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On the emission and distributional effects of a CO_2eq-tax on agricultural goods—The case of Germany

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ABSTRACT

We analyze how a potential CO_2eq-tax on the most emission-intensive agricultural goods in Germany affects CO_2eq-emissions and the income distribution. Based on data from the German survey of income and expenditure, we use a linear approximated Exact Affine Stone Index demand system to estimate own-price and cross-price elasticities for meat, dairy goods and eggs. These elasticities allow us to obtain demand changes and thus emission reductions following the introduction of a CO_2eq-weighted carbon tax based on the social cost of carbon. We find that it can reduce annual agricultural emissions in Germany by more than 15.3 $MtCO_2$eq or about 22.5%. The tax generates an annual revenue of more than 8.2 billion EUR. Since the carbon tax is regressive, we consider the distributional effects of a per capita lump-sum compensation scheme. We show that this “fee and dividend” approach has a slightly progressive effect on the distribution of income.

1. Introduction

A carbon price has shown to be an effective instrument to decrease emissions (Stechemesser et al., 2024). For example, using data on French manufacturing firms, Colmer et al. (2024) estimate that the European Union Emission Trading System (EU ETS) induced regulated firms to reduce CO_2 emissions relative to unregulated firms by 14% during trading phase I and by 16% in trading phase II. However, the urgency to limit global warming makes it obvious that countries do not only need to address emissions arising from fossil fuels, industrial processes, heating and transportation but that all sectors need to reduce emissions. There is significant variation in the types of policy instruments used in the agricultural sector worldwide (Wuepper et al., 2024). Examples include agro-environmental schemes, subsidies, taxes on fertilizers and organic certification. However, to date, no carbon price has been implemented in the sector, although Denmark's government recently agreed to introduce a livestock emissions levy in the year 2030. Globally, agriculture, forestry and other land use (AFOLU) account for 22 % of total annual greenhouse gas (GHG) emissions with 13 $GtCO_2$eq (IPCC, 2022), while these are projected to increase by up to 80 % until 2050 due to population growth and dietary changes (Hedenus et al., 2014). Thus, emissions related to agriculture alone could account for roughly 23 $GtCO_2$eq in the year 2050, leaving hardly any remainder of the CO_2eq budget for the rest of the world economy, if global warming is supposed to be limited to 2 °C (Springmann et al., 2016; Wellesley et al., 2015). In fact, Ivanovich et al. (2023) suggest, that global agricultural emissions alone are sufficient to exceed the 1.5 °C and likely the 2 °C limit, even if all other sectors achieve carbon neutrality instantly.

In the European Union (EU), 80 % of CO_2eq emissions from the agricultural sector originate from meat and dairy goods (Tukker et al., 2006). More precisely, livestock farming contributes to climate change through the emission of methane (CH_4) from enteric fermentation in the digestive systems of ruminants, nitrous oxide (N_2O) from fertilizer application and carbon dioxide (CO_2) from feed-related direct land-use changes such as deforestation and the drainage of moors (Hedenus et al., 2014; Funke et al., 2022). The production of animal goods uses about 83 % of the world's farmland while only providing 37 % of our protein and 18 % of our calories (Poore and Nemecek, 2018). Therefore reducing livestock farming could contribute to reducing pressure on land markets, freeing up the potential for land-based climate mitigation options such as afforestation and rewetting of peatlands. Additionally, reducing livestock farming would vacate land for the production of plant-based food for humans, which may decrease global food prices and increase food security in particular for consumers in the Global South (Funke et al., 2022).

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In Germany, agriculture accounts for about 8 % of GHG emissions (Umweltbundesamt, 2022) and when taking into account land use changes for agricultural use such as deforestation and the drainage of moors, this share is even higher (FÖS, 2020). Germany aims to reduce annual emissions in the agricultural sector to a total of 56 $MtCO_2eq$ by 2030 (BMEL, 2022), while annual agricultural emissions in Germany currently amount to 62 $MtCO_2eq$ (Statistisches Bundesamt, 2022). As of writing this article, the German Federal Ministry of Food and Agriculture has proposed several measures to achieve emission reductions (BMEL, 2024). Among these measures are, for example, improved data availability for fertilization, increased energy efficiency, a nutrition strategy and strategies to reduce food waste. While BMEL (2024) highlights that reducing the consumption of animal products is beneficial, pricing instruments are not mentioned, even though they have been recommended by different governmental expert groups (Borchert Kommision, 2020; WBAE, 2020; Zukunftskommission Landwirtschaft, 2024).

This paper quantifies potential emission reductions in the German agricultural sector following the implementation of a carbon tax[1] on the most CO_2eq-intensive goods, which are meat and other animal products. Market prices currently do not include climate impacts and therefore not the true costs of most agricultural goods (Kehlbacher et al., 2016). Consumers, thus, face an obstacle to making climate-friendly consumption decisions, in particular those with low incomes. The carbon tax serves as a means to internalize the external costs of the goods taxed, namely their contribution to climate change and thereby changes relative prices (Bonnet et al., 2018; FÖS, 2020).

We use the *Einkommens- und Verbrauchsstichprobe (EVS) 2018 [Survey of income and expenditure 2018]* data set of consumption expenditures that is representative of most German households[2] to show that our proposed tax design could reduce annual agricultural emissions in Germany by more than 15.3 $MtCO_2eq$. Hence, a carbon tax on CO_2eq-intensive food could play a key role in achieving Germany's emission reduction goal for 2030. The tax design proposed assures that each good is taxed according to its particular CO_2eq-content. This implies higher prices for goods with higher CO_2eq-contents and a relative cost advantage for those goods associated with low emission contents, such as vegetables, meat substitutes, or plant-based food in general but even those meat or dairy goods with relatively smaller emission contents. This is expected to make it easier for consumers to switch towards more climate-friendly consumption patterns.

The extent of emission mitigation is determined by the domestic demand reduction following the price increase due to the carbon price and potential carbon leakage, which could arise when German producers increase exports of carbon-intensive products as a reaction to the carbon price. We abstract, however, from the analysis of carbon leakage and discuss this limitation after presenting our main results. Potential domestic demand reductions are obtained by estimating elasticities using the linear approximated Exact Affine Stone Index (LA-EASI) demand system (Lewbel and Pendakur, 2009). Since carbon taxes can be regressive (Klenert and Mattauch, 2016; Grainger and Kolstad, 2010), we emphasize distributional effects on income before and after the additional introduction of a lump-sum climate dividend paid to each citizen from the carbon tax revenue. Accompanying compensation measures are generally expected to benefit public approval of carbon taxes (Carattini et al., 2019) if affected citizens are well informed and have correct beliefs — which, however, cannot unambiguously be documented in the empirical literature (Douenne and Fabre, 2022; Schaffer, 2023). We find that the compensation mechanism is able to counteract the regressive effects of the carbon tax and results in a slightly progressive effect on the distribution of income.

This paper is structured as follows: In Section 2, we discuss the previous literature. Section 3 introduces the database and the methods used to calculate elasticities as well as the policy simulation for our analysis. Section 4 presents the elasticity estimates and the projected emission reductions as well as potential distributional effects following the introduction of our tax, both with and without a compensation mechanism. We discuss limitations and policy implications in Section 5. In Section 6 we conclude.

2. Previous literature

There are a few papers that examine the emission effects of a potential carbon tax on agricultural goods in European countries using similar approaches. We discuss the most important contributions and present an overview in Table 1 including each study's estimated emission reductions, the assumed carbon price and the market analyzed.

Säll and Gren (2015) evaluate the impacts of an environmental tax on meat and dairy goods in Sweden. They use an Almost Ideal Demand System (AIDS) to compute elasticities and find that a weighted tax based on a carbon price of 1000 SEK/tCO_2eq (roughly 90 EUR) has the potential to reduce emissions from the livestock sector by 12 %. García-Muros et al. (2017) estimate that taxing agricultural goods in Spain regarding their emission contents based on a price of $50EUR/tCO_2eq$ may reduce agricultural emissions by 7.6%. They also include an analysis of the regressive distributional effects of the carbon tax introduced. Bonnet et al. (2018) find that taxing animal goods in France based on a carbon price of 200 EUR/tCO_2eq can reduce agricultural emission by 6.1%. Essentially the resulting differences in potential emission reductions stem from different elasticity estimates and carbon prices, the taxed goods included and also their underlying emission contents.

The most recent contribution on the topic of agricultural carbon taxes is by Roosen et al. (2022), who focus on Germany. Among two different levels of ad valorem taxes they also investigate the emission reductions following a weighted emission tax based on a price of 100 EUR/tCO_2eq for four meat groups. However, most likely because their database is not representative for the whole of Germany, they do not provide estimates for resulting emission reductions for the German agricultural sector. An advantage of the EVS-NGT data that we use in our study is that it allows us to extrapolate from households' demands, and, thus, to derive emission reductions and tax revenue for the whole of Germany. Like most other studies described above, they use values for the good's emission contents based on Life Cycle Analysis (LCA), which would result in double taxation, because they do not exclude those origins of emissions that are already subject to carbon pricing instruments. Roosen et al. (2022) take into account distributional aspects by comparing two income groups and two age groups. Their results confirm the regressive impact of food taxes. However, they do not include compensation mechanisms for counteracting the regressive effects of the tax. Moreover, they only focus on the meat groups beef & veal, pork, poultry and mixed meats and do not include dairy goods, which appears very crucial, since our results show that almost 40 % of the CO_2eq reductions are due to demand reductions for dairy products and eggs.

3. Data and methods

3.1. Data

We rely on the German *Einkommens- und Verbrauchsstichprobe (EVS) 2018* (Forschungsdatenzentren der Statistischen Ämter des Bundes und der Länder, 2018) as the data source for our estimation. It is based

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[1] Note that if in the following the term carbon tax is used, it is meant to refer to a tax that covers all greenhouse gases expressed in terms of their CO_2 equivalents (CO_2eq).

[2] Altough the EVS is not representative of 100% of the German population, as very high and very low income households are not included, the EVS covers the vast majority of households, which allows us to use it approximatively for the whole German population.

Table 1
Results from previous literature.

Study	Carbon price	Emission reduction	Market
Säll and Gren (2015)	90 EUR/tCO$_2$eq	12.0%	Meat and dairy, Sweden
García-Muros et al. (2017)	50 EUR/tCO$_2$eq	7.6%	Agricultural goods, Spain
Bonnet et al. (2018)	200 EUR/tCO$_2$eq	6.1%	Animal goods, France
Roosen et al. (2022)	100 EUR/tCO$_2$eq	N/A	Meat only, Germany

on a household survey and contains micro-level household income and expenditure data. The data set is a cross-sectional household micro database collected once every five years. With a total of about 60,000 households surveyed across Germany, it is the largest survey of its kind in the European Union. Specifically, we use the EVS-NGT[3] scientific use files of the EVS 2018 for our analysis. The EVS-NGT data is a subsample of the EVS, in which every fifth household of the overall survey participates (10,351 households). It records detailed food consumption expenditures and quantities of households for one month. The data collection is evenly distributed over all 12 months of the survey year to provide annual average results. In addition to food expenditures, the EVS-NGT data set also includes quarterly household net income, which we use in the analysis of the distributional effects. Since the data contains household weights it is possible to ensure representativeness for the vast majority of the German population.

3.2. *Demand system estimation*

To assess the change in demand for the food products on which the CO$_2$eq-tax is applied, we estimate demand elasticities using the linear approximated Exact Affine Stone Index (LA-EASI) implicit Marshallian demand system (Lewbel and Pendakur, 2009). The LA-EASI demand system is the most recent demand system estimation approach and has several advantages over previously developed approaches. It allows for non-linear Engel curves, is not subject to Gorman's rank restriction, and accounts for non-observable idiosyncratic preferences through the error terms. The LA-EASI estimable system of demand budget share equations is given by:

$$\mathbf{w}_h = \sum_{r=0}^{R=4} \mathbf{b}_r y_h^r + \mathbf{A}\mathbf{p}_h + \mathbf{B}\mathbf{z}_h + \mathbf{C}\mathbf{z}_h y_h + \mathbf{D}\mathbf{p}_h y_h + \varepsilon_h, \tag{1}$$

where $\mathbf{w}_h$ is the n−vector of budget shares spent on the n food categories by household h, y_h denotes log real food expenditures, $\mathbf{p}_h$ is the n−vector of log prices over all n food categories, and $\mathbf{z}_h$ is a vector of socio-demographic characteristics of household h. To allow for flexible Engel curves that describe the relationship between budget shares and the log of real food expenditures we use a polynomial specification with R=4 (Lewbel and Pendakur, 2009). The socio-demographic demand shifters $\mathbf{z}_h$ include dummy-coded information on the age and gender of the reported reference person of the household, children in the household, household income, and urbanity of the household location. The log real food expenditures y_h are log nominal food expenditures, x_h, deflated using the Stone price index:

$$y_h = \log(x_h) - \log(\mathbf{p}_h)'\mathbf{w_h}. \tag{2}$$

The to be estimated coefficients are denoted by vectors and matrices $\mathbf{b}_r$, $\mathbf{A}$, $\mathbf{B}$, $\mathbf{C}$, and $\mathbf{D}$.

A common problem in household expenditure survey data is the potential recording of zero expenditures for a given good within the limited data collection period, even though the household generally consumes the good. The resulting censored distribution of expenditures and thus budget shares is addressed using the well-established two-step procedure by Shonkwiler and Yen (1999). In the first step, the sample selection process is modeled:

$$\mathrm{w}_{hi} = d_{hi}\mathrm{w}_{hi}^* \quad \text{with} \quad d_{hi} = \begin{cases} 1 & \text{if } d_{hi}^* > 0 \\ 0 & \text{if } d_{hi}^* \leq 0. \end{cases} \tag{3}$$

The observed budget share of household h for category $i = 1, \dots, n$, w_{hi} equals the true latent budget share w_{hi}^* if $d_{hi} = 1$. The probability that the observed budget shares equal the true budget shares is estimated for each category i separately with the following probit model:

$$d_{hi} = \mathbf{s}_h'\boldsymbol{\gamma}_i + \zeta_{hi}, \tag{4}$$

where d_{hi} is a binary outcome variable indicating non-zero expenditure shares, and $\mathbf{s}_h$ is a vector of household characteristics. The estimated coefficients $\boldsymbol{\gamma}_i$ are then used to compute the cumulative probability distribution (cdf), $\hat{\boldsymbol{\Phi}}_{hi}$, and the probability density function (pdf) $\hat{\boldsymbol{\phi}}_{hi}$.

In the second step, the to-be-estimated system of equations given in Eq. (1) is adjusted for the censored distribution:

$$\mathbf{w}_h = \hat{\boldsymbol{\Phi}}_h \left[\sum_{r=0}^{R=4} \mathbf{b}_r y_h^r + \mathbf{A}\mathbf{p}_h + \mathbf{B}\mathbf{z}_h + \mathbf{C}\mathbf{z}_h y_h + \mathbf{D}\mathbf{p}_h y_h \right] + \hat{\boldsymbol{\phi}}_h \delta + \boldsymbol{\varepsilon}_h, \tag{5}$$

To obtain price elasticities, Eq. (5) needs to be differentiated with respect to $\mathbf{p}_h$. The resulting price semi-elasticities are then divided by the budget share to derive household-specific compensated (Hicksian) own- and cross-price elasticities given by:

$$\boldsymbol{\eta}_h^{\mathrm{PE}} = \frac{\nabla_p' \mathbf{w}_h}{\mathbf{w}_h} = \boldsymbol{W}_h^{-1} \hat{\boldsymbol{\Phi}}_h \left[\mathbf{A} + \mathbf{D} y_h \right] + \boldsymbol{W}_h - \mathbf{I}_h, \tag{6}$$

where $\boldsymbol{\eta}_h^{PE}$ is an $n \times n$-matrix of compensated own- and cross-price elasticities, $\boldsymbol{W}_h$ is an identity matrix with the ones replaced by the budget shares $\mathbf{w}_h$, and $\mathbf{I}_h$ is an $n \times n$ identity matrix. The uncompensated price elasticities can be obtained using the Slutsky equation and expenditure elasticities. The expenditure elasticities are obtained by differentiating Eq. (5) with regard to y_h and dividing by the budget shares. This yields the equation:

$$\boldsymbol{\eta}_h^{EE} = \boldsymbol{W}_h^{-1} \hat{\boldsymbol{\Phi}}_h \left[\sum_{r=0}^{R=4} r \mathbf{b}_r y_h^{r-1} + \mathbf{C}\mathbf{z}_h + \mathbf{D}\mathbf{p}_h \right] + \mathbf{1}_n, \tag{7}$$

where $\boldsymbol{\eta}_h^{EE}$ is the $n \times 1$-vector of expenditure elasticities and $\mathbf{1}_n$ is an n−vector of ones.

Another common problem in the estimation of demand systems is the availability of price data that exhibits variation and can be matched to households (Castellón et al., 2015; Hoderlein and Mihaleva, 2008). As the underlying household data does not include price data and the anonymization of the data set makes it impossible to match separate price data to household observations we use the unit value approach. Unit values (UV) are defined as expenditures per unit purchased. We adjust the unit values for quality differences of the specific food product purchased by different households using the approach by Cox and Wohlgenant (1986). Specifically, we regress household characteristics $\mathbf{c}_h$ on the log of unit values in food category i:

$$\log(\mathrm{UV}_{hi}) = \delta_i + \mathbf{c}_h' \boldsymbol{\kappa}_i + \epsilon_{hi}. \tag{8}$$

The vector $\mathbf{c}_h$ of household characteristics includes household net income, the number of household members, the educational background of the reported reference person of the household and a regional dummy variable representing whether the household is located in the Western or Eastern part of Germany.[4] The vector of quality-adjusted

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[3] NGT stands for "Nahrungsmittel, Getränke und Tabakwaren", that is, this part of the EVS data covers food, drinks and tobacco products.

unit values across all n food categories is then computed as:

$$\mathbf{p}_h = \exp(\hat{\delta} + \hat{\varepsilon}_h). \tag{9}$$

These quality-adjusted unit values are inserted as the $n \times 1$ price vector in Eq. (5) which is estimated using sample-weighted seemingly unrelated regression (SUR).

The procedure outlined above closely follows Plinke et al. (2024) where further details are provided. We estimate the LA-EASI demand system for eleven food categories: Bread and cereals, fruits, vegetables, vegetable oils and fats, dairy and eggs, fish and seafood, beef, pork, poultry, other meat products,[5] and not elsewhere classified (NEC). The adding-up restriction commonly applied to uncensored demand systems is not applicable due to the adjustment for the censored distribution of the budget shares (Bilgic and Yen, 2013; Yen et al., 2003). As the system of equations given by Eq. (5) does not have a singular variance–covariance, all $N = 11$ equations can be used in the estimation (Drichoutis et al., 2008; Castellón et al., 2015). Homogeneity is ensured through the use of normalized prices. The eleven food categories cover all food expenditures. Since there is no data on total consumption expenditure available in the data set used, we estimate a partial demand system on food. This requires a weak separability assumption between food and non-food expenditures (Deaton and Muellbauer, 1980; LaFrance, 1991; Moschini et al., 1994; Edgerton, 1997).

3.3. Microsimulation

We analyze the effect of a CO_2eq-tax applied to meat and dairy products according to their respective CO_2eq-content per kilogram, i.e., their emission intensity. This Pigouvian tax (Pigou, 1920) is intended to incentivize consumers to shift consumption to food products with lower emission intensity. The tax applied per kilogram purchased depends on the food categories' CO_2eq-intensity as well as the applied CO_2eq-tax (Baumol and Oates, 1988):

$$t_i = E_i \; p^{GHG}, \tag{10}$$

where t_i is the tax in EUR/kg applied to food category i, E_i, is the food category's CO_2eq intensity in kgCO_2eq/kg, and p^{GHG} is the CO_2eq price in EUR/tCO_2eq. The emission intensities used are taken from Moberg et al. (2019) and Klenert et al. (2023). Moberg et al. (2019) reports European average CO_2eq intensities for most food products relevant to our analysis.[6] The intensities are computed using the cradle-to-farm gate approach excluding emissions occurring from processing and packaging, transportation, and cooling at retailers which is crucial as the energy and transportation sectors are already subject to CO_2eq-pricing instruments in Germany. Thus, including the latter in the CO_2eq-tax for meat and dairy products would lead to double taxation. While this is not only at odds with Pigouvian taxation, this may also lead to political debates about the legitimacy of the tax. Moberg et al. (2019) do not provide intensities for processed meat products that contain mixtures of meat types such as sausages. For these products, in the demand system analysis aggregated in the food category *other meat*, we use the intensity reported by Klenert et al. (2023).

Table 2 shows the CO_2eq-intensities for the relevant food products to be included in the simulated CO_2eq-pricing scheme. For *beef*, *pork*, and *poultry* the emission intensities given by Moberg et al. (2019) coincide with the food categories used for the demand system estimation. For *other meat* and *dairy and eggs* the demand system estimation aggregates over several of the food products for which intensity estimates are available. For those categories, we compute household-category-specific intensities based on the household-specific quantity composition of each category. That is, the household-specific category intensities are computed as:

$$E_{hi} = \mathbf{q}_{hi}' \, \mathbf{E_i}, \tag{11}$$

where $\mathbf{q}_{hi}$ is a household-specific vector containing the quantities for (1) *sheep and goat* and *other meat* for the category *other meat products*, and (2) *cheese*, *butter*, *milk*, *yoghurt*, *cream*, and *eggs* for the category *dairy and eggs*. The vector $\mathbf{E_i}$ comprises the respective relevant emission intensities given in Table 2. Ideally, we would also take into account emission intensities for the non-taxed food categories but lack data for them. However, it can be argued that the emission intensities of the other food products are very small and thus any substitution from meat and dairy to plant-based and/or fish products will yield very small additional emissions (that would in fact reduce the reported emission reductions).

Regarding p^{GHG}, our analysis is based on a carbon price of 201 EUR/tCO_2eq, which is the latest estimate[7] of the social cost of carbon (SCC) provided by the German Federal Environment Agency (Umweltbundesamt, 2021). Internationally, no carbon price of this magnitude exists so far. Therefore, we compare our results to the effect of a CO_2eq-tax set to 30 EUR/tCO_2eq which equals the price level of the German national emission trading system (NTS) in 2023. That is, we use the NTS price as a low and the SCC estimate as a high CO_2eq-tax scenario.

Table 2 displays the resulting CO_2eq-taxes applied to the taxed food categories and the resulting average price increase in EUR per kg. However, both the average nutritive content as well as the average amount consumed by households vary between food groups. Therefore, it is more interesting to look at relative price increases because they reveal how "underpriced" certain goods are regarding their climate externalities. With a carbon tax based on the SCC estimate, the price of beef increases on average by 51.3% and the price of sheep and goat meat increases by 48.5%. Also cheese and butter experience high price increases of 48.8% and 49.1%. The relative price increases in each food category are the basis for the further simulation of consumption changes due to the introduction of a CO_2eq-tax and resulting emission reductions as well as distributional effects.

The percentage changes in demanded quantities for the food categories to which the CO_2eq-tax is applied is computed taking own- and cross-price elasticities into account:

$$\frac{\Delta \mathbf{q}_h}{\mathbf{q}_h} = \boldsymbol{\eta}_h^{PE} \frac{\Delta \mathbf{p}_h}{\mathbf{p}_h}, \tag{12}$$

where $\boldsymbol{\eta}_h^{PE}$ is the matrix of household-specific uncompensated own- and cross-price elasticities. The vector of relative price changes, $\frac{\Delta \mathbf{p}_h}{\mathbf{p}_h}$, contains zero values for the non-taxed food categories and positive values for the taxed food categories. The positive values are computed as household-specific price increases in food category i:

$$\frac{\Delta p_{hi}}{p_{hi}} = \frac{p_{hi}^0 + p^{\mathrm{GHG}} E_{hi}}{p_{hi}^0}, \tag{13}$$

where p_{hi}^0 is the household-category-specific adjusted unit value as given by Eq. (8).[8] To compute emission reductions, the difference

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[4] The approach to use these and/or similar household characteristics goes back to Cox and Wohlgenant (1986) and is frequently used in related publications estimating elasticities such as Thiele (2008) and Roosen et al. (2022).

[5] Other meat products mostly include mixtures of different meat types such as sausages and burger patties. Thus, no consistent intensity estimates are available as the share of different meat types may vary considerably. We thus apply a common emission intensity following Klenert et al. (2023).

[6] For pork they also provide values particularly for Germany, where the CO_2eq-intensity of 4.64 kgCO_2eq/kg carcass weight is about 8 % higher than the average value of 4.27 kgCO_2eq/kg carcass weight for the rest of Europe.

[7] This estimate is equity-weighted and based on a time discount rate of 1 %.

[8] Due to the linear structure of our model, the relative difference between the two assumed CO_2eq-taxes also translates into a commensurate relative difference between the percentage change in demand for the taxed food categories.

Table 2
CO_2eq-intensities and respective tax per kg based on high (low) CO_2eq-tax.

	Emission content in kgCO_2eq/kg	High (low) CO_2eq tax in EUR/kg	High (low) CO_2eq tax in %
Beef	21.70	4.36 (0.65)	51.30 (7.66)
Pork	4.64	0.93 (0.14)	16.71 (2.49)
Poultry	2.70	0.54 (0.08)	9.63 (1.44)
Sheep And Goat	20.00	4.02 (0.60)	48.54 (7.25)
Other Meat Products	13.00	2.61 (0.39)	31.55 (4.71)
Yogurt	1.29	0.26 (0.04)	5.19 (0.77)
Cheese	12.12	2.44 (0.36)	48.77 (7.28)
Cream	3.76	0.76 (0.11)	15.13 (2.26)
Milk	1.23	0.25 (0.04)	4.95 (0.74)
Eggs	2.16	0.43 (0.06)	8.69 (1.30)
Butter	12.20	2.45 (0.37)	49.09 (7.33)

in household-specific demand in the taxed food categories pre- and post-policy (i.e., before and after the introduction of a CO_2eq-tax) is computed and then multiplied by the household-specific emission intensities for the respective food categories. The tax revenue from the CO_2eq-pricing is computed by multiplying post-policy emissions with the respective assumed CO_2eq-tax. For the presentation of the results, household-specific elasticities, emission reductions, and tax revenue are averaged or summed using sample weights to ensure representativeness for almost the whole German population.

4. Results

We first present our elasticity estimates in Section 4.1. Based on these estimates, we then derive the potential emission reductions (Section 4.2) and distributional effects (Section 4.3).

4.1. Elasticity estimates

Table 3 shows our elasticity estimates with own-price elasticities on the diagonal. Note that all elasticities presented are uncompensated elasticities, that is, they include both income and substitution effects which are both relevant for the policy analysis. Since we estimate elasticities at the household level, Table 3 shows average elasticities. Own-price elasticities are highest for poultry and beef with values of −1.073 and −0.937. This suggests that for poultry the demand is elastic. All other food groups exhibit own-price elasticities smaller than 1 in absolute values. The own-price elasticity for pork is −0.885 and −0.881 for dairy and eggs.

Our results lie within the expected range of those from the related literature and are very close to those estimated by Roosen et al. (2022) who obtain slightly higher own-price elasticities for pork and for beef and slightly lower ones for poultry, with absolute values slightly below 1 for all of the above. Thiele (2008) estimates own-price elasticities for beef of −0.53 and for poultry of −0.69 which are smaller than the ones we obtain. García-Muros et al. (2017) find own-price elasticities of −1.313 for beef and −0.735 for pork, as well as −0.675 for poultry.

Estimated cross-price elasticities are rather small with values ranging from −0.559 to 0.292. For beef, poultry and pork, respective cross-price elasticities are positive but very small, with values between 0.003 and 0.102, which indicates that the income and substitution effects offset each other. These estimates are plausible and also fall within the expected range found in the related literature Bonnet et al. (2018), Thiele (2008), Säll and Gren (2015).

4.2. Emission effects

We now present the effects of the CO_2eq-tax in Germany. The results are summarized in Table 4 for the CO_2eq-tax of 201 EUR/tCO_2 and in Table 5 for 30 EUR/tCO_2. Note that since the EVS-NGT is very close to being fully representative of all German households[9] and also contains frequency weights, we are able to extrapolate from the given households. Hence, the values provided in Tables 4 and 5 hold for Germany as a whole.

The pre-tax demand in the first column corresponds to the actual consumption habits in Germany per year. The post-tax demand in the third column is the projected per year consumption after the introduction of the tax. The projected consumption changes are largest for beef with −53.3% and other meat products with −33.5%. For pork as well as dairy and eggs consumption changes are −15.3% and −18.1% while poultry with a rather low CO_2eq-intensity only exhibits a consumption change of −7.2%. CO_2eq-emission reductions are largest for dairy goods and eggs as well as other meat products with 5,862 and 5,732 kt CO_2eq. Beef, although only having a relatively small demand compared with the former two food groups, shows large emission reductions of 3,364 kt CO_2eq due to its high CO_2eq-content. Overall, a CO_2eq-tax based on the SCC has the potential to reduce CO_2eq-emissions in the agricultural sector by approximately 15.3 MtCO_2eq.

To put these numbers into context, note that in the year 2018, for which our data applies, the whole German agricultural sector was responsible for emissions equivalent to 68 MtCO_2eq (Statistisches Bundesamt, 2022). Germany's target for the agricultural sector is to reduce annual emissions by 14 MtCO_2eq by the year 2030 – a 20 % reduction relative to the 2018 level of 68 MtCO_2eq per year (BMEL, 2022). The carbon tax we analyze, thus, corresponds to a reduction of 22.5% measured in terms of total sector emissions, thereby even slightly overachieving the political target. The simulated reduction by 22.5% only corresponds to about 1.8% of overall German emissions of the year 2018 since agricultural emissions are only responsible for around 8 % of German emissions. Yet, the reduction is more than twice as large as the total annual emissions of, for example, the chemical industry with 6.8 MtCO_2eq and almost six times the amount of emissions arising from the rather frequently discussed German domestic flights (BDL, 2020).

As can be seen in Table 4, the tax revenue share each food group contributes is not proportional to their share of emission reductions, since the tax revenue depends on the residual demand after the tax whereas the emission reductions depend on the consumption change of the pre-tax demand. Other meat products, with 5.7 MtCO_2eq contribute almost as much to saving emissions as dairy and eggs with almost 5.9 MtCO_2eq but with about 2.3 billion EUR only generate half as much tax revenue. For all the taxed goods together, a CO_2eq-tax based on the SCC would raise fiscal revenue of more than 8.2 billion EUR. The revenue could be channeled towards investments for more sustainable agriculture or used for a climate dividend aimed at compensating households for the additional burden of the tax. We discuss the latter more thoroughly in Section 4.3.

For a lower carbon tax of 30 EUR tCO_2eq, the results presented in Table 5 show that emission effects are much smaller. Such a tax would

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[9] Only very high and very low income groups are not covered.

Table 3
Overview of average uncompensated own-price and cross-price elasticities with standard deviations in parentheses. Each cell represents the weighted mean of household-specific elasticities of demand (i.e. the percentage change in demand) for the column product in response to a one percent change in the price of the row product. Diagonal elements (in bold) represent own-price elasticities, off-diagonal elements represent cross-price elasticities.

	Bread & cereals	Fruits	Vege-tables	Veg. oils & fats	Fish & seafood	Dairy & eggs	Beef	Pork	Poultry	Other meat products	Not elsewhere classified
Bread & cereals	**−0.615** (0.028)	−0.080 (0.013)	−0.202 (0.017)	0.181 (0.009)	−0.093 (0.011)	0.050 (0.018)	−0.056 (0.016)	0.193 (0.016)	−0.165 (0.016)	0.147 (0.015)	0.017 (0.014)
Fruits	−0.042 (0.021)	**−0.821** (0.024)	−0.001 (0.021)	0.168 (0.010)	−0.010 (0.014)	−0.018 (0.019)	0.057 (0.019)	−0.134 (0.017)	0.201 (0.014)	−0.029 (0.018)	−0.011 (0.020)
Vegetables	−0.148 (0.022)	−0.007 (0.017)	**−0.664** (0.026)	0.292 (0.010)	0.117 (0.012)	0.063 (0.017)	0.108 (0.015)	−0.041 (0.016)	−0.040 (0.015)	−0.018 (0.017)	−0.063 (0.013)
Veg. oils & fats	0.011 (0.069)	0.020 (0.053)	0.038 (0.060)	**−0.760** (0.088)	−0.022 (0.043)	0.010 (0.058)	0.004 (0.042)	−0.067 (0.062)	−0.027 (0.056)	−0.105 (0.067)	−0.022 (0.054)
Fish & seafood	−0.060 (0.036)	−0.034 (0.031)	0.022 (0.030)	−0.043 (0.020)	**−0.622** (0.039)	−0.008 (0.028)	0.049 (0.029)	−0.110 (0.032)	0.086 (0.026)	−0.095 (0.033)	−0.030 (0.030)
Dairy & eggs	−0.009 (0.017)	−0.106 (0.011)	0.015 (0.012)	0.141 (0.006)	0.014 (0.008)	**−0.881** (0.020)	0.048 (0.009)	−0.046 (0.014)	−0.143 (0.012)	0.139 (0.012)	−0.072 (0.011)
Beef	−0.092 (0.048)	−0.034 (0.038)	−0.017 (0.038)	−0.011 (0.017)	0.014 (0.026)	−0.043 (0.041)	**−0.937** (0.071)	0.071 (0.039)	0.088 (0.041)	−0.033 (0.039)	−0.054 (0.053)
Pork	0.045 (0.058)	−0.075 (0.039)	−0.031 (0.045)	−0.139 (0.032)	−0.101 (0.033)	−0.017 (0.046)	0.083 (0.046)	**−0.885** (0.089)	0.003 (0.040)	−0.017 (0.051)	0.007 (0.058)
Poultry	−0.071 (0.054)	0.086 (0.030)	−0.034 (0.038)	−0.058 (0.025)	0.091 (0.027)	−0.051 (0.043)	0.102 (0.043)	0.003 (0.036)	**−1.073** (0.065)	0.019 (0.047)	−0.001 (0.038)
Other meat products	0.013 (0.020)	−0.145 (0.016)	−0.125 (0.016)	−0.559 (0.015)	−0.243 (0.013)	0.045 (0.017)	0.030 (0.017)	−0.062 (0.017)	0.030 (0.019)	**−0.876** (0.024)	−0.115 (0.017)
Not elsewhere classified	−0.002 (0.020)	−0.038 (0.018)	−0.081 (0.015)	−0.046 (0.010)	−0.020 (0.013)	−0.023 (0.017)	0.020 (0.023)	0.038 (0.025)	0.019 (0.018)	−0.028 (0.017)	**−0.785** (0.027)

Table 4
Results for Germany as a whole based on a CO_2eq-tax of 201 EUR/tCO_2eq.

	Pre-tax demand in kt	Consumption change in %	Post-tax demand in kt	Saved emissions (CO_2eq) in kt	Tax revenue in MEUR
Beef	290.81	−53.3	135.79	3363.93	592.26
Pork	413.75	−15.3	350.28	294.50	326.69
Poultry	390.47	−7.2	362.49	75.53	196.72
Other meat products	1,272.17	−33.5	846.53	5,731.97	2,291.38
Dairy and eggs	7,704.10	−18.1	6,309.34	5,862.03	4,832.32
$\sum$				15,327.96	8239.37

Table 5
Results for Germany as a whole based on a CO_2eq-tax of 30 EUR/tCO_2.

	Pre-tax demand in kt	Consumption change in %	Post-tax demand in kt	Saved emissions (CO_2eq) in kt	Tax revenue in MEUR
Beef	290.81	−8.0	267.67	502.08	174.25
Pork	413.75	−2.3	404.28	43.95	56.28
Poultry	390.47	−1.1	386.29	11.27	31.29
Other meat products	1,272.17	−5.0	1,208.64	855.52	488.29
Dairy and eggs	7,704.10	−2.7	7,495.93	874.93	870.85
$\sum$				2,287.75	1,620.96

result in emission reductions of about 2.3 MtCO_2eq, which corresponds to only 3.3% of sectoral emissions.

4.3. Distributional effects

We now discuss the distributional effects considering households' income. In high-income countries, carbon taxes are generally known to be regressive, because low-income households on average pay a higher share of their income on carbon-intensive goods, such as electricity or heating than high-income households (Wang et al., 2016; Dorband et al., 2019; Ohlendorf et al., 2021). The reason is that for most carbon-intensive goods, there is a subsistence level that essentially needs to be consumed by each household (Grainger and Kolstad, 2010).

Fig. 1 shows the annual tax burden based on the two CO_2eq-taxes at the mean point of each income quintile. Income quintiles are constructed based on equivalence-weighted annual household net incomes in order to recognize that additional resources needed by larger groups of people living in one household are not directly proportional to the size of the group.[10] We construct equivalence weights based on the OECD-modified scale (OECD, 2013). The figure shows that in absolute terms the tax burden at first increases in each income quintile and slightly decreases in the highest quintile. That is, households with higher income may be able to afford more beef instead of pork, with the former having a higher CO_2eq-content. However, households in the top quintile pay less in taxes than in the fourth quintile. That is, the consumption of households in the top quintile is less CO_2eq-intensive than it is for households in the fourth quintile. Pfeiler and Egloff (2018) find, that meat consumption generally decreases with the level of education.

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[10] Adults, for example, are assumed to have greater needs than children.

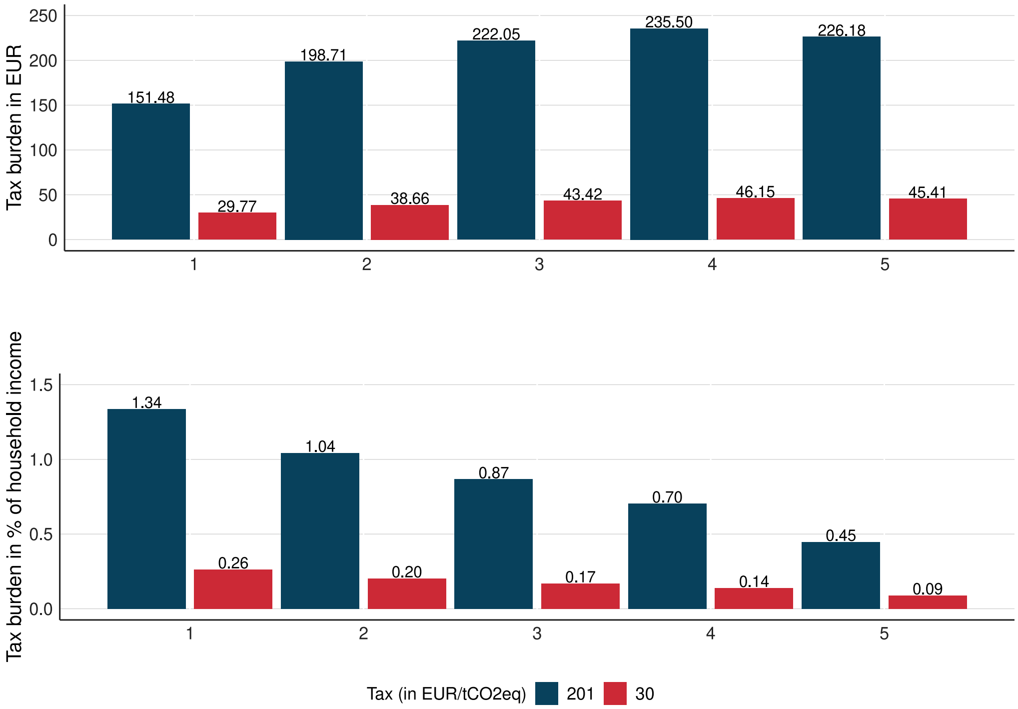

Fig. 1. Distributional effect of the carbon tax per year by household income quintiles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

If we take income as a rough proxy for education, this may explain why the tax burden does not continue to grow in the top quintile. Based on a carbon price of 201 EUR per ton, which is displayed in blue, households in the lowest income quintile pay on average 151.48 EUR per year on agricultural CO_2eq-taxes. This corresponds to about 1.34% of their income. Households in the fourth quintile pay 235.50 EUR per year, corresponding to 0.7% of their income. The absolute differences among the quintiles are less pronounced for a CO_2eq-tax based on a carbon price set equal to 30 EUR, which is displayed in red.

To evaluate whether the tax burden disproportionately affects low-income households, we consider the tax burden relative to income, which is depicted in the bottom part of Fig. 1. As expected, the carbon tax is regressive, that is, low-income households pay a larger share of their overall income in taxes than high-income households. In fact, it is one of the most verified relationships in economics, that relative spending on food falls with rising income (Caillavet et al., 2019), which is also known as Engel's Law (Funke et al., 2022). This is also the main reason behind reduced value-added taxes (VAT) for many food items in Germany and the core behind the distributional arguments against carbon taxes (Grainger and Kolstad, 2010). In fact, we find that the tax burden relative to household net income almost linearly decreases with rising income. Households in the bottom income quintile pay on average 1.34% of their net income in taxes. Those in the top quintile pay 0.45%, based on a carbon price set equal to the SCC. For the lower carbon price, the relative tax burden ranges between 0.26% for the lowest quintile and 0.09% for the highest one.

Although the overall tax burden appears moderate, its regressive nature with respect to income has the potential to undermine social acceptance. A common approach to counteract the negative effects of carbon taxes on income and wealth distribution as well as on purchasing power is a compensation scheme also known as "fee and dividend",[11] which has already been implemented, for example, in Austria, Canada and Switzerland. This approach consists of a carbon tax together with a transfer to each citizen financed by the fiscal revenues generated by the tax. Since high-income households tend to spend more in absolute terms (Klenert and Mattauch, 2016), this generally counteracts the regressive effects of carbon taxes in a progressive way and thereby is supposed to increase the fairness of carbon taxes and generate public support.

Fig. 2 shows the distributional effects of a "fee and dividend" approach in monetary terms. The dividend is calculated by dividing the tax revenue by the number of people in the extrapolated sample, that is every person receives the same lump-sum transfer. This is in line with West and Williams (2004) and Douenne (2020). For a carbon price of 201 EUR per ton, the annual dividend amounts to 103.89 EUR per person. The dividend is the same for children and adults. A household consisting of two people receives 207.78 EUR and so on. For a carbon price of 30 EUR per ton the dividend amounts to 20.44 EUR per person. As expected, this policy has a progressive distributional effect. Although low-income households pay a higher share of their income in taxes than high-income households, this is reversed in absolute terms, that is high-income households pay a larger total amount in CO_2eq-taxes. Hence, if each citizen receives the same lump-sum transfer, low-income households are on average overcompensated, while high-income households are undercompensated. This suggests that the "fee and dividend" policy largely cushions regressive effects of the CO_2eq-tax while even mildly contributing to a progressive distribution. Yet, the dividend is primarily meant to counteract the regressive effects of the tax and not as a measure to redistribute income.

5. Discussion and policy implications

One limitation of our data is the limited availability of goods that consumers may buy when substituting meat, dairy goods, and eggs.

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[11] Baranzini and Carattini (2017) suggests that by calling a policy instrument a tax, people have negative associations with it and therefore other labels such as "fees" or "charges" may be useful to increase public support. In this context, we also use the term "fee and dividend".

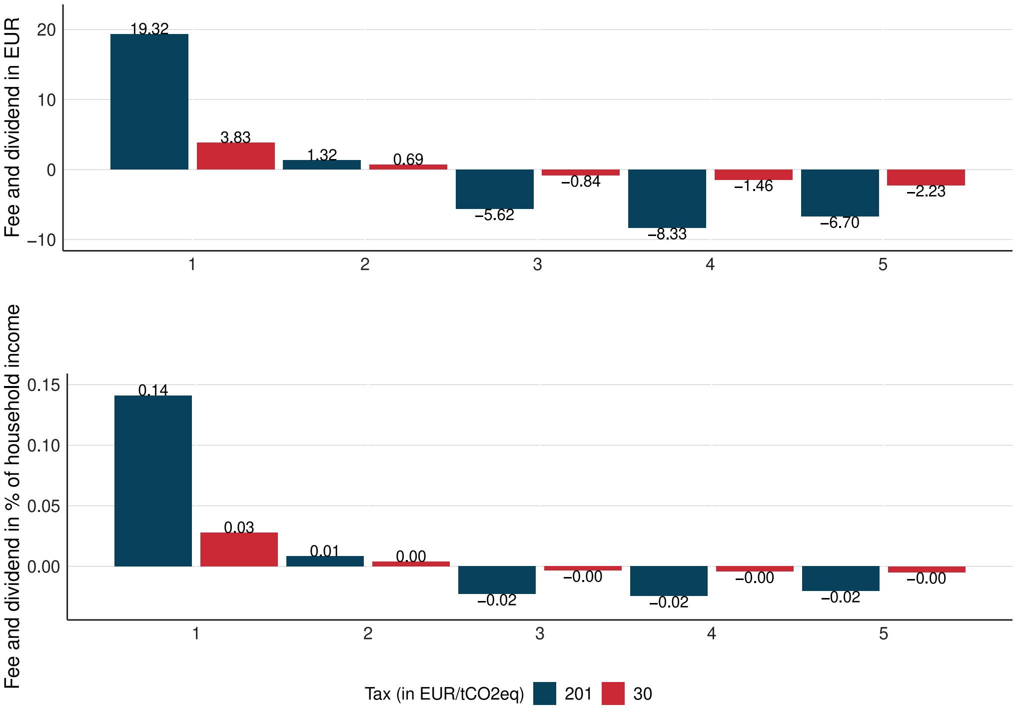

Fig. 2. Distributional effect of the "Fee and dividend" per year by household income quintiles.

In particular, the data do not contain quantity information about the consumption of oat milk and no information whatsoever about non-dairy yogurt or plant-based meat alternatives based on pea or soy protein.[12] Because elasticities also depend on possibilities to substitute, we did include a broad variety of food groups to which consumers could switch when the taxed carbon-intensive goods become more expensive. Yet, we acknowledge that the substitutes we have in our data do not resemble the properties of animal goods.

The demand system approach neglects certain aspects of consumer behavior as it abstracts from within-category substitution with food items belonging to the same category. Quantity changes due to price increases may be overestimated to the extent that, first, emission intensities within a category vary significantly, leading to differing impacts of a carbon tax, and second, the products are strong substitutes. A fully disaggregated demand system, however, is not desirable due to reduced computational efficiency and statistical power. Also, higher level product groups often better match consumers' actual decision-making process, as they typically choose between broader categories before making within-category decisions.

Moreover, we have estimated elasticities only for food, that is we assumed that total expenditure on food remains constant. However, households may compensate for increased food prices by shifting some of their non-food expenditures towards food (Kehlbacher et al., 2016). In this case, our estimated elasticities would be upper-bound estimates. Also, the data only covers expenditures for food consumed at home and thus meals consumed in restaurants, canteens and the like are excluded from our analysis. Since the carbon tax would also raise the price of out-of-home consumption of emission-intensive meals, our estimated emission reductions can be interpreted as lower bounds.

Another limitation concerns demand elasticities in the case of non-marginal price increases. Typically, the relative change in demand is assumed to be a linear function of relative price changes, but it is unclear whether this holds in case of large price jumps. For instance, in reaction to price increases by 20 %, consumers may disproportionately decrease their demand for the concerned goods, for example, due to a high salience of the strong price increase. While our approach focusing on elasticities for marginal price changes is fully in line with the literature, we believe more research on how to account for potentially non-linear elasticities would be valuable.

Leaving aside horizontal equity considerations,[13] we have shown that a lump-sum compensation scheme can counteract the regressive effects of a carbon tax. However, because the dividend paid increases household income, it may to some extent counteract the income effects of the carbon tax. Hence, one could argue in favor of using compensated elasticities instead of the uncompensated ones. Recall that compensated elasticities only include the substitution effect, while excluding the income effect. We deliberately relied on uncompensated elasticities because not all households are exactly compensated for the taxes they actually pay through the lump-sum dividend. In fact, Fig. 2 shows, that even on average most quintiles exhibit differences in that regard. In this light, the use of compensated elasticities would also lead to distortions. Even if households were to receive a fully compensating dividend, the use of compensated elasticities would only be valid if households are aware of the compensation. Recent studies, however, suggest that people usually fail to understand this Mildenberger et al. (2022), Douenne and Fabre (2022). Moreover, the agricultural carbon tax can be expected to be paid almost on a daily basis at grocery stores, while the lump-sum dividend may be distributed only once every fiscal year as, for example, in the case of Austria or Switzerland. The larger the time interval between the "fee" paid and the "dividend" received,

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[12] Some preliminary empirical findings on substitution to plant-based alternatives can be found in Liu and Ansink (2024) and Nes et al. (2024).

[13] Distributional considerations may not only concern the vertical dimension, that is, the distribution of monetary income or wealth. Horizontal inequality can also play an important role. In the context of climate policy, it may refer to differences in the carbon intensity of consumption of households with similar incomes. For example, horizontal inequality has shown to be an important issue in German climate policy debates, where the heterogeneous impact of carbon prices on urban vs. rural households was emphasized. See Hänsel et al. (2022) for an analysis of carbon taxation and horizontal inequality in Germany in an optimal taxation model.

the harder it may be for people to relate these two and act according to the theory behind compensated elasticities.

It is a key question whether to tax producers or consumers. The question becomes more relevant the less competitive the supply chain is. In the following, we thus discuss the main points. However, we acknowledge that drawing detailed conclusions would require modeling the supply chain explicitly, which is beyond the scope of this paper. The main argument to directly tax consumers is that domestically produced and imported goods are equally affected by the carbon tax (Säll and Gren, 2015; Wirsenius et al., 2011). If the carbon tax is levied on domestic producers only, imports become relatively cheaper, which in turn is expected to increase production abroad and thereby lead to emission leakage. However, one could also argue that taxing consumers would simply result in more exports from domestic producers while the total quantities produced remain largely unchanged. This would also counteract the potential emission reductions from decreased domestic demand.

One way to circumvent the issue of emission leakage may be the use of a carbon border adjustment mechanism (CBAM) (Kuik and Hofkes, 2010). In this case, in addition to the carbon price on domestic producers, a tariff on imports that equals the difference between the domestic carbon price and the carbon price paid by foreign producers in their respective countries would be imposed. Thus, domestic and foreign producers are equally affected. In the case of Germany, introducing such measures would require careful harmonization with the climate policy architecture on the EU level. From an environmentally concerned policymaker's perspective, it may, thus, be more promising to work towards an ETS III that covers the European agricultural sector, instead of focusing on the national level. After all, for the sectors covered by the ETS I, a CBAM will take effect in 2026, which could serve as a blueprint for the agricultural sector.

A CBAM could also have favorable effects on the implementation of carbon taxes in other countries (Condon and Ignaciuk, 2013). For example, if the EU implements an ETS III for agricultural goods, China would face the choice between paying carbon tariffs to the EU or creating their own domestic carbon pricing instrument, which would also have the advantage of creating revenue for the Chinese government. Franks et al. (2017), for example, show in a game theoretic analysis that implementing carbon taxes is a dominant strategy for governments that face different policy options to pursue their fiscal goals to finance public infrastructure, even when environmental benefits are not accounted for.

However, it is considered a key driver of the French "Yellow Vest" protests, that the carbon tax revenue was mostly used to fund the budget rather than being redistributed to households (Douenne and Fabre, 2022). The protests started due to the planned trajectory of the French government for a rising CO_2 tax on fossil fuels. Eventually, due to the social unrest, the price trajectory was abandoned by the French government and the tax level was frozen to the initial level indefinitely (Douenne and Fabre, 2022). Substituting away from taxed agricultural goods may be easier than refraining from the use of a car. However, it could still be considered unfair that high-income households may be less affected in their food consumption choices than low-income households, who can hardly afford certain meat and dairy products anymore. This holds in particular in times where inequality in the distribution of income and wealth is observed more critically (Edenhofer and Jakob, 2019). Focusing on Germany, though, Sommer et al. (2022) find that most respondents to their survey prefer lump-sum payments over targeted transfers to the poorest households. In this context, a well-designed and communicated "fee and dividend" as analyzed in this paper could be key to balancing out ambitious climate policy and social cohesion.

Eventually, through the ETS II an increasing number of sectors will soon be covered by EU carbon pricing (European Parliament, 2022) and it appears possible that in the future also agricultural emissions will be included. In this context, this paper can provide an insight into the potential effects of a CO_2eq-tax on agricultural goods in Germany but also in other EU countries with similar income levels and food consumption patterns.

6. Conclusion

This paper has quantified the potential emission reductions in the German agricultural sector from the implementation of a CO_2eq-tax on the most CO_2eq-intensive goods, which are meat as well as dairy goods. To this end, we have used a linear approximated Exact Affine Stone Index (LA-EASI) to estimate own-price and cross-price elasticities for 11 distinct food categories. These elasticities allowed us to obtain potential demand changes and thus emission reductions following the introduction of a CO_2eq-weighted carbon tax on meat, dairy goods, and eggs. We found that the CO_2eq-tax has the potential to reduce annual agricultural emissions in Germany by more than 15.3 MtCO_2eq or about 22.5%. Additionally, the tax generates an annual revenue of more than 8.2 billion EUR. Since the CO_2eq-tax is regressive, we also considered the distributional effects on different income groups before and after the additional implementation of a per capita lump-sum compensation scheme, also known as "fee and dividend". The annual dividend amounts to 103.89 EUR and redistributes the CO_2eq-tax revenue in a uniform way to every citizen. This compensation mechanism counteracts the regressive effects of the tax and has a slightly progressive effect on the distribution of income. Overall, our results provide clear evidence that a CO_2eq-tax on agricultural goods could play a key role in achieving the sectoral emission reductions targeted by the German government.

CRediT authorship contribution statement

Julian Schaper: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Max Franks:** Writing – review & editing, Supervision, Project administration. **Nicolas Koch:** Writing – review & editing, Supervision, Project administration. **Charlotte Plinke:** Writing – review & editing, Visualization, Software, Methodology. **Michael Sureth:** Writing – review & editing, Visualization, Software, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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