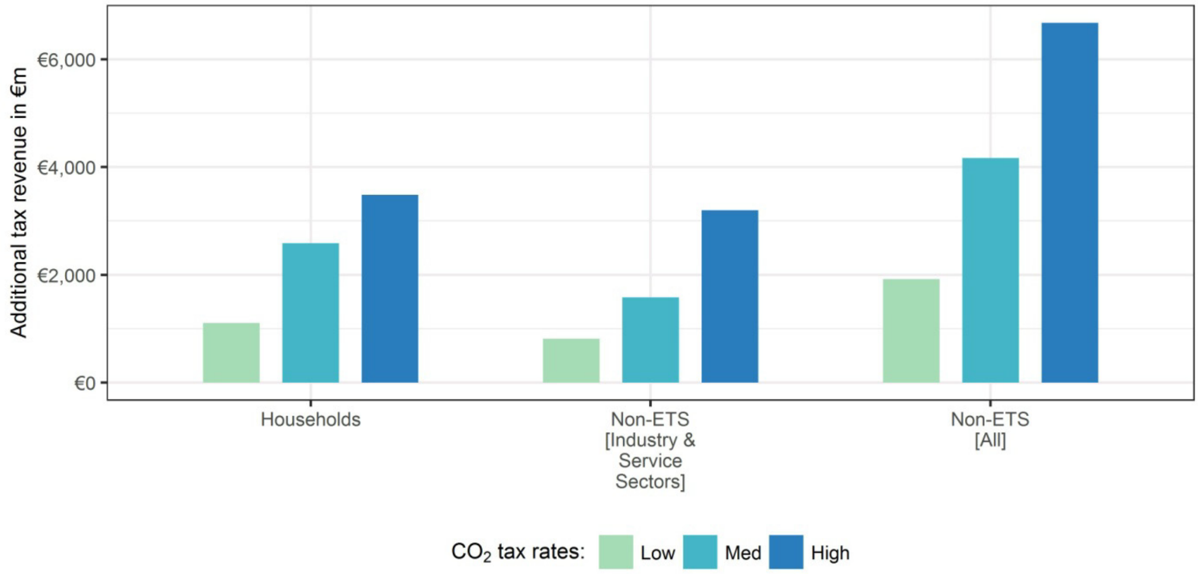


Figure 22: Change in nominal household income and expenditure (CO_2 tax rate: High*).*

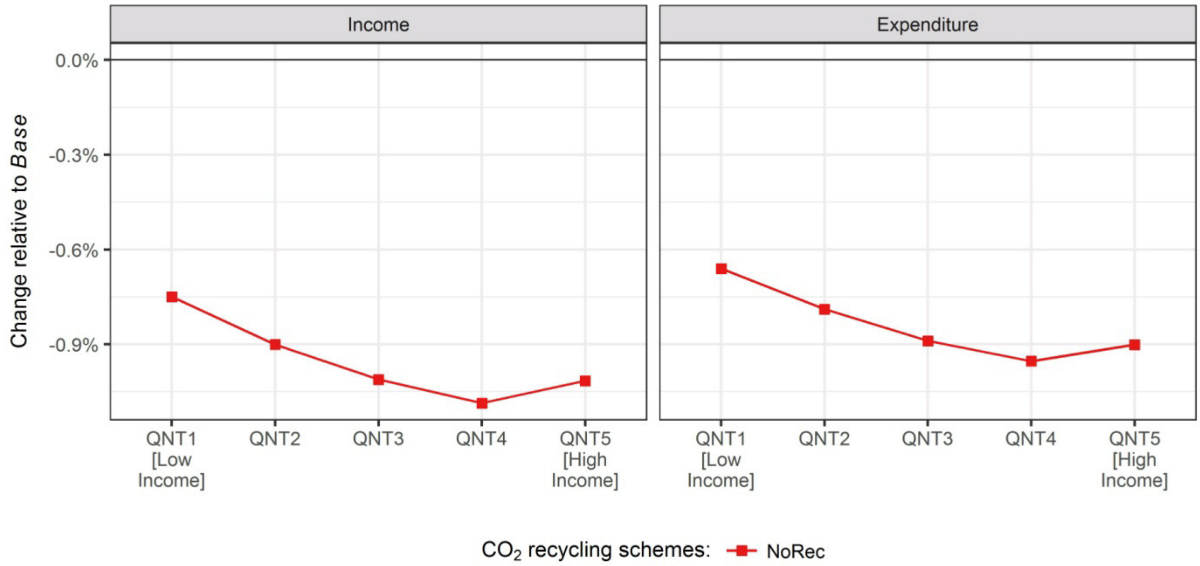
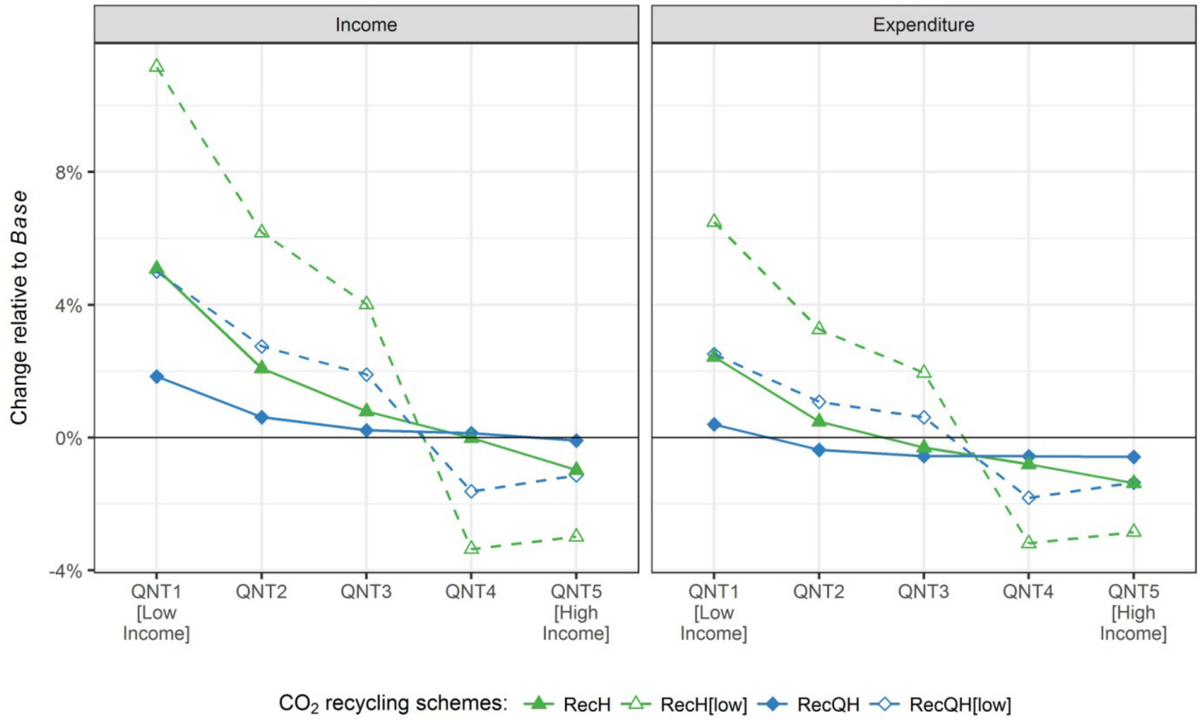
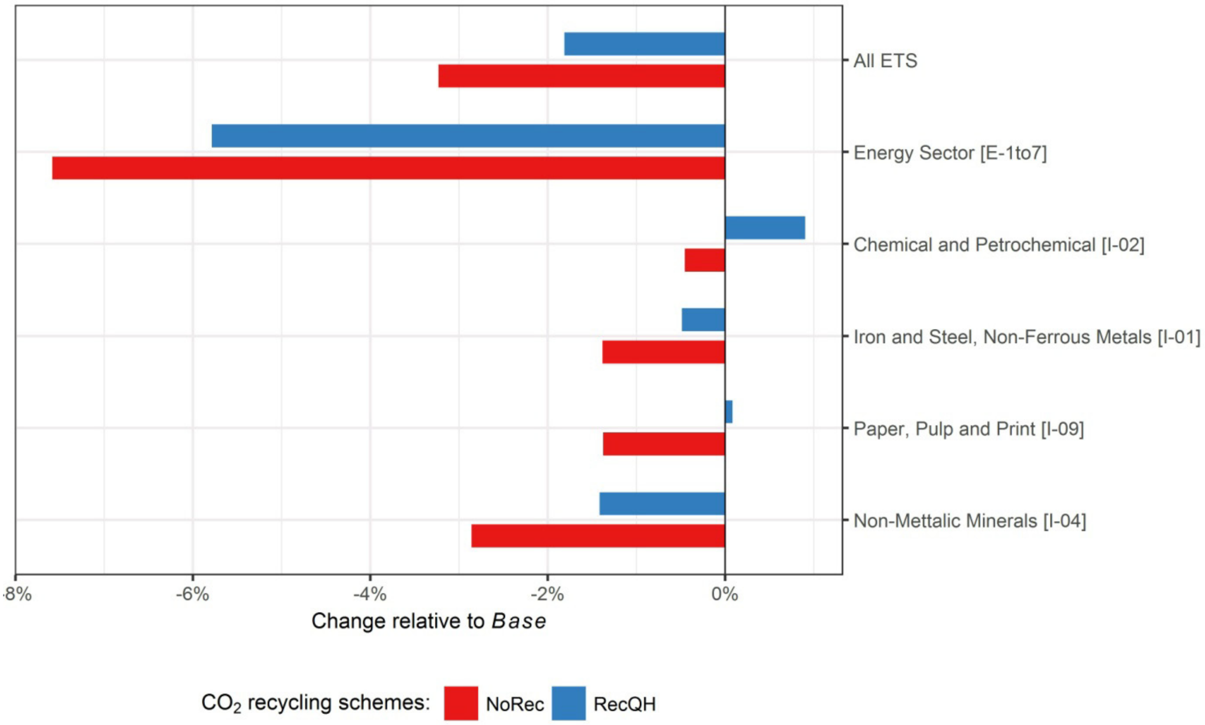


Figure 23: Changes in real household income and expenditure (CO_2 tax scenario: High).



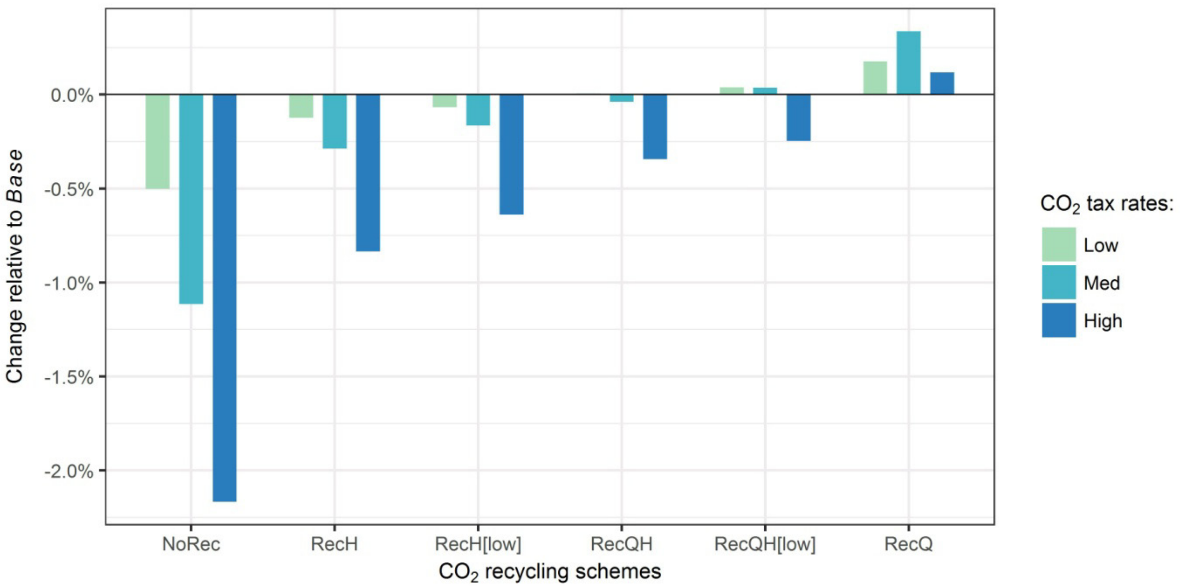
8.4.3 Macroeconomic impacts

Figure 24: Changes in real value added of ETS industry & service sectors (CO_2 tax rate: High incl. a floor price for ETS sectors).



Note: Sectors are ordered according to their share in total value added of ETS sectors (the respective shares are 30% (E-1to7), 21% (I-02), 21% (I-01), 16% (I-09) and 13% (I-04)).

Figure 25: Change in real GDP.



8.5 Sensitivity analysis

8.5.1 Armington elasticities

Table 10: Available Armington elasticities for final demand (private expenditure) in DYNK[AUT] as well as import shares for selected scenarios

CPA Number	Description	Armington Elasticities		Import Shares		
		WIOD (Fidelio2)	Hertel & Németh	*Scenario: Base Year 2012*	*Scenario: NoRec & High* WIOD	*Scenario: NoRec & High* Hertel & Németh
CPA29	Manufacture – motor vehicles	0.99	2.80	98,5%	98,5%	98,5%
CPA13	Manufacture – textiles	1.39	3.75	97,3%	98,2%	99,7%
CPA24	Manufacture – basic metals	0.67	2.95	96,3%	96,4%	96,7%
CPA26	Manufacture – computer & electronic	0.75	4.05	95,8%	96,1%	97,1%
CPA22	Manufacture – rubber and plastic	0.28	3.30	95,3%	95,3%	95,3%
CPA23	Manufacture – non-metallic mineral	0.96	2.90	92,4%	92,7%	93,1%
CPA21	Manufacture – pharmaceutical	0.76	3.30	92,1%	92,3%	92,9%
CPA20	Manufacture – chemicals	0.76	3.30	90,5%	90,6%	91,0%
CPA25	Manufacture – fabricated metal	0.67	4.20	86,1%	86,4%	88,4%
CPA27	Manufacture – electrical equipment	0.75	4.05	82,6%	82,6%	82,6%
CPA17	Manufacture – paper	0.74	2.95	82,3%	82,5%	83,2%
CPA28	Manufacture – machinery	0.00	3.75	80,6%	80,6%	81,8%
CPA30	Manufacture – other transport	0.99	4.30	74,3%	74,3%	74,3%
CPA19	Manufacture – coke & petroleum	0.00	2.10	68,6%	68,6%	68,6%
CPA16	Manufacture – wood	1.22	3.40	65,4%	66,2%	67,5%
CPA05	Mining and quarrying	0.79	3.05	63,6%	63,6%	63,6%

CPA01	Crop and animal production	1.11	3.60	62,1%	64,5%	70,2%
CPA31	Manufacture – furniture	0.00	3.75	59,5%	59,5%	60,3%
CPA03	Fishing and aquaculture	1.11	1.25	47,0%	48,1%	48,2%
CPA10	Manufacture – food & beverages	1.21	2.00	45,9%	48,8%	50,7%
CPA50	Water transport	0.69	1.90	42,6%	49,4%	63,9%
CPA58	Publishing activities	1.03	1.90	38,6%	38,8%	38,9%
CPA37	Sewerage & waste management	1.03	1.90	18,5%	18,5%	18,5%
CPA87	Residential care activities	0.52	1.90	16,3%	16,4%	16,6%
CPA59	Motion picture & video & TV	1.03	1.90	14,1%	14,2%	14,2%
CPA02	Forestry and logging	1.11	2.50	13,8%	13,8%	13,8%
CPA52	Warehousing	0.86	1.90	7,0%	7,0%	7,0%
CPA65	Insurance & reinsurance and pension	0.38	1.90	3,6%	3,6%	3,6%
CPA49	Land transport and pipelines	0.31	1.90	1,8%	1,9%	2,0%
CPA96	Other personal service activities	1.03	1.90	1,2%	1,2%	1,2%
CPA51	Air transport	0.79	1.90	0,4%	0,4%	0,4%
CPA64	Financial service activities	0.38	1.90	0,3%	0,3%	0,3%

Note: This table only includes commodities that are imported.

8.5.2 Quintile differentiated reactions

Figure 26: Tax burden impact for quintile differentiated fuel price elasticities and our CO_2 tax rate scenarios (Tax recycling scenario: NoRec*).*