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► To cite this version:

France Caillavet, Adélaïde Fadhuile, Veronique Nichèle. Assessing the distributional effects of carbon taxes on food: Inequalities and nutritional insights in France. *Ecological Economics*, 2019, 163 (September), pp.20-31. 10.1016/j.ecolecon.2019.04.020 . hal-02130816

HAL Id: hal-02130816

<https://hal.science/hal-02130816>

Submitted on 22 Oct 2021

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Assessing the distributional effects of carbon taxes on food: Inequalities and nutritional insights in France

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Acknowledgements: This work has been partially supported by INRA DIDIT Metaprogramme and the French National Research Agency in the framework of the "Investissements d'avenir" program (IDEX Univ. Grenoble Alpes, IRS). None of these sources had any involvement in any stage of this research.

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Abstract

A carbon tax on food could contribute to emissions mitigation and act as a strong signal to economic actors. However, tax regressivity is a major disadvantage. This study addressed equity issues using several means. First, reallocation proposals in a revenue-neutral approach of several emission-based carbon taxation scenarios at the consumption level of food are included. Second, these proposals' distributional incidence was developed, evaluating the role of carbon pricing in policy impacts. Using a carbon-based approach, differing emission potentials of food groups highlight the relevance of using proteins as a tax base to redirect animal to plant sources in a diet. Thus, a scenario of taxing foods rich in animal proteins and subsidizing those rich in plant proteins was constructed. Scanner data of French households in 2010 were analyzed. Several GHG emission indicators and related nutritional impacts, such as diet quality scores and a shift from animal to plant proteins, were evaluated. Using individual changes in food expenditure, distributional effects based on continuous distribution and inequality indexes were measured, allowing for a discussion of policy options of a targeted vs. nontargeted tax and a revenue-neutral approach in the food sector.

Highlights

- Animal protein taxes and plant protein subsidies support the environment and nutrition.
- A revenue-neutral approach does not increase the average consumer cost.
- Unexpected adverse equity effects originate from subsidies for fruits and vegetables.
- Higher carbon prices increase revenue and nutritional benefits over proportionally.
- Higher carbon prices in food taxation allow for a GHG emission reduction of 15%.

Keywords: carbon fiscal policy; revenue-neutral; food consumption; regressivity; inequalities. **Funding:** This work was supported by the INRA DIDIT Metaprogramme and IDEX Univ Grenoble Alpes. None of these sources were involved during any stage of this research.

Assessing the distributional effects of carbon taxes on food:

Inequalities and nutritional insights in France

1. Introduction

The recent IPCC report (2018) emphasizes the need for urgent action to preserve the planet from further adverse effects of climate change. At its current rate of change, the temperature is expected to increase by 2.7°C before the end of this century, far exceeding the temperature specified in the 2015 Paris Agreement. The Agriculture, Forestry and Other Land Use (AFOLU) sector is the second-highest greenhouse gas (GHG) emitter after energy (FAO, 2017). This sector is estimated to contribute 30% of total GHG emissions, with the livestock sector responsible for 14.5% of the total emissions (Wellesley et al., 2015). Because world demand for proteins and meat is expected to steadily increase because of population growth and a preference for animal protein, the unsustainability of this demand is threatening global environmental resources. If meat and dairy consumption continue to increase at their current rates, by 2050, the agricultural sector alone will produce 20 GtCO₂e of the 23 GtCO₂e yearly limit, leaving only 3 GtCO₂e for the remainder of the global economy (Wellesley et al., 2015). Restrictions on meat consumption in developed countries are also supported by nutritional recommendations that encourage lower levels of protein and meat consumption than those currently observed (World Cancer Fund, French Nutritional and Health Plan). Therefore, protein consumption is a key issue for GHG mitigation and human health. For Europe, the 7th Environment Action Program provides a strategic direction for environmental and climatic policy planning until 2020 (EEA, 2017). Among the 29 indicators monitored, consumption of animal products including animal proteins and the proportion of environmental taxes to total taxes have been identified. Indeed, a carbon tax on food could provide an incentive for consumers to modify their diets to be more climate-friendly, which would provide health benefits by reducing caloric consumption from proteins and/or increase the importance of plant proteins compared to animal proteins.

Therefore, environmental taxation on food consumption has been considered in recent literature; however, it raises several specific issues. First, considering the substitutions among all food groups and addressing compatibility between the environment and nutritional outcomes are important issues. Indeed, the possibility that households could respond to the internalization of environmental costs in food prices through virtuous substitutions implying all foods and changes to consumption patterns that would reduce GHGs is not guaranteed (Wirsenius et al., 2011; Briggs et al., 2013; Edjabou and Smed, 2013; Caillavet et al., 2016; Revoredo-Giha et al., 2018; Bonnet et al., 2018). Second, distributional issues are critical. A major disadvantage to food taxation policies is their regressivity because lower-income households spend a higher proportion of their budget on food. At the same time, differences in diet compositions and purchasing patterns according to socioeconomic status are known to be of importance. In France, meat products in particular have been shown to be recently consumed more by lower socioeconomic status populations (Laisney, 2013; ANSES, 2017). Addressing the equity impact of the carbon tax enhances its social acceptability. From this perspective, because food taxation can result in substantial revenue to enable the implementation of compensation policies, the allocation of revenue through a combination of taxes and subsidies is a strategic issue that is seldom studied in the food sector (García-Muros et al., 2017). Finally, on a methodological basis, carbon pricing is key for the establishment of emission-based taxes and is among the policy tools for meeting distributional challenges (IPCC 2018), although the evaluation of carbon pricing is very much subject to debate (Stiglitz and Stern, 2017).

This study contributes to the carbon tax debate by considering a revenue-neutral fiscal policy for food consumption and measuring its effects at a very disaggregated level, thus highlighting its distributional aspects. Applied to food consumption, a taxation policy may have important distributional and nutritional disadvantages, which can be addressed through specific scenario designs. The reallocation of revenue can modify distributional outcomes and diet quality. Furthermore, the importance of carbon pricing can be questioned to obtain not only substantial emissions mitigation but also co-benefits. This study provides two main contributions. First, a revenue-neutral scenario is implemented through subsidies for plant-protein-rich foods. Second, distributional effects are assessed at the individual level, thus allowing the derivation of inequality indexes. The lesser contributions of this study consist of evaluating the impact of this fiscal policy using two levels of carbon prices on several indicators. The revenue-neutral scenario is also compared to taxes-only scenarios, a carbon tax on all food products, and a tax on all animal-based protein products.

This study retained an *Exact Affine Stone Index* (EASI) demand system (Lewbel and Pendakur, 2009) to simulate the effects of these fiscal policies on environmental, inequality and nutritional indexes based on French scanner data. The environmental effects were computed based on three different indicators capturing climate change, air acidification, and eutrophication. Inequality measures were evaluated through consumer surplus as well as the change in income because of each fiscal policy at the household level. Finally, the nutritional effects include separate nutrient results and a focus on proteins through total protein intake and plant protein proportion as well as an overall assessment of diet quality through a global score.

The remainder of the article is organized as follows. Section 2 provides the literature review. Section 3 describes the empirical method and the French household food consumption data. Section 4 presents the outcomes of the simulated tax scenarios with different carbon prices. Section 5 discusses the results. Section 6 concludes the paper.

2. Literature review

The regressive nature of environmental taxes has been a topic of concern during recent decades following the introduction of energy taxes in several countries or in simulation scenarios targeting reduced GHG emissions from the seminal OECD report (1994). Wier et al. (2005) evaluated the incidence of a tax on household consumption in Denmark and found a worsened marginal Gini index of +0.021% on disposable income and +0.007% on expenditure. Kerkhof et al. (2008) presented 2 tax scenarios (concerning CO₂ or more GHG) and studied the distribution of the tax burden across income groups in the Netherlands. The researchers showed a worsening of the Gini coefficient by + 0.4 points for a CO₂ tax and by + 0.11 points for a GHG tax. Feng et al. (2010) evaluated the incidence of a CO₂ tax on UK households as a tax burden relative to an income of 6.0% in the lower decile compared to only 2.4% in the highest decile; 4.3% and 1.7%, respectively, in the case of a GHG tax. Addressing regressivity, revenue-neutral approaches are key strategies to target distributional neutrality. In Metcalf (2008), the regressivity of the carbon tax in the US case was offset by using the revenue to fund a reduction in the income tax.

All of these works highlight that any policy increasing the cost of energy will disproportionately impact low-income households, making equity a major concern when taxes are discussed. Regarding this latter aspect, food can be directly compared to energy,

although very few studies have addressed the distributional issue of a carbon tax on food and have neglected social issues, welfare and acceptability. The key issue of introducing compensating mechanisms with a combination of taxes and subsidies has been used in certain carbon scenarios designed for food consumption (Briggs et al., 2013; Edjabou and Smed, 2013; Markandya et al., 2016); however, they did not target distributional neutrality or frequently measure its effect. Evaluating whether the tax burden disproportionately affects households in the lower socioeconomic groups, making carbon taxes on food regressive can be primarily completed by comparing the incidence of taxation in different income classes at the mean point. Kehlbacher et al. (2016), in the case of a carbon food tax, reported a higher tax burden on lower-income households in the UK. However, their finding may depend on the income classes chosen and some effects may be discontinuous. In the case of the taxation of animal-based foods, Caillavet et al. (2016) found **a loss in purchasing power related to food** varying by -9.25% to -5.84% (according to age groups) in 2 lower-income classes vs. a variation of -7.74% to -4.53% in 2 higher-income classes in the French case. In particular, the lowest income class did not bear the highest burden but a less-than-average one. This discontinuity is confirmed by Sall's work (2018) computing the compensating variations for various income groups after a meat tax in Sweden was implemented. In both cases, the lowest income group may not expect major change.

However, to *fully* assess the inequality impact, individual effects must be observed, and this is not the case for most works. The incidence of a food carbon tax at the level of individual distribution was analyzed in a Spanish work by Garcia-Muros et al. (2017). Using several inequality measures, the researchers assessed the regressive impact of different scenarios. With a carbon tax on all food (25 and 50€/t), the average tax rate varies from 0.83% to 0.40% between the lowest and highest food groups and it decreases with income level. At the individual level, very weak regressivity effects of the carbon tax were found; however, they were stronger with a higher carbon price.

Carbon pricing is a related issue, both for emission-based taxes and the redistribution of tax revenue. Guivarch and Rogelj (2017) reviewed scenarios that limit warming to less than 2°C with a greater than 66% probability. The latest carbon price trajectory quantifications show short-term prices varying from 15 USD to 360 USD₂₀₀₅/tCO_{2e} in 2030. Compared to the aforementioned range of estimations, studies of a carbon tax on food consumption set carbon prices at moderate levels. For the world, Revell (2015) applied a level of USD 80/tCO_{2eq}/t meat (0.06 €/tCO_{2eq}/kg meat at 2010 rates). In the UK case, Briggs et al. (2013) assumed 2.86 £/tCO_{2eq}/100 g food (0.32 €/tCO_{2eq}/kg food at 2010 rates). Edjabou and

Smed (2013) tested two prices: 0.26 DKK/kgCO₂/kg and 0.76 DKK/kgCO₂/kg food (35 €/t and 102 €/tCO₂eq/kg food at 2010 rates, respectively). The range of rates varied greatly; however, they could be floor values. The Stern-Stiglitz Commission (2017) suggested that carbon values computed using older models tend to be underestimated because they do not consider the many risks and costs associated with climate change.

3. Materials and methods

3.1. Empirical strategy

To evaluate the effects of a carbon tax, we used an ex ante framework modeling food-at-home purchases. The *Exact Affine Stone Index* (EASI) demand system (Lewbel and Pendakur, 2009) was retained to model a complete food demand system. The demand for each food group was defined under a weak separability assumption as a function of prices, food expenditure, and socioeconomic characteristics. First, this theoretical demand system is linear for prices and nonlinear for food expenditure, providing a very flexible demand function. This system enables aggregation over preferences as well as considers complementarities and substitutions by defining implicit Marshallian demand functions. The flexibility is also provided by Engel curves, which depend on each food group in the entire food purchase bundle. In this specification, the implicit utility is expressed as the log of the expenditure on food deflated by the log of the Stone price index, i.e., an exact deflator instead of an approximate expenditure. Second, the EASI demand system is dual in terms of cost functions; therefore, cost change can easily be derived from the demand parameters. Generally, any price change can be measured given the implicit utility level compared to the baseline situation. Hence, consumer surplus variations are computed from food cost and its corresponding implicit utility level at the individual level. This last measure enables calculation of the total revenue generated by a fiscal policy that is used to subsidize selected goods. The subsidy rate is deduced such that the whole revenue is allocated to the households consuming the foods. Distributional effects are computed first through the consumer surplus loss concerning food, i.e., the loss in purchasing power induced by a price change. At the global level, this methodology allows comparison of the social impact of different scenarios. However, this measure does not inform on the distributive pattern of the loss or, in particular, on whether the tax burden disproportionately affects lower-income households. Thus, we

computed inequality measures based on food expenditure and income changes by exploiting the individual heterogeneity captured by our individual evaluations. Using the Gini inequality index, we measured the change between the distribution of expenditures pre- and postscenario. We also computed the distribution of the share of food expenditure to income pre- and postscenario using an Engel curve. Furthermore, assuming that a fiscal policy is directly set on consumer prices, we evaluated the impact of this price change on consumer behavior. Using the demand parameters, we computed Hicksian elasticities and food expenditure elasticities. Then, Marshallian elasticities were computed at the individual level of households' purchases. Finally, for several environmental and nutritional indicators, we deduced the change implied by the fiscal policy, deriving indicator elasticities at the individual level. Therefore, for each food group j ($j \in \mathbb{N}$), we let ϑ_j represent the emission level and υ represent the extra cost corresponding to the value of the carbon tax. We defined a subset c of the taxed food groups proportional to the emission level. Let $\tau_{c(j)} = \vartheta_j \tau_j$ if j is taxed in subset c , and 0 if j is not taxed. This designation enabled computation of the quantity, denoted $q_{k,j}$, for each indicator k of the post-taxation situation as follows:

$$q_{k,j} = (1 + \varepsilon_{k,j} \tau_{c(j)}) q_j / 100,$$

where $\varepsilon_{k,j}$ is the indicator elasticity (computed in the first step);

q_j is the initial quantity of food group j ;

and $\tau_{c(j)} = \vartheta_{c(j)} / \text{exp}_j$, where exp_j is the household expenditure.

To evaluate the precise impact of the fiscal policy as described later, we used individual purchases, i.e., individual prices and quantities for each food group, and total expenditures on food-at-home. These individual values enabled evaluation of the statistical distributional effects by comparing the distribution of each indicator before and after the taxation scenario effects. Then, the confidence interval was computed. The elasticities used to predict changes in consumer behavior were based mainly on the elasticities estimated in Caillavet et al. (2016). The demand parameters were used to compute demand elasticities for 21 food groups. The model considered the substitutions between food groups and the household's budget constraints. Here, we used the Hicksian and food expenditure elasticities from that study to compute Marshallian elasticities based on individual observations. We then computed environmental and nutrient elasticities at the individual level. Based on these last estimates, we computed the changes in all environmental and nutrient indicators as described in section 3.2. These results were calculated for each household based on postscenario

purchase levels by income (in Euros/day). The results provided individual effects and allowed for the derivation of the continuous distribution. Furthermore, the decile thresholds were also provided with 95% confidence intervals.

3.2. Data

The dataset was based on the merging of several sources. First, purchases were computed from scanner data from the 2010 Kantar Worldpanel. This survey registers households' food purchases, i.e., quantities and expenditure. Households with complete purchase data were selected resulting in a sample of 7,134 households.

Environmental data were collected using Greenext, an environment consultancy that assessed the environmental impact of 311 food products in France based on life-cycle analysis (Goedkoop et al., 2009). The final values were represented by three different indicators: GHG emissions (gCO₂eq/100 g), air acidification (gSO₂eq/100 g), and marine water eutrophication (gNeq/100 g) denoted as CO₂, SO₂ and N, respectively. These estimations are the only ones available in France for food environmental impact.

The calories and nutrient equivalences of food purchases were based on food composition CIQUAL data¹ provided by the French Agency for Food and Environmental, Occupational, and Health and Safety. CIQUAL data provide information regarding the number of calories per 100 g of the edible portion of each food item and a set of 18 nutrients, which are used to assess diet healthiness using the mean adequacy ratio (MAR) nutritional score (see Madden et al., 1976). The MAR has been adapted to the French average intakes and nutritional guidelines (Martin, 2006). It has been used in several works evaluating the French diet (for example, Vieux et al. 2012; Caillavet et al, 2018). Computed on the basis of a 2,000 kcal per day intake, this score shows the suitability of a diet to the nutritional recommendations in France. The nearer this score is to 100, the better the household diet is.

Finally, foods were allocated to 21 groups that consider their environmental emissions and nutritional content, consumer preferences and the willingness to substitute products within food categories, as in Caillavet et al. (2016). Table 1 summarizes the characteristics of

¹ Available at <http://www.ansespro.fr/tableciqual>. □

our sample by food groups, in terms of budget proportion, emissions, and nutrients. This table provides daily emission quantities, food expenditure, and purchased quantities per household.

[Table 1 near here]

3.3. Simulation set up

Carbon pricing was based on the French estimations that are compatible with the European Commission's commitment (Quinet, 2009). To evaluate the comparative benefits of different tax rates, and particularly in a revenue-neutral approach, we chose 2 different carbon prices. As a floor price, we used the minimum value set by the Quinet report (56€/t) and a higher value (140€/t), multiplied from the basic value (2.5 times). This ratio allowed for comparison among our proposed scenarios. All food groups have different GHG-emitting potentials. Table 1 presents the average CO₂eq values, expressed per 100 g, for each food group (column A) on which the targeted group choices were completed.

Our redistribution scheme was based on (1) the redirection of protein consumption, by diminishing the share of animal and increasing the plant-based proteins on environmental and nutritional grounds, and (2) a revenue-neutral approach for the state and the consumer; the revenue from "sin" taxes is allocated to "virtuous" subsidies. As steps in the revenue-neutral approach, we constructed the 3 following scenarios based on GHG levels for each food group (see Table 2).

- **TAX_ALL** concerns all food. With a purely environmental focus, this scenario measures the incorporation of the environmental cost to the entire food sector by applying taxes to all food groups with emission-based rates.

- **TAX_ANI** taxes only the four highest-emitting food groups that are rich in animal proteins. Sustainability is linked to nutritional goals by targeting the set of products most unfavorable to the environment and health, i.e., foods rich in animal proteins, and by highlighting the desired shift to plant-protein-rich foods. The highest-emitting food groups are primarily animal-based and include "beef," "other meats," "cooked meats," and "cheese." Taxing other animal-based products appears to be less relevant; "fish and seafood" is near the emissions average and, according to French nutritional guidelines, has suitable nutritional properties. Similarly, "prepared mixed dishes" is near the emissions average, while "animal-based fats" have a low protein content.

- **TAX_SUB** is the revenue-neutral scenario. This scenario uses TAX_ANI revenue to subsidize two food groups rich in plant proteins, "fresh fruits and vegetables" and

“starchy foods” (including pulses). This scenario subsidizes healthier and more environmentally friendly foods, including foods rich in plant protein. There is a consensus on the role in diets of fruits, vegetables, and pulses (PNNS, 2017; EFSA, 2012). We consider fresh fruits and vegetables whose protein content is higher (4.10%) than processed fruits and vegetables (2.56%). In addition, consumption of fresh compared to processed fruits and vegetables is socially differentiated. In France, dietary intake surveys (ANSES, 2017; Plessz and Gojard, 2013) show that low-income households consume fewer fresh fruits and vegetables. In the case of pulses, for data reasons, we consider the whole “starchy foods” group. Therefore, two food groups are candidates for subsidies. The food groups targeted for subsidies are consumed less by lower-income households and meet explicit nutritional goals (PNNS, 2017), as improvements are more necessary in disadvantaged households. In addition, subsidizing a restricted set of foods is advantageous to the finances available in the revenue-neutral approach and should have a greater impact on environmental and nutritional outcomes.

4. Results

The scenarios implemented represent different shares among household food consumption. Compared to TAX_ALL, which includes all food groups (100% of household food budget) and related emissions, TAX_ANI concerns 28.2% of the food budget, 52.4% of the SO₂ emissions, 30.7% of the CO₂ emissions, 39.1% of the N emissions, and 19.7% of the calories of food-at-home purchases. This scenario also taxes 64.3% of the animal proteins (Table 2). TAX_SUB focuses on 42.9% of the food budget, 48.8% of the CO₂ emissions, 60.8% of the SO₂ emissions, 53.0% of the N emissions, and 34.9% of the calories. This scenario taxes 64.3% of the animal proteins and subsidizes 44.2% of the plant proteins.

[Table 2 near here]

The effects of each scenario are evaluated for the two carbon price levels previously described (56 €/tCO₂eq and 140 €/tCO₂eq); see Table 2. When applied to all food groups (TAX_ALL), average tax rates vary from 0.37% to 0.93% (for “coffee and tea” at 56 € and 140 €/t, respectively) to 9.28% to 23.20% (for “animal-based foods high in fats”). For the food groups in TAX_ANI, the tax rates are 7.77% to 19.41% for “beef,” 7.74% to 19.35% for “other meats,” 3.67% to 9.18% for “cooked meats,” and 4.29% to 10.73% for “cheese.”

TAX_SUB rates are the same as TAX_ANI rates, and the subsidy rates are 4.93% to 14.92% for “fresh fruits and vegetables” and 1.47% to 4.53% for “starchy foods” including pulses.

In relation to *environmental changes*, all the scenarios predict a significant decrease in emissions (Table 3 and Figure 1). In the case of TAX_ALL, which taxes all foods, the variations in the environmental indicators are noticeable, with average emission changes of -6.19% to -15.48% for CO₂, -6.97% to -17.43% for SO₂ and -6.11% to -15.24% for N. In TAX_ANI, which targets 4 animal protein-based food groups, a lower emissions reduction was induced, with changes of -2.20% to -5.50% for CO₂, -3.92% to -9.80% for SO₂, and -2.76% to -6.88% for N. TAX_SUB demonstrates further nuances to the effects on the environment with changes of -0.97% to -1.78% for CO₂, -3.41% to -8.24% for SO₂, and -1.92% to -4.31% for N. Figure 1, for 140 €/tCO₂eq, shows that some scenarios do not always differ in trend. Regardless of the income level, TAX_ALL provides the strongest decreases for all indicators; for example, SO₂ emissions at the 95% confidence interval overlap for TAX_ANI and TAX_SUB except for households with the lowest incomes.

[Table 3 near here]

[Figure 1 near here]

The distribution of individual effects shows higher emissions with income up to a threshold and then decreases. This general pattern can illustrate the debate of the Environmental Kuznets Curve (Chancel, 2014; Caillavet et al., 2015). The range of emissions variation between scenarios increases with income, but the confidence intervals suggest that these results may not be significant. Of interest is that the 3 environmental indicators show very similar trends.

If we examine *equity* first in terms of average loss of purchasing power relative to the food budget, incorporating the cost of carbon into all components of household food has the strongest impact under the TAX_ALL scenario, as expected, compared to the scenarios that involve fewer food groups. TAX_ALL induces a supplementary daily expenditure on food per household of 4.49% to 11.22%, while TAX_ANI increases expenditure by 1.59% to 3.98%, respectively, for 56 €/tCO₂eq and 140 €/tCO₂eq. TAX_SUB induces no increase in food expenditure, on average (Table 1). Further investigating the impact of taxation on equity among households, the Gini pre- and postscenarios show a different range of variations. Based on the distribution of food expenditure, they decrease very slightly under TAX_ALL (-

0.001/-0.002 points, respectively) and slightly more after taxing and subsidizing the protein food groups (-0.004/-0.010 points, respectively) under TAX_SUB. This small effect barely affects the Gini index of the income distribution, which remains unchanged except in the 4th decimal. To obtain a more precise measure of the incidence of taxes and subsidies, we consider the change in the share of food expenditure according to income. Figure 2 shows an increase for TAX_ALL and TAX_ANI compared to the baseline. This figure shows a weaker incidence for scenarios TAX_ANI and TAX_SUB, and the confidence intervals overlap explaining the Gini results. However, the TAX_SUB curve shows an interesting pattern because it rotates around an approximate average daily income of 100 €. This curve shows that post-TAX_SUB, lower-income households have a higher food burden, while higher-income households have a decreased food burden.

[Figure 2 near here]

In relation to *nutritional effects*, three indicators are summarized for the different scenarios (Table 3). First, MAR indicates the suitability of food purchases in relation to French nutritional recommendations (Figure 3). On average, MAR improves slightly under TAX_ALL (+0.16 to +0.38 percentage points), more than TAX_SUB (+0.12 to +0.33 percentage points), but decreases under TAX_ANI (-0.08 to -0.21 percentage points). Second, the proportion of protein in total calories measures the impact of protein substitutions following taxation. Regardless of the carbon price used, all the scenarios show a decrease in the protein proportion, with the greatest being under TAX_SUB (-0.28 to -0.71 percentage points), inducing a protein content of less than 14% for 140 €/tCO₂eq pricing. Third, the share of plant protein in total proteins measures the desired substitution from animal to plant proteins. Under all the scenarios, the plant protein share increases at the highest rate, 27.59%, under TAX_SUB (+0.92 to +2.54 percentage points). Note that the reduction in total calories purchased reaches -14.85% under TAX_ALL and -2.68% under TAX_ANI but is nearly neutral under TAX_SUB (-0.73%).

[Figure 3 near here]

The distribution of individual effects shows further disparities according to income and differences between scenarios. The higher the income, the higher is the MAR, confirming the results of Caillavet et al. (2018). The scenarios modify the MAR distribution curve, in particular with subsidies showing an improving MAR effect with improving income. Concerning the protein content, beyond the difference in levels between scenarios, taxation does not modify the distributional profile, with a protein share increasing with income

(Figure 4). Conversely, the balance between plant and animal proteins is greatly modified by the different policies. As the plant protein distribution shows a basic U-curve at the baseline, Figure 5 shows that taxing animal-based foods (TAX_ANI) introduces a disruptive pattern; the plant protein share post-taxation at a lower income is farther from the baseline than at a higher income. This finding shows more virtuous substitutions in the purchases of low-income households; one element of explanation is more sensitivity to price increases. Conversely, the new pattern post-subsidies (TAX_SUB) shows a greater distance from the baseline for the higher-income households, which show the highest potential for improvement.

[Figure 4 and Figure 5 near here]

A comparison of the impact of the two *carbon prices* shows a difference in the magnitude of the effects that does not always correspond to the gap between the 56 € and 140 € values (2.5 times), as listed in Table 3. Under the pure taxation scenarios (TAX_ALL and TAX_ANI), the tax rates are exactly proportional (Table 2), as are the environmental, nutritional and consumer loss effects. Under TAX_SUB, the tax rates obtained remain proportional; however, the subsidy rates, which are higher (3.02 times for “fruits and vegetables” and 3.09 times for “starchy foods”) than the carbon price gap, do not.

Note that our data induce certain limits. Kantar scanner data cover only food. Therefore, we assume that food consumption is separable from other consumer goods, as with other works encountering such constraints (among others, Zhen et al. 2014). However, the results presented here are related to household income, assuming relevant substitutions within food expenditure. Concerning at-home purchases, these estimates can be considered to be lower bound. Considering the whole diet would lead to higher GHG reductions. However, in France, food consumed at home represents 80% of calories (ANSES, 2017), a higher proportion than in other developed countries. Finally, another limit consists of assuming here that the price increase directly concerns consumer prices. Because we do not include in our analysis firm strategies, consumers are assumed to respectively pay the whole carbon tax directly. Indeed, supply-side policies are complex issues that could not be developed in this study because we focused on entire food purchases and not a specific sector of the agro-industry. Firms have a role to play, with challenges such as product reformulation and uncertainty on pass-through measures (see Réquillart and Soler, 2014).

5. Discussion

The fiscal policies presented here target virtuous substitutions between food groups on an environmental basis. Our first issue is measuring the policies' expected regressive content. Our second issue states the potential of a revenue-neutral approach to control this regressivity, using the redirection of proteins as an allocation tool. Uncertainty remains because certain meat products may be consumed more by lower-income households. The distribution of individual effects on the equity and nutritional aspects remain unknown.

5.1. Respective benefits of the scenarios implementing only taxes: a generalized tax vs. a targeted tax

TAX_ALL provide the first ex ante evaluation of the incorporation of carbon costs to all foods for France, distinguishing the emission potential within animal-based and plant-based categories. A similar analysis has been conducted in several European countries, with the range of emissions reductions depending on the carbon cost applied. For instance, estimated reductions varied in the UK by 7.5% (Briggs et al., 2013) or 6.3% (Kehlbacher et al. 2016) and, in Denmark, by 7.9% to 19.4% (Edjabou and Smed, 2013). While at a similar rate in Spain (50 €/t, Garcia-Muros et al., 2017 and 52€/t, Markandya et al., 2016), the respective emissions reductions of 7.5% and 7-10% are in accordance with our results at the mid-range price (56 €/t). In comparison, only a high carbon price (140 €/t) allows substantial environmental impacts (15% or more decrease in emissions) based on the resulting tax rates (0.9% to 19.4% depending on the food group). The nutrition tax literature argues that a minimum 20% tax rate is necessary to achieve dietary change (Mytton et al., 2012). At 140 €/t, TAX_ALL reduces annual emissions by 318 kgCO₂eq per household. Note that GHG emissions expressed in CO₂eq do not show the highest variations. SO₂eq emissions are more sensitive to food carbon tax policies and show a change of -17.43%.

TAX_ALL rates induce the highest emissions reductions among the three scenarios considered because it includes all food groups. Interestingly, this scenario also provides nutritional co-benefits, although moderate (the MAR and the shift from animal to plant protein are improved). Therefore, substitution and complementary patterns have favorable environmental and nutritional impacts, providing compatibility between these 2 aspects.

However, the real disadvantage of this scenario concerns equity, because there are both an important negative effect on food budgets observed on average and a regressive impact with an increasing proportion of food relative to income for all households, particularly at the lower end of the income distribution (Figure 2). This finding confirms the worsening of the Gini index + 0.001 at 56 € and + 0.002 at 140 €. This regressive effect of environmental taxes on all foods was found for Spain with a worsening Gini of +0.004 points at a carbon cost of 50 €/t (Garcia-Muros et al., 2017).

TAX_ANI, targeting foods rich in animal proteins, shows a moderate reduction in emissions, nutritional degradation, an extra cost, and a very slight difference related to increased food proportion at both ends of the income distribution (Figure 2). Among food groups, meat and cheese are indeed the main contributors to emissions and vitamin B12 or iron. This finding may explain the lower MAR, which includes, in particular, the adequacy of nutrients found in animal foods. The higher consumption of meat products by lower socioeconomic households in France, as in Denmark (Smed et al., 2007) and Spain (Garcia-Muros et al., 2017), confirms the small regressive effect also found in these countries. However, the distributional effects are not directly comparable in the Danish case, where taxes are applied to products other than meat in a nutrition-based scenario targeting foods with high saturated fat content. A study in Sweden found meat taxes to be nearly neutral in the context of expenditure and regressive in the context of income, although lower-income households spend a lower proportion of their budget on meat (Säll, 2018).

Compared to other French works, the reduction obtained with the 140 €/t under TAX_ANI remains slightly lower than the decrease with a 20% tax imposed on animal-based foods (Caillavet et al., 2016), providing a CO₂ reduction of 7.5%. Compared to Bonnet et al. (2018), the maximum emission reduction they found at a 56 € rate was 1.90%. This finding is lower than our results, regardless of the scenarios targeting different sets of products (most foods, fruits, fats and sugar excluded; only beef; only ruminants). The authors used a different approach: a random utility framework to model the demand for animal products and an outside option (certain plant-based products) and a different disaggregation of animal-

based products. Here, we used a complete food demand model to analyze the possible substitutions among all food purchases for a higher level of aggregation and considering the entire food purchase.

On a nutritional basis, our approach enables the measurement of the effects on several nutrients (appendix online) and compiles them to obtain an overall impact on a diet quality score. Here, we find a deterioration in the MAR. Therefore, such a fiscal policy cannot be recommended on a nutritional basis. Furthermore, our results show a regressive effect in both food expenditure and income distributions.

However, these scenarios could provide important revenue for the State. Based on 27.8 million households in France in 2010, TAX_ALL and TAX_ANI approximately provide a yearly revenue per household of €2009.87 and €731.7, which respectively corresponds to €55.87 billion and €20.33 billion. This is in line with the evaluation of €16 billion/year in Markandya et al. (2016).

5.2. A revenue-neutral approach: taxes/subsidies using the source of proteins as a tool

Concerning *emissions* mitigation, the implementation of subsidies results in an additional emissions effect known as the rebound effect (Greene and Braathen, 2014), compared to the pure tax scenario. This effect may be related to a quantity effect because subsidized products benefit from higher purchases. Indeed, the decrease in total calories purchased remains unsubstantial under TAX_SUB. These results are consistent with findings highlighting the relationship between emissions and caloric intake (Vieux et al., 2012).

The reallocation of the food budget through subsidies is expected to have a favorable impact on lower-income households. Accordingly, the *equity* effects are very different from those of the other scenarios. The revenue-neutral scenario is the only policy that is not regressive, on average, because the food budget remains unchanged. However, disaggregating over household income suggests that regressivity continues to be observed because the proportion of food expenditure in income increases for lower-income households and decreases for higher-income households. These results are explained by socially differentiated consumption patterns. Although lower socioeconomic status households consume more meat products, this regressivity result is not induced by meat taxation because this crossover effect is not observed under TAX_ANI. The other patterns of consumption specific to lower income households consist of smaller quantities of fruits and vegetables, particularly those that are fresh. Indeed, the regressivity of the TAX_SUB scenario can be

explained by the impact of subsidies on fresh fruits and vegetables. Comparing the variations in quantities for households below the poverty line (Burrigand et al., 2012) to those for the average population shows that the baseline quantities are lower in lower-income households (180 g vs 354 g/capita/day) and that the rate of increase post-TAX_SUB is lower (17.2% vs 23.2%). As the Marshallian elasticities are very similar for the two sample populations (appendix online), total and households below the poverty line, this finding can be interpreted as a pure quantity effect.

Therefore, subsidizing healthier foods will provide greater benefits for those consumers who currently consume more of these foods, i.e., higher-income households, at the level of improvement of diet healthiness (Figure 3) or in economic terms (Figure 2). This finding may not always be the case, as Garcia-Muros et al. found that in Spain, a combination of taxes and exemptions yields better results in terms of distribution regressivity, as the exempted goods (cereals, milk, fruits and vegetables) are consumed in greater proportions by lower-income households. They show that households with children have increased impacts of the tax and advocate for exempting dairy products from a tax. The choice of targeted foods for redistribution purposes may be very different on nutritional or social bases. To maintain consistency in the reallocation principle, we assumed that the full costs of food should incorporate its environmental externalities as economic signaling. In this framework, the subsequent loss in welfare due in particular to specific nutritional needs should be compensated for more vulnerable households, i.e., according to their income level, rather than to household composition.

TAX_SUB shows the efficiency of a reallocation of tax revenue to combine environmental and nutritional benefits, by allowing a reduction of GHGE and an increase in the balance of consumption with more plant-based foods. As shown by Briggs et al. (2013) for Britain, a revenue-neutral approach cannot build a reallocation rule based on a pure emissions criterion. The authors showed that taxing the highest emitting food groups (above the average level of emission) to subsidize the lowest-emission food groups would have adverse health effects. Our results confirm this finding. Indeed, the average emissions are 360 kgCO₂eq per kg of food for French households. Using the approach in Briggs et al. (2013), seven food groups would exceed this threshold and would be candidates for taxation (Table 1). At the same time, in a revenue-neutral approach focused on a pure environmental basis, subsidies would be allocated to the food groups below this threshold. This allocation would favor nutritionally undesirable products such as “alcohol,” “soft drinks,” and “foods high in sugar.” In contrast, promoting a shift from animal- to plant-based protein on an

environmental basis improves the nutritional indicators. In this case, the MAR degradation of TAX_ANI is overtaken by the beneficial effect of subsidies under TAX_SUB, which target the main contributors of fiber and vitamin C intake, mainly fruits and vegetables. The highest carbon price allows a 14% reduction in calories from protein and an increase in fresh fruit and vegetable purchases consistent with nutritional guidelines (400 g/capita/day for fruits and vegetables in PNNS). Averaging household per capita quantities, we obtain an average of 404 g at 56 € versus 502 g at 140 €. However, because fruit and vegetable consumption is known to be heterogeneous, and because increasing this consumption for disadvantaged populations is a national priority, it is necessary to assess whether the TAX_SUB impact holds for lower-income households. For households below the poverty threshold, quantities purchased were found to remain well under the nutritional recommendations (232 g/capita/day including at a carbon price of 140 €/t). From this perspective, a high carbon price is more than adequate. Then, using the source of protein as a reallocation rule is much better than a pure environmental criterion based on emissions.

Finally, the revenue-neutral scenario shows strategic co-benefits compared to the two other scenarios and that a high carbon price is a necessary condition for its impact. The resulting nutritional indicators of TAX_SUB are all favorable, with an improving diet quality score, a decreasing total protein content, and an increasing proportion of plant proteins. As in other works that do not impose an isocaloric constraint, our scenarios based on taxation alone induce caloric reductions, raising doubts regarding the feasibility of the consumer behavior change. In contrast, TAX_SUB is more reasonable by showing caloric stability (less than a 1% decrease). Compared to other studies, the scenarios including subsidies induce caloric changes, increases in Edjabou and Smed (2013), and a decrease in Garcia-Muros et al. (2017).

A high carbon price logically induces a larger decrease in emissions (in TAX_SUB: 20 kgCO₂eq per household) than the intermediate price. However, the high carbon price is also crucial in achieving better compliance with nutritional guidelines. Indeed, the higher the carbon price, the higher is the revenue available for public action at a nonproportional rate (here, a factor of 2.7). Because the revenue amount in a revenue-neutral scenario determines subsidies, the gap between the subsidy rates at different carbon prices is observed to be higher than the carbon price gap. Although regressivity is also stronger when the carbon price is higher (as also noted in Garcia-Muros et al.), the decision over the use of revenue results in the difference. The social acceptability of the carbon tax relies on the political choices of redistribution. While a distributionally neutral scenario for a carbon tax appears to be difficult

to develop, considering nutritional constraints, another perspective is to study income compensation in another field, in the manner of Metcalf (2008), combining energy carbon taxes with labor taxes. To match the nutritional priorities, the use of food stamps for lower-income populations appears to be more adequate than global subsidies.

6. Conclusions and perspectives

This study analyzed the impacts of several taxation scenarios targeting GHG mitigation. Carbon taxation represents an efficient tool for discouraging carbon-intensive patterns of food consumption but can be regressive. Therefore, a revenue-neutral scenario has been implemented for France. Proportional emission-based tax rates allowing discrimination among foods according to their environmental impacts were designed. The investigation was based on two carbon prices in middle and high ranges (56 €/tCO₂eq to 140 €/tCO₂eq). The key environmental food tax issues were discussed with a specific focus on the distributional impacts and nutritional co-benefits.

The results show that carbon pricing needs to be high to obtain substantial impacts. A carbon tax policy could reduce GHGs by more than 15% if all food groups are targeted. We show that the reallocation scenario improves the nutritional quality of food purchases, particularly related to the desired substitution of animal with plant proteins. However, although neutral on average, this scenario induces overall unfavorable distributional effects between households and subsidies. The literature shows (Briggs et al., 2013; Caillavet et al., 2016) that compatibility among environmental objectives, health, and social equity is difficult and leads to trade-offs.

Regarding the direction set by the 7th Environment Action Program, our results show that it is possible to reduce consumption of animal protein and increase the proportion of environmental taxes in total tax revenues in France. We also show that the magnitude of the carbon price matters. Indeed, a high carbon price can have several benefits for food environmental taxation. This price provides a stronger signal to consumers, is more efficient at changing consumption patterns, and induces higher emission reductions. Interestingly, the induced impacts are nonproportional to the price gap and are higher for tax revenues, accelerating nutritional improvements and providing more means to improve equity. Further research could, at the least, consider a policy of targeted subsidies on fresh fruits and vegetables, perhaps via stamps issued to lower-income households, to address the regressivity

effects, although nonfood compensation could be more efficient as other literature on energy taxes suggests (Metcalf 2008). In all cases, higher carbon pricing would provide large co-benefits, which should encourage policy-makers to prioritize this option to achieve European and world environmental goals.

Disclosure statement: No potential conflict of interest is reported by the authors.

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Table 1 Summary statistics by food group: shares, emissions, household expenditure and quantity (daily basis per household), N=7134.

Food groups	Shares (in %)				Nutrition		(A) Emissions (gCO ₂ eq/100 g food)	(B) Food expenditure (€)	(C) Quantity (kg)
	Food Budget	CO ₂	SO ₂	N	Calories	Proteins			
Plant-based food groups									
<i>Beverages</i>									
Juices	1.99	3.41	1.81	3.39	1.71	0.72	70.59	0.21	0.20
Alcohol	7.57	6.89	3.94	4.55	4.40	0.44	175.82	0.84	0.26
Soft drinks	1.98	2.38	1.10	1.86	2.73	0.02	62.74	0.21	0.27
Bottled water	1.72	3.46	1.17	1.50	0.00	0.00	26.09	0.19	0.79
Coffee and tea	2.53	0.25	0.15	0.24	0.31	1.51	36.14	0.26	0.04
<i>Other plant-based products</i>									
Fresh fruits and vegetables	11.16	14.22	6.39	10.08	5.90	4.10	129.23	1.27	0.75
Spices	0.46	0.71	0.40	0.46	0.39	0.36	245.26	0.05	0.02
Plant-based foods, high in fats	1.16	1.15	0.47	5.17	6.59	0.06	181.43	0.12	0.04
Plant-based dishes	1.10	0.75	0.30	0.67	0.88	0.36	141.74	0.11	0.02
Plant-based foods, high in sugar	5.67	2.51	1.89	2.81	10.06	2.85	194.22	0.61	0.12
Starchy foods	3.56	3.86	2.09	3.73	9.30	7.59	195.81	0.37	0.20
Processed fruits and vegetables	5.15	4.86	2.13	6.56	4.28	2.56	223.67	0.54	0.17
Animal-based food groups									
<i>Animal-based products</i>									
Beef	5.10	13.29	22.93	9.81	2.08	7.61	1387.10	0.60	0.05
Other meats	8.65	7.37	13.59	15.04	4.93	14.95	817.08	0.95	0.15
Cooked meats	6.31	7.32	11.88	13.15	3.27	8.41	562.92	0.67	0.08
Animal-based foods, high in fats	2.46	7.19	11.14	4.93	7.29	1.25	620.73	0.26	0.07
Cheese	8.14	2.71	3.95	1.15	9.42	17.07	454.48	0.87	0.14
Fish and Seafood	5.24	2.75	1.43	0.86	1.08	4.20	380.27	0.57	0.05
Dairy products	6.45	0.09	0.08	0.04	7.93	13.18	159.55	0.69	0.57
<i>Mixed origin-based products</i>									
Prepared mixed meals	6.11	4.11	4.24	4.60	5.89	6.25	390.23	0.64	0.11
Prepared desserts	7.48	10.73	8.93	9.42	11.57	6.49	273.37	0.79	0.20

Table 2: Average price variation (%) per food group by scenario and carbon price (tax and subsidy rates)

Scenario Carbon price in €/tCO ₂ eq	TAX_ALL		TAX_ANI		TAX_SUB	
	56	140	56	140	56	140
Plant-based food groups						
<i>Beverages</i>						
Juices	3.95	9.87				
Alcohol	3.21	8.03				
Soft drinks	4.18	1.44				
Bottled water	6.20	15.50				
Coffee and tea	0.37	0.93				
<i>Other plant-based products</i>						
Fresh fruits and vegetables	4.63	11.57			-4.93	-14.92
Spices	7.41	18.54				
Plant foods, high in fats	3.69	9.23				
Plant dishes	1.87	4.67				
Plant foods, high in sugar	2.43	6.07				
Starchy foods	6.36	15.91			-1.47	-4.53
Processed fruits and vegetables	4.07	10.18				
Animal-based food groups						
<i>Animal-based products</i>						
Beef	7.77	19.41	7.77	19.41	7.77	19.41
Other meats	7.74	19.35	7.74	19.35	7.74	19.35
Cooked meats	3.67	9.18	3.67	9.18	3.67	9.18
Animal-based foods, high in fats	9.28	23.20				
Cheese	4.29	10.73	4.29	10.73	4.29	10.73
Fish and Seafood	1.92	4.80				
Dairy products	7.71	19.27				
<i>Mixed origin-based products</i>						
Prepared mixed meals	3.89	9.72				
Prepared desserts	3.89	9.73				

Table 3: Average variations in environmental, inequality and nutritional indicators by scenario for each carbon price

Carbon price	56 €/tCO2eq					140 €/tCO2eq							
	Baseline	TAX_ALL (%)	TAX_ANI (%)	TAX-SUB (%)	TAX_ALL (%)	TAX_ANI (%)	TAX-SUB (%)	TAX_ALL (%)	TAX_ANI (%)	TAX-SUB (%)			
<i>Environmental indicators</i>													
Q_co2 (g/day/hh)	5,635.93	5,286.96	-6.19	5,511.92	-2.20	5,581.25	-0.97	4,763.50	-15.48	5,325.91	-5.50	5,535.75	-1.78
Q_so2 (g/day/hh)	65.05	60.51	-6.97	62.50	-3.92	62.83	-3.41	53.71	-17.43	58.68	-9.80	59.69	-8.24
Q_nitrates (g/day/hh)	22.10	20.75	-6.11	21.49	-2.76	21.68	-1.92	18.73	-15.24	20.58	-6.88	21.15	-4.31
<i>Nutritional indicators</i>													
MAR (%)	84.33	84.50	0.16 ^a	84.26	-0.08 ^a	84.45	0.12 ^a	84.72	0.38 ^a	84.12	-0.21 ^a	84.66	0.33 ^a
Protein share (% calories)	14.69	14.66	-0.03 ^a	14.43	-0.26 ^a	14.41	-0.28 ^a	14.60	-0.09 ^a	14.03	-0.65 ^a	13.97	-0.71 ^a
Plant proteins (% proteins)	25.05	25.23	0.18 ^a	25.71	0.66 ^a	25.97	0.92 ^a	25.55	0.50 ^a	26.79	1.74 ^a	27.59	2.54 ^a
Calories (day/hh)	4,716.64	4,436.51	-5.94	4,666.16	-1.07	4,696.26	-0.43	4,016.31	-14.85	4,590.44	-2.68	4,682.12	-0.73
<i>Equity effects</i>													
Food expense (€/day/hh)	10.83	11.31	4.49	11.00	1.59	10.83	0.00	12.04	11.22	11.26	3.98	10.83	0.00
Gini of food expenditure	0.308	0.307	-0.001 ^b	0.308	-0.0002 ^b	0.304	-0.004 ^b	0.306	-0.002 ^b	0.308	-0.0005 ^b	0.298	-0.01 ^b

Notes: ^aPercentage point variation; ^bAbsolute variation.

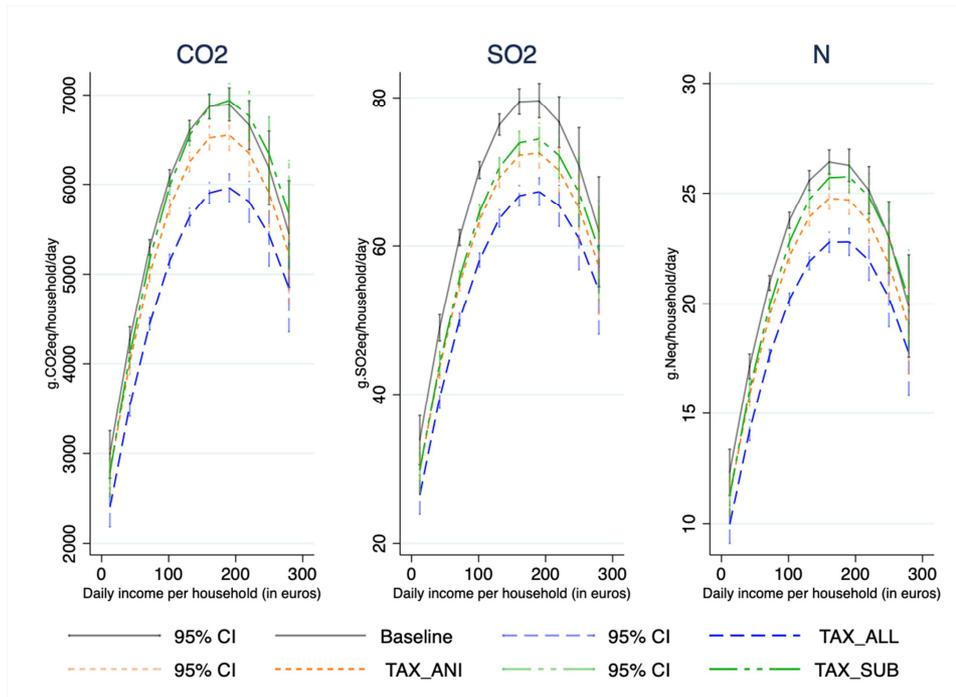


Figure 1: Distribution of environmental values for CO₂, SO₂ and N at the baseline and for each scenario at 140 €/tCO₂eq (with 95% confidence intervals at each decile threshold) according to income.

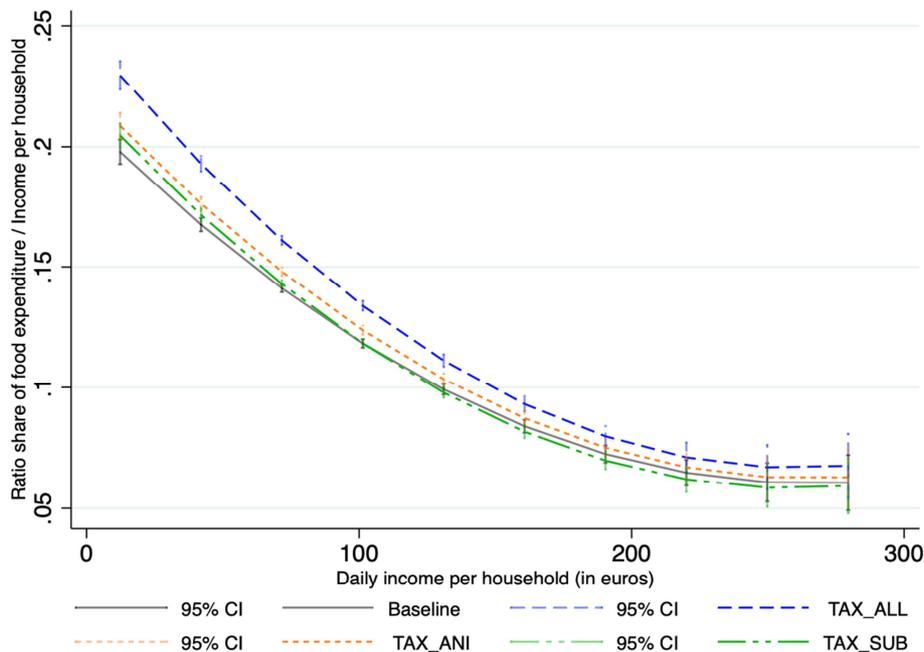


Figure 2: Income share of food expenditure at the baseline and for each scenario at 140 €/tCO₂eq (with 95% confidence intervals at each decile threshold) according to income.

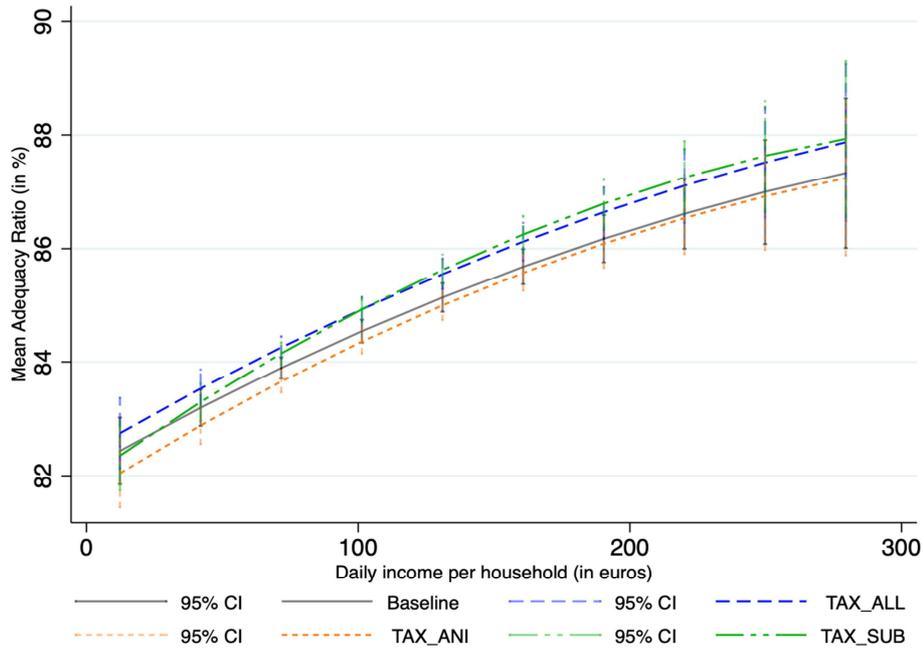


Figure 3: MAR value (2000-kcal basis) for the baseline and each scenario at 140 €/tCO₂eq (with 95% confidence intervals at each decile threshold) according to income.

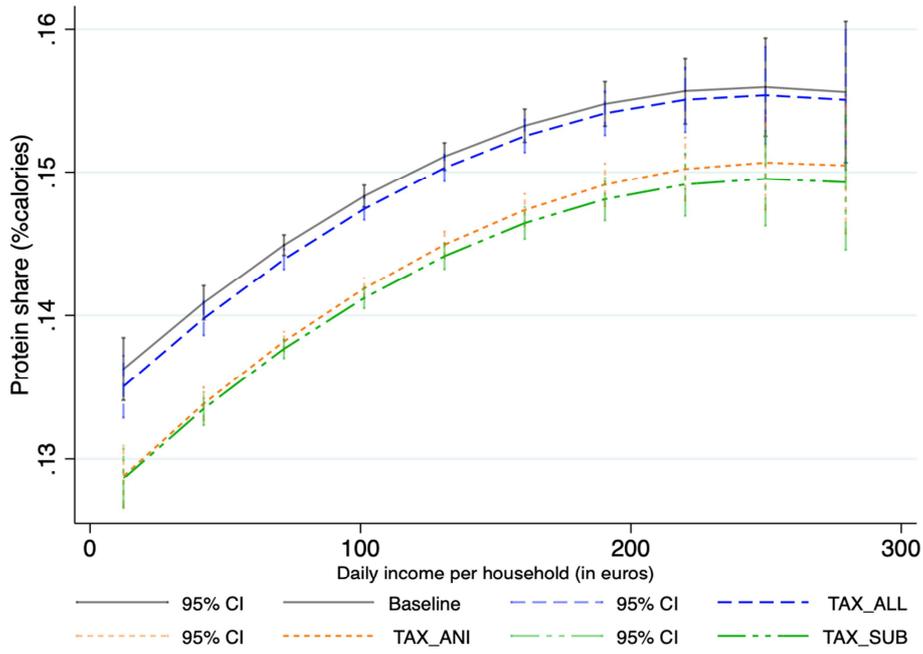


Figure 4: Protein share (% calories) for the baseline and each scenario at 140 €/tCO₂eq (with 95% confidence intervals at each decile threshold) according to income

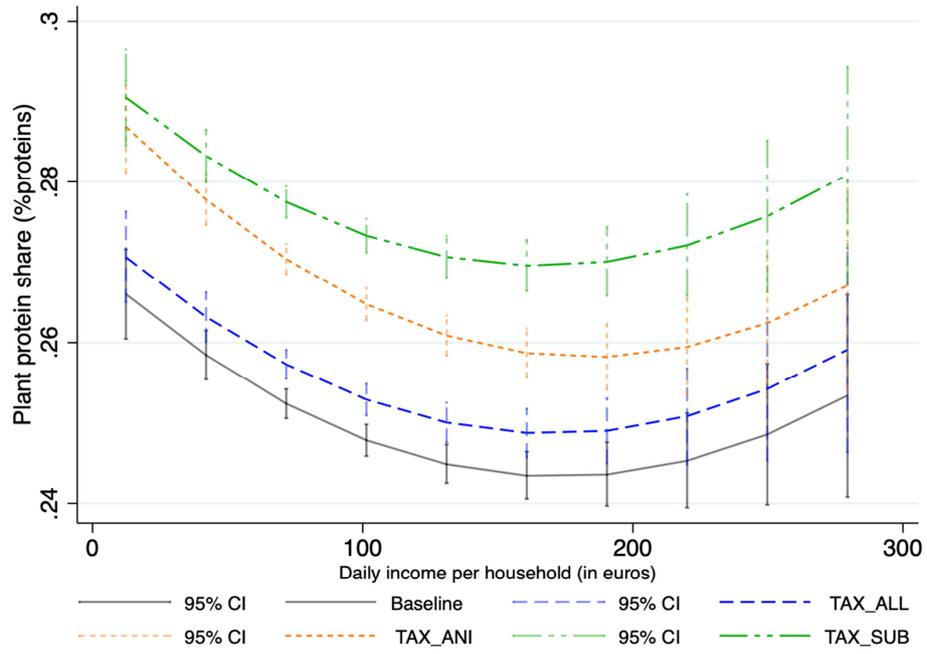


Figure 5: Plant protein share (% proteins) for the baseline and each scenario at 140 €/tCO₂eq (with 95% confidence intervals at each decile threshold) according to income